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Cardiopulmonary exercise performance and factors associated with aerobic capacity in neuromuscular diseases

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Abstract

Introduction/Aims: Aerobic deconditioning, due to lower levels of physical activity, could impact independence for people with neuromuscular conditions. We report the maximal cardiopulmonary response in a cohort of people with Charcot Marie Tooth disease type 1A (CMT 1A) and inclusion body myositis (IBM). We also explored potential predictors of aerobic capacity with measures of physical impairment and functional performance.

Methods: Participants underwent maximal cardiopulmonary exercise testing (CPET) using a semi-recumbent cycle ergometer. Data were analyzed to determine the peak O_2 consumption (VO_2 peak), anaerobic threshold (AT), maximum heart rate (MHR), ventilatory equivalent for CO_2 slope (V_E/VCO_2), and respiratory exchange ratio (RER). Impairment, functional and patient reported measures were also recorded. Predicted CPET variables were calculated based on published normative data for age, gender, and weight.

Results: Twenty-two people with CMT and 17 people with IBM were recruited. Both groups showed significantly lower VO_2 peak, MHR, AT, and V_E/VCO_2. The CMT group overall performed better than the IBM group, with significantly higher VO_2 peak, MHR, and AT, but lower V_E/VCO_2. Linear regression analysis demonstrated that VO_2 peak was related to body fat percentage and 6-min walk distance for both groups, and steps per day for the IBM group.

Discussion: Lower than predicted CPET variables were observed that were not explained by cardiopulmonary limitations or reduced effort, implicating peripheral factors in limiting the cycling task. Regression analysis implied prediction of VO2 peak by body fat percentage and 6-min walk distance. Six-minute walk distance could be a potential proxy measure of cardiopulmonary fitness.

Abbreviations: 10MTW, 10 meter timed walk; AT, anaerobic threshold; BMI, body mass index; BP, blood pressure; CMT, Charcot Marie Tooth disease; CMT 1A, Charcot Marie Tooth disease type 1A; CMTESv2, CMT Examination Score version 2; CPET, cardiopulmonary exercise testing; FVC, forced vital capacity; IBM, inclusion body myositis; IBMFRS, Inclusion Body Myositis Functional Rating Scale; IPAQ, International Physical Activity Scale; MHR, maximum heart rate; NMD, neuromuscular disease; P-P plots, normally probability plots; RER, respiratory exchange ratio; SBP, systolic blood pressure; VAS, Visual Analogue Scale; V_E/VCO_2, ventilatory equivalent for CO_2 slope; VO_2 peak, peak O_2 consumption.

1 | INTRODUCTION

People with neuromuscular diseases (NMDs) may be at increased risk of morbidities such as obesity, cardiovascular, and metabolic conditions,[1] because of lower levels of physical activity.[2,3] Insufficient physical activity is a major risk factor for the development of non-communicable diseases, with an associated 20%–30% increased risk of all-cause mortality.[4] Low aerobic capacity can negatively impact on independent community living. Aerobic de-conditioning and secondary disuse muscle atrophy are common in people with NMD and are a likely consequence of reduced general activity levels. Investigations of people with Charcot Marie Tooth disease (CMT) found they are less active than the general population[2,3,5] and are "de-conditioned," as measured by oxygen uptake during exercise.[6] Similar reductions in aerobic capacity have been reported in people with idiopathic inflammatory myopathy,[7] but this has not been explored in inclusion body myositis (IBM).

The objective of this study was to undertake detailed measurement of the cardiopulmonary response during maximal cycling exercise in large cohorts of adult patients with two neuromuscular diseases: CMT type 1A (CMT 1A) and sporadic IBM. We anticipated that both disease groups would have lower than predicted aerobic capacity when compared to normative data; however, we also aimed to explore body structure, impairment and functional factors that relate to aerobic capacity. This would allow us to understand if there are factors that can be targeted with rehabilitation, and whether there are proxy measures that may indicate aerobic capacity without complex, laboratory measurement procedures.

2 | METHODS

Potential participants were recruited as a convenience sample from clinics and research databases of the National Hospital for Neurology and Neurosurgery, plus national clinics of colleagues from the British Myology Society over a 26-mo period. All participants were recruits on an aerobic exercise training intervention trial,[8] and here we present an analysis of the baseline data This study achieved NHS NRES ethical approval (ref: 11/LO/0760) and consent for participation was obtained. The main trial was registered on the ISRCTN clinical trials registry (ID: 99826269).

Participants were included in the study if they met the following criteria: clinical and genetic diagnosis of CMT1A, or a clinical diagnosis of IBM, supported by histological confirmation as per the established Griggs criteria (only Griggs definite IBM cases were included[9]); aged 18–80 y; able to walk for 30 m with or without a walking aid or orthotic devices; able to safely mount/dismount an exercise bike with minimal assistance.

Exclusion criteria were: presence of other significant neurological disorders or major co-morbidities; limb surgery during the 6 mo prior to screening (or planned before final assessment); failure to pass the screening assessment for exercise testing; concurrent involvement in another intervention trial; people already participating in moderate (3–5.9 times the intensity of rest) to vigorous (six or more times the intensity of rest)[10] aerobic exercise more than three times per week; women of child-bearing age if they were pregnant.

In total, 282 people with CMT 1A were invited to participate in the main intervention trial[8] and 254 were excluded, refused or did not respond. The most common reasons for active exclusion were co-existing illness or recent limb surgery; already exercising over 3 days per week; unable to meet time commitments; did not meet the more detailed screening criteria. In total, 122 people with IBM were invited to participate and 102 were unable to commit to the trial or did not meet the study criteria on initial screening. The most common reasons were too old for the age criteria; did not want to participate; co-existing illness.

Study subjects with CMT 1A and IBM underwent cardiopulmonary exercise testing (CPET) in accordance with American Thoracic Society/American College of Chest Physicians.[11] A screening algorithm was used, prior to maximal exercise testing, that included details of medical history, physical examination and electrocardiogram (ECG) findings. Participants performed a single symptom-limited, incremental ramp protocol to volitional exhaustion using a semi-recumbent electromagnetically braked cycle ergometer (Lode Corival, Groningan, Netherlands). During the test on-line gas exchange analysis, ECG monitoring, and arterial blood pressure were measured with a Cortex MetaLyzerII® (Biophysik, Leipzig, Germany). ECG and blood pressure (BP) were monitored before, during, and after the test. Tests were considered suitable for inclusion if it was judged that the participant gave a maximal effort and reached their physiologic limitation as per the American Thoracic Society/American College of Chest Physicians statement on Cardiopulmonary Exercise Testing.[10] Other tests were excluded if technical or practical difficulties stopped the test early (e.g., unable to get a clear BP or ECG reading, or the participant was unable to keep their foot on the bike pedal due to straps having loosened). This ensured that all data included in this analysis were true maximal test data.

CPET data only were analyzed by an experienced exercise physiologist (co-author P.H.) to determine the peak O_2 consumption ($VO_{2\ peak}$) normalized to body weight, anaerobic threshold (AT) using the modified v-slope method,[12] maximum heart rate and ventilatory equivalent for CO_2 slope (V_E/VCO_2). AT is the physiological point during exercise at which lactic acid starts to accumulate in the muscles, which occurs around the point during increasing intensity exercise that anaerobic processes become more dominant. The VE/VCO_2 slope reflects the increase in ventilation in response to CO_2 production, and thus shows increased ventilatory drive. The peak respiratory exchange ratio (RER) is an indicator of exercise exertion level. It is defined as carbon dioxide production divided by oxygen consumption, and a peak RER equal to or more than 1.10 indicates maximal exercise effort.[13] The exercise physiologist only had access to the CPET data and not additional demographic and clinical data.

Other variables recorded were age, sex, and disease severity; version 2 of the CMT Examination Score (CMTESv2) was recorded by a neurologist for CMT participants[14] and Inclusion Body Myositis Functional Rating Scale (IBMFRS) for IBM participants.[15] Body structure and impairment measures were recorded: body mass index, body fat percentage using skinfold callipers, waist circumference, forced vital capacity (FVC), resting heart rate, blood pressure, isokinetic peak

torque of the knee flexors and extensors at 60°/s (Cybex HUMAC dynamometer). After a minimum of 1 h of rest, measures of functional activity included: 10 m timed walk (10MTW), 6-min walk; and 7 days of physical activity monitoring using a multi-sensor wearable device (Sensewear Activity Monitor). The 6-min walk was the final functional measure to maximize the time following the exercise testing. Participant reported outcome measures captured some of the non-motoric symptoms and perceptions: Fatigue Severity Scale,[16] Walk-12,[17] Visual Analogue Scale (VAS) for pain, International Physical Activity Scale (IPAQ),[18] barriers to activity and exercise.[19]

3 | ANALYSIS

Predicted CPET variables were calculated based on published normative data for age, gender and weight.[20-22] Comparing the actual with predicted values between the groups accounted for potential confounds of age, gender, and weight.

Normally probability plots (P-P plots) of the CPET data were drawn and indicated that the data were normally distributed. Unpaired t-test were used to compare CPET variables between the disease groups, ascertain differences between CPET variables and predicted values and explore disease group differences in continuous secondary outcomes. Categorical secondary outcomes were compared between disease groups using a Wilcoxon rank sum test.

Linear regression modeling was used to explore potential associations with VO_2 peak for each disease group (Stata, version 15, UK). Two models were explored: body structure and physical impairment variables associated withVO_2 peak and functional performance predictors of VO_2 peak. First, an exploratory correlation analysis was undertaken with individual variables. A modified Bonferroni correction was used account for multiple comparisons[23]: 15 variables for model 1 and 7 variables for model 2. Variables that reached significance following correction were then entered into a multiple linear regression model. A stepwise method was used to remove the variables that showed the weakest associations. Weak associations were defined as

TABLE 1 Demographic, disease severity, body structure and impairment measures, and functional activity outcomes

	Group	CMT	IBM	*P*-Value
Demographics	*N*	22	17	
	Age (y)	43.8 ± 14.5	61.5 ± 10.08	>.0001
	Sex (male/female)	9 female, 13 male	4 female, 13 male	
Disease severity scales	CMTES	10 (8–12)		
	IBMFRS		28 (24–31)	
Body structure and impairments	Body mass index (kg/m^2)	27.70 ± 3.49	26.08 ± 3.77	.154
	Waist/hip ratio	0.89 ± 0.09	0.95 ± 0.11	.099
	Body fat %	25.45 ± 5.69	24.27 ± 4.78	.503
	Forced vital capacity in sitting (L)	3.28 ± 0.85	2.88 ± 0.91	.172
	Resting heart rate (beats/min)	67.64 ± 7.89	68.13 ± 8.91	.895
	SBP (mmHg)	121.68 ± 15.70	131.13 ± 13.22	.037
	Diastolic blood pressure (mmHg)	77.73 ± 6.21	78.69 ± 5.49	0.699
	Peak isokinetic knee extensor torque (nm)	85.25 ± 41.93	23 ± 23.74	>.0001
	Peak isokinetic knee flexor torque (nm)	46.16 ± 19.18	24.18 ± 19.16	.0011
	Fatigue severity scale	32 (20–40)	29 (22–46)	.681
	Visual analogue scale for pain	2 (0.9–4.5)	1 (0–2)	.117
Functional activities	10 meter timed walk (s)	17.09 ± 3.19	22.58 ± 7.10	.0026
	6-min walk (m)	378.81 ± 79.12	292.03 ± 87.85	.0025
	Total daily energy expenditure (calories)	2613.28 ± 463.40	2356.18 ± 487.15	.101
	Average steps per day	8214 ± 3965	4732 ± 2840	.0041
	Average METs per day	1.432 ± 0.189	1.306 ± 1.187	.067
	Physical activity duration per day (min)	120.14 ± 64.36	85.65 ± 71.20	.122
	Sedentary time (min)	1151.14 ± 242.03	1281.18 ± 146.58	.059
	Walk-12	34.5 (31–41)	42 (36–49)	.055
	IPAQ sitting time (min/day)	378 ± 183.58	388 ± 177.63	.871
	Falls self-efficacy scale	41 (33.3–50.0)	42 (36–49)	.379

Note: Continuous data are expressed as the group mean ± standard deviation and categorical data as the group median and interquartile range. Continuous *P* values are shown following inferential testing.
Abbreviation: METs, metabolic equivalent.

TABLE 2 CPET variables for the CMT and IBM groups

Group	CMT ($n = 22$)	Predicted variables for CMT cohort	*P*-Value for comparison: CMT cohort	IBM ($n = 22$)	Predicted variables for IBM cohort	*P*-Value for comparison: IBM cohort	*P*-Value for group comparison
Max heart rate (bpm)	134.2 ± 17.7	176.2 ± 14.5	>.0001	121.4 ± 13.9	158.5 ± 10.1	>.0001	.019
Anaerobic threshold (ml/kg/min)	12.1 ± 2.1	15.4 ± 2.2	>.0001	8.35 ± 2.3	14.8 ± 2.3	>.0001	>.0001
VO_2 peak (ml/kg/min)	21.6 ± 4.6	28 ± 5.2	.0001	14.3 ± 3.1	25.6 ± 4.81	>.0001	>.0001
VE/VCO_2 slope	25.3 ± 2.5	26.6 ± 1.6	.0423	27.6 ± 3.1	28.1 ± 1.4	.559	.0117
Max ventilation (L/min)	44.4 ± 14.0			37.6 ± 13.7			.138
RER	1.1 ± 0.13			1.14 ± 0.08			.217

Note: Variables are expressed as the group mean ± standard deviation. Continuous *P* values are shown following inferential testing.

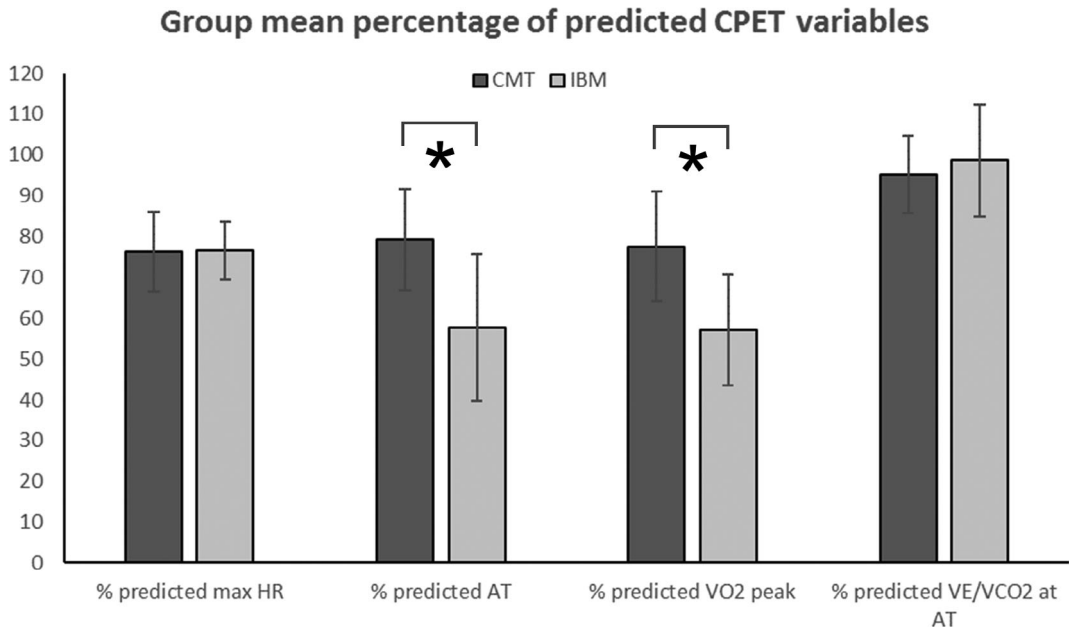

FIGURE 1 Cardiopulmonary exercise test data as a percentage of values predicted from normative data. * denotes a significant difference between groups

having non-significant *p*-values (above .05) and a correlation coefficient below .2.

4 | RESULTS

Twenty-two people with CMT and 17 people with IBM were recruited to the study. The IBM group was older with a smaller proportion of females and slightly higher systolic blood pressure (SBP), but there were no other differences between disease groups in demographics and general health measures (Table 1).

4.1 | CPET performance

Comparisons with normative data demonstrated that the CMT participants had significantly lower CPET performance for all variables (Table 2). In the IBM group, the same was true for all variables except for VE/VCO_2 slope. There was a highly significant difference in percentage predicted AT and percentage predicted VO2 peak (Table 2), with the IBM group performing worse (Figure 1).

Participants with CMT performed significantly better than the IBM group when comparing the actual values, with the exception of maximum ventilation and RER (Table 2). No differences between the groups were observed for maximum heart rate and ventilatory efficiency (VE/VCO2) slope. RER was 1.10 and above for both groups indicating patients in both groups were working at high intensities at exercise cessation (Table 2).

4.2 | Differences in body structure and impairment, activity, and patient reported outcomes

Body structure and impairment measures were comparable between groups, with the exception of higher SBP for the IBM group (Table 1).

TABLE 3 Summary of univariate regression analysis with VO peak

		IBM				CMT			
		R coefficient	*P*-Value	Lower CI	Upper CI	R coefficient	*P*-Value	Lower CI	Upper CI
Disease severity scales	IBMFRS	0.756	.001[a]	0.467	0.911				
	CMTES					−0.242	.279	−0.610	0.266
Body structure and impairments	BMI	−0.302	.239	−0.744	0.174	−0.182	.419	−0.570	0.223
	Waist/hip ratio	−0.020	.939	−0.396	0.633	0.098	.664	−0.287	0.523
	Body fat %	−0.568	.022[a]	−0.841	−0.086	−0.606	.003[a]	−0.795	−0.377
	FVC in sitting	0.486	.048	−0.060	0.867	0.532	.011[a]	0.223	0.758
	Resting heart rate	0.084	.749	−0.420	0.539	0.077	.732	−0.285	0.412
	Resting SBP	−0.460	.063	−0.843	0.227	0.247	.268	−0.172	0.719
	Isokinetic knee extensor torque	0.520	.032[a]	0.266	0.732	0.501	.017[a]	0.128	0.721
	Isokinetic knee flexor torque	0.646	.005[a]	0.422	0.867	0.473	.026	0.066	0.761
	Fatigue severity scale	−0.289	.260	−0.717	0.188	−0.187	.404	−0.617	0.317
	VAS for pain	−0.249	.335	−0.710	0.331	−0.439	.041	−0.759	0.042
Functional activities	10-meter-walk time	−0.611	.009	−0.554	−0.004	−0.290	.190	−0.568	0.008
	6-min-walk distance	0.776	.001[a]	0.344	0.777	0.581	.005[a]	0.331	0.782
	Total energy expenditure per day	0.372	.142	−0.140	0.545	0.201	.369	−0.162	0.553
	Steps per day	0.657	.004[a]	−0.186	0.367	0.092	.684	−0.200	0.382
	Average METs per day	0.641	.006[a]	−0.099	0.652	0.312	.158	−0.097	0.660
	Physical activity duration per day	0.623	.008[a]	−0.279	0.448	0.070	.758	−0.292	0.428
	Sedentary time	−0.264	.306	−0.644	0.128	−0.181	.421	−0.666	0.124
	Walk-12 scale	−0.607	.010[a]	−0.862	−0.269	−0.573	.005[a]	−0.779	−0.189
	IPAQ sitting time (min/day)	−0.174	.505	−0.643	0.381	0.051	.827	−0.361	0.467
	Falls self-efficacy scale	−0.014	.957	−0.496	0.472	0.372	.088	−0.115	0.780

[a]Significant correlations following modified Bonferroni adjustment. Pearson correlations were undertaken for continuous data and Spearman correlation tests were undertaken for ordinal data.
Abbreviation: CI, confidence interval.

However, there was a difference in muscle function, with significantly higher peak knee extensor and flexor isokinetic torque observed in the CMT group (Table 1). The CMT group also walked significantly faster over 10 m and covered a greater distance in 6 min (Table 1). Physical activity monitoring revealed that the CMT group took significantly more steps per day, but interestingly there were no differences in total daily energy expenditure. There were no differences in time spent in sedentary, moderate, or vigorous physical activity. Patient reported outcome measures were comparable with no differences between the groups.

4.3 | Associations with aerobic capacity (VO_2 peak)

The disease severity measures for both conditions performed differently in the correlation analysis. In the group of participants with IBM, the IBMFRS scale showed a moderate to strong correlation with VO2 peak but the same was not observed for the CMTES scale in the CMT cohort (Table 3).

Exploratory correlation analysis between VO_2 peak with body structure and impairment variables for the CMT group revealed significant, moderate relationships with three measures: body fat percentage, FVC and peak isokinetic knee extensor torque (Table 3). Multiple regression modelling showed no significant associations with the three variables. FVC, then isokinetic knee extensor torque was removed using a stepwise method. The final model showed body fat percentage had low association with VO2 peak (Table 4).

For the IBM group, initial correlation analysis showed significant relationships with the same three variables. FVC and peak knee extensor torque were removed stepwise from the model due to weak correlations leaving body fat percentage had a low association with VO2 peak (Table 4).

Functional performance measures were explored associated with VO2 peak in the same way. Initial correlation analysis for the CMT group revealed relationships between VO2 peak and two functional measures: 6-min walk test distance and the Walk-12 scale. Both variables were entered into the multiple regression model, and the Walk-12 scale was removed stepwise due to weak correlation. Six-minute walk test distance had a low association with VO2 peak (Table 4):

TABLE 4 Summary of multivariate regression models

	Condition	R^2	Variable	Coefficient	Standard error	*P*-Value	Lower CI	Upper CI
Associations of body structure and impairment measures	IBM	0.323	Body fat percentage	−0.358	0.138	.022	−0.645	−0.061
			Constant	23.249	3.42	.0001	15.913	30.584
	CMT	0.367	Body fat percentage	−0.491	0.144	.003	−0.791	−0.19
			Constant	34.075	3.75	.0001	26.252	41.897
Associations of functional measures with VO2 peak	IBM	0.717	6-min walk distance	0.021	0.006	.002	0.009	0.033
			Steps per day	0.0004	0.00017	.031	0.0004	0.0007
			Constant	6.079	1.534	.001	2.787	9.369
	CMT	0.338	6-min walk distance	0.0338	0.011	.005	0.012	0.056
			Constant	8.773	4.094	.045	0.233	17.313

Note: Model 1: associations between body structure and impairment variables and VO_2 peak. Model 2: associations between functional measures and VO_2 peak.
Abbreviation: CI, confidence interval.

For the IBM group, a larger number of functional variables were identified in the initial correlation analysis: IBMFRS, 10 MTW time, 6-min walk distance, Walk-12, IPAQ, and average steps per day. The following variables were removed stepwise from the model: Walk-12, IPAQ, IBMFRS, 10 MTW time. The resulting model included 6-min walk distance and average steps per day showing a strong association with VO_2 peak (Table 4):

5 | DISCUSSION

There are some similarities in performance between the two cohorts but also some key differences that may help us understand the impact of the presenting impairments on cardiorespiratory fitness.

When comparing the two conditions, both disease groups demonstrated lower maximum heart rate, lower anaerobic threshold and reduced VO2 peak variables compared to predicted norms. Participants with IBM showed even greater limitations than the CMT group with the very low VO2 peak value of 14.3 ml/kg/min; this is particularly notable when one considers that, a VO2 peak of 18 ml/min/kg is deemed the minimum required for independent community living.[24] The CMT group were younger, with less proximal muscle wasting, which could have influenced the cycling task used for testing.

In healthy individuals, VO_2 peak is considered to be limited by central O2 delivery mechanisms, in particular due to the achievement of maximal cardiac output.[25] In this study, participants with CMT and IBM terminated exercise with a reserve in heart rate (CMT, 76.1%; IBM, 76.6%) and ventilation (CMT, 50.5%; IBM, 48.2%), indicating central O2 delivery did not limit exercise. The low maximum values for HR and ventilatory effort are unlikely due to early exercise cessation as patients exhibited high RER values, indicating high effort levels.[26] These two conditions do not have cardiac dysfunction as a presenting symptom so chronotropic incompetence is unlikely, therefore, the attainment of VO_2 peak in our cohorts appears largely due to peripheral limiting factors.

The exercise test protocol in this study used a bicycle ergometer that requires activity of the knee extensors and flexors in the most part. It is reported in MRI studies that knee extensor function is altered in both CMT and IBM.[27] In people with IBM this is due to primary atrophy and fat infiltration. Weakness of the quadriceps is a primary presentation so if individuals are weaker to start with, they may reach thresholds of function earlier, even if they are fatiguing at a normal rate. No previous work has been published exploring peripheral fatiguability of muscle in people with IBM.

The same MRI study showed more general loss of thigh muscle volume in the cohort of people with CMT that was thought to represent secondary disuse atrophy.[27] Previous studies using stimulation to explore fatigue in people with CMT demonstrate increased central activation failure.[28] Another study found normal fatigue rate, but people with CMT demonstrated lower activation initially, possibly due to central activation failure.[29] More recently, increased compensatory central activation in the prefrontal cortex has been observed during a fatiguing task.[30] The same group also observed impaired neuromuscular recovery from fatigue in CMT1A. These studies are in small cohorts, but there is an implication that central activation influences task fatigue in people with CMT. This may explain the early cessation during CPET testing observed.

The regression analysis demonstrated that body fat percentage in both conditions was associated with aerobic capacity. A negative relationship between VO_2 max and body fat percentage has been observed in younger, healthy populations,[31] so this may also be an influence in this study but the direction of causality is not clear. Body weight also forms part of the calculation for VO2 peak so could increase the likelihood of association, but weight does not automatically imply adiposity and is further complicated in muscle wasting diseases. In addition, body mass index (BMI) was not associated with VO_2 peak in this cohort. The R^2 values were relatively low, however, implying that other factors that were not measured in this study could have greater associations with aerobic capacity.

Functional predictors of aerobic capacity are useful to ascertain as they may be potential surrogate measures where CPET testing is

not available or indicated in an individual. Six-minute timed walk was predictive of VO2 peak in both exercise groups and is a simple clinical test to administer. The IBM participants also demonstrated that steps per day were associated. Steps per day give an indication of physical activity levels in this ambulant group and may represent the impact of deconditioning through sedentary behavior. The same relationship was not seen in the CMT participants, but there was greater variability in steps per day as evidenced by the very high standard deviation.

It is important to acknowledge the limitations of this study. We made comparisons with normative data from upright bicycle ergometry and participants in this study were in a semi-recumbent position. The literature in non-neurological cohorts indicates no significant difference in VO_2 peak between upright and semi-recumbent cycling position of 65°, comparable to the cycling position in this study.[32] This has not been tested in people with neuromuscular diseases.

Participants were able to ambulate, so we did not have an opportunity to explore cardiorespiratory fitness in more severe disease and/or at later stages due to the inclusion criteria for the main intervention study, that may have also introduced recruitment bias. This will be impacted by the small sample size. Recruitment of people with rare diseases is difficult, and small samples are common in trials, but the bias to more able individuals will influence how representative the participants were of the population.

6 | CONCLUSIONS

This study explores performance of CPET testing in two neuromuscular diseases and factors that may relate to performance. Maximum heart rate was not reached by the participant groups at peak oxygen uptake indicating that peripheral factors, such as muscle atrophy, may have limited performance. Peak oxygen uptake was predicted by body fat percentage in both groups. Performance of the 6-min walk test was also associated and could be recommended as a surrogate measure in the clinic.

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CONFLICT OF INTEREST

None of the authors has any conflict of interest to disclose.

ETHICAL PUBLICATION STATEMENT

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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