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Associations between isokinetic muscle strength, high-level functional performance, and physiological parameters in patients with chronic obstructive pulmonary disease

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Abstract: High-level activities are typically not performed by patients with chronic obstructive pulmonary disease (COPD), which results in reduced functional performance; however, the physiological parameters that contribute to this reduced performance are unknown. The aim of this study was to determine the relationships between high-level functional performance, leg muscle strength/power, aerobic power, and anaerobic power. Thirteen patients with COPD underwent an incremental maximal cardiopulmonary exercise test, quadriceps isokinetic dynamometry (isometric peak torque and rate of torque development; concentric isokinetic peak torque at 90°/sec, 180°/sec, and 270°/sec; and eccentric peak torque at 90°/sec), a steep ramp anaerobic test (SRAT) (increments of 25 watts every 10 seconds), and three functional measures (timed up and go [TUG], timed stair climb power [SCPT], and 30-second sit-to-stand test [STS]). TUG time correlated strongly ($P < 0.05$) with all muscle strength variables and with the SRAT. Isometric peak torque was the strongest determinant of TUG time ($r = -0.92$). SCPT and STS each correlated with all muscle strength variables except concentric at 270°/sec and with the SRAT. The SRAT was the strongest determinant of SCPT ($r = 0.91$), and eccentric peak torque at 90°/sec was most significantly associated with STS ($r = 0.81$). Performance on the SRAT (anaerobic power); slower-velocity concentric, eccentric, and isometric contractions; and rate of torque development are reflected in all functional tests, whereas cardiopulmonary exercise test performance (aerobic power) was not associated with any of the functional or muscle tests. High-level functional performance in patients with COPD is associated with physiological parameters that require high levels of muscle force and anaerobic work rates.
Keywords: stair climb, sit to stand, timed up and go, steep ramp, isokinetic

Introduction

Patients with chronic obstructive pulmonary disease (COPD) often exhibit severe muscle wasting, which may be due to skeletal muscle dysfunction, deconditioning/disuse, systemic inflammation, poor nutrition and energy conservation, and/or corticosteroid use.[1] This is of importance because leg muscle mass and strength have been shown to predict mortality,[2] morbidity,[3,4] health status,[5] and quality of life[3] in COPD patients. Leg strength has even been shown to better predict mortality than measures of lung function in this population.[2] COPD patients also exhibit significant reductions in functional mobility and balance that may affect their ability to perform activities of daily living.[6] It has been suggested that these reductions in functional performance are related to the muscle dysfunction present in these patients.[6]

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The majority of research that has focused on examining leg muscle function in patients with COPD has used either isometric or concentric quadriceps torque as correlates or outcome measures.[7–9] In healthy older adults and those with disabilities, isokinetic strength using eccentric contractions or fast-velocity contractions may be more important as methods of assessing functional performance.[10–13] Peak eccentric muscle strength of the quadriceps has been found to be moderately associated with climbing stairs.[8] Conversely, concentric strength has been demonstrated to have either a smaller association with stair climbing[8] or no relationship[9] with other functional tasks. At the present time, the association between eccentric muscle strength, fast-velocity muscle contractions, and high-level functional and physiological performance has not been reported in COPD.

The objectives of this study were to determine the relative importance of isometric strength, and concentric and eccentric muscle strength at various velocities, in contributing to functional and physiological performance. Our hypotheses were three-fold: (i) that functional and physiological performance scores would correlate highly with measures of quadriceps muscle strength and power; (ii) that eccentric and fast-velocity (180°/sec or 270°/sec) concentric knee extension contractions would be associated with functional and physiological performance to a greater degree than slow-velocity concentric and isometric contractions; and (iii) that anaerobic power would be more strongly associated with functional performance than aerobic power.

Methods

This study employed a randomized, crossover design to assess the relative contributions of isokinetic and isometric torque to functional and physiological performance. Ethical approval was granted by ethics committees of the University of Saskatchewan, Saskatoon, Saskatchewan, Canada, and the Saskatoon Health Region, Saskatchewan, Canada. Thirteen patients (eight male) with moderate to severe COPD, as defined by the Canadian Thoracic Society Guidelines,[14] were recruited from the Saskatoon Pulmonary Rehabilitation Program and the Respirology Clinics at the Royal University Hospital in Saskatoon. Subjects were excluded if there was evidence of resting hypoxemia ($P_aO_2 < 60$ mmHg if available or $S_aO_2 < 88\%$),[15] if they required continuous supplemental oxygen usage, if their oxygen desaturation decreased to <80% during exercise, if they had any contraindications to exercise testing (per American Thoracic Society/American College of Chest Physicians exercise testing guidelines),[15] and if there was a history of known or suspected cardiac disease or musculoskeletal concerns that might limit the ability of these subjects to perform active exercise. Subject demographics are presented in Table 1.

Measurements

Participants attended the laboratory on four occasions. Pulmonary function tests and a cardiopulmonary exercise test (CPET) were obtained in the first session. The next three sessions were randomized such that participants performed functional tests, quadriceps leg strength testing, or an anaerobic performance test.

Pulmonary function tests

Spirometry (forced expiratory volume in 1 second, forced vital capacity), lung volumes (total lung capacity), and diffusion capacity for carbon dioxide tests were completed as per American Thoracic Society standards[16–18] using a V_{max} Autobox (SensorMedics, Yorba Linda, CA).

Cardiopulmonary exercise test

A maximal incremental cycle ergometry exercise test was performed to the standards of the American Thoracic Society-American College of Chest Physicians[15] as the first physiological test. The test began with a 3-minute warm-up of unloaded cycling on an electronically braked cycle ergometer (800S, SensorMedics), followed by ramped increases in work rate by 5–15 W/min until symptom limitation. Respiratory gas analysis was performed using a V_{max} Metabolic Measurement System (SensorMedics). Heart rate and oxygen saturation were recorded using pulse oximetry and electrocardiogram, respectively. Symptoms of dyspnea and leg fatigue were recorded using a modified Borg scale for perceived exertion.[19]

Table 1 Subject demographics

	Mean (SD)
Gender (M/F, n)	8/5
Age, yr	74.1 ± 3.5
Weight, kg	83.4 ± 24.7
Body mass index, kg/m^2	29.7 ± 7.1
FEV_1, L	1.09 ± 0.23
FEV_1, % predicted	47.9 ± 13.9
FEV_1/FVC, %	43.2 ± 12.2
TLC, L	5.99 ± 1.20
RV, L	1.62 ± 0.86
D_LCO, % predicted	63.2 ± 14.6
VO_2 peak, mL/kg/min	13.2 ± 2.82

Abbreviations: D_LCO, diffusion capacity for carbon dioxide; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; RV, residual volume; TLC, total lung capacity; VO_2 peak, maximal oxygen consumption.

Steep ramp anaerobic test

The second physiological test was the steep ramp anaerobic test (SRAT), which has been used to prescribe interval training in patients with heart failure[20,21] and COPD,[22] and has been shown to be a reliable measure of anaerobic power in patients with COPD.[23] This test is considered more clinically appropriate than the Wingate Anaerobic Test.[23] The test began with a 2-minute unloaded warm-up on the cycle ergometer followed by ramped increases of 25 watts every 10 seconds until volitional fatigue, as per the protocol of Meyer et al.[21] The same measures used for the CPET were recorded for the SRAT, and the primary outcome was peak work rate attained.

Functional tests

Tests that mimic higher-intensity activities of daily living were used. These tests included the stair climb power test (SCPT), timed-up-and-go test (TUG), and 30-second sit-to-stand test (STS). The SCPT as per the protocol of Bean et al[24] was used. Subjects climbed a flight of ten steps as quickly as possible. Leg muscle power was calculated from body weight, stair height, and time to perform the test, as previously described.[8] The TUG was performed as described by Podsiadlo and Richardson.[25] Subjects started seated in a chair and, upon command, rose, walked 3 meters, turned around, walked back to the chair, and sat down as fast as possible. The STS was performed as described by Rikli and Jones.[26] Subjects started seated in a chair and, upon command, stood up and returned to sitting as many times as possible in a 30-second time period. Each functional test was performed twice, in a standardized order, with a 5-minute break between trials. The best score attained on each test was recorded.

Quadriceps measurements

Using an isokinetic dynamometer (Humac NORM, CSMi, Stoughton, MA), the dominant leg quadriceps muscle (knee extension) was tested for the following parameters: concentric contractions at 60°/sec, 90°/sec, 180°/sec, and 270°/sec, eccentric contractions at 90°/sec, and isometric contractions at 0°/sec. Each test was randomized and performed three times with a minimum 2-minute rest period between tests and trials. The reliability of this method in patients with COPD has been demonstrated previously.[27] Peak torque was recorded for each trial, and the relative torque (peak torque per kg of body mass) was used in the analysis.[28] In addition, the rate of torque development was recorded during the isometric contraction. The means of the two greatest values for each measure were used in the analysis.

Statistical analysis

Data were analyzed for normalcy. Pearson's or Spearman's correlation analyses were used as appropriate to determine significant relationships between all measures. The strengths of correlations were low (0–0.25), moderate (>0.25–0.50), strong (>0.50–0.75), and very strong (>0.75).[8] Statistical significance was set at $\alpha = 0.05$. Data are presented as means and standard deviations.

Results

All subjects completed the various study procedures. Test scores for all data and correlation coefficients are presented in Tables 2 and 3, respectively.

Physiological tests

The SRAT and CPET were assessed for significant associations with both the functional tests and the muscle strength tests. Performance on the SRAT was reflected by strong associations with the TUG and STS and by a very strong association with SCPT, whereas CPET performance was not significantly reflected in any of the functional tests. Slow-velocity concentric, isometric, and eccentric torque was associated with SRAT performance, whereas none of the muscle strength variables correlated with CPET performance.

Table 2 Mean scores for muscle, functional, and physiological measures

	Mean (SD)	Range
CPET peak (W)	49.0 ± 14.7	25–80
SRAT peak (W)	157.4 ± 29.0	125–200
SCPT (W)	237.5 ± 63.8	159–365
STS (reps)	10.2 ± 3.05	5–15
TUG (sec)	7.98 ± 1.94	5.4–11.6
Iso (Nm)	130.7 ± 39.7	79–187
Iso (Nm · kg^{-1})	1.66 ± 0.57	0.68–1.88
RTD (Nm · s^{-1})	254.6 ± 183.4	67.5–528.4
RTD (Nm · s^{-1} · kg^{-1})	3.32 ± 2.48	0.58–7.93
Con 90 (Nm)	96.7 ± 33.8	62–161
Con 90 (Nm · kg^{-1})	1.20 ± 0.37	0.61–1.87
Con 180 (Nm)	72.5 ± 27.6	41–125
Con 180 (Nm · kg^{-1})	0.89 ± 0.29	0.48–1.38
Con 270 (Nm)	60.7 ± 27.1	26–110
Con 270 (Nm · kg^{-1})	0.74 ± 0.27	0.38–1.08
Ecc 90 (Nm)	145.4 ± 51.4	84–213
Ecc 90 (Nm · kg^{-1})	1.82 ± 0.64	0.72–2.75

Abbreviations: Con 90, concentric peak torque at 90°/sec; Con 180, concentric peak torque at 180°/sec; Con 270, concentric peak torque at 270°/sec; CPET, cardiopulmonary exercise test; Ecc 90, eccentric peak torque at 90°/sec; Iso, isometric peak torque; RTD, rate of torque development; SCPT, stair climb power test; SRAT, steep ramp anaerobic test; STS, sit-to-stand test; TUG, timed up and go.

Table 3 Correlations of leg strength (expressed as values relative to body weight), functional performance, and physiological performance (torque variables in Nm · kg^{-1})

Variables	TUG	SCPT	STS	CPET	SRAT
RTD	–0.683[a]	0.727[a]	0.722[a]	0.612	0.668[a]
Iso	–0.924[c]	0.686[a]	0.763[a]	0.161	0.663[a]
Con 90	–0.863[b]	0.781[a]	0.755[a]	0.171	0.642[a]
Con 180	–0.793[b]	0.749[a]	0.673[a]	0.062	0.589
Con 270	–0.687[a]	0.569	0.540	0.110	0.571
Ecc 90	–0.903[c]	0.718[a]	0.809[b]	0.366	0.804[b]
CPET	–0.323	0.303	0.436	N/A	N/A
SRAT	–0.712[a]	0.914[c]	–0.671[a]	0.573	N/A

Notes: [a]$P < 0.05$; [b]$P < 0.01$; [c]$P < 0.001$, significant correlation.
Abbreviations: Con 90, concentric peak torque at 90°/sec; Con 180, concentric peak torque at 180°/sec; Con 270, concentric peak torque at 270°/sec; CPET, cardiopulmonary exercise test; Ecc 90, eccentric peak torque at 90°/sec; Iso, isometric peak torque; RTD, rate of torque development; SCPT, stair climb power test; SRAT, steep ramp anaerobic test; STS, sit-to-stand test; TUG, timed up and go.

Functional tests

TUG time was significantly associated with all muscle strength variables and SRAT performance either strongly or very strongly. The strongest associations for the TUG were with isometric and eccentric peak torque, suggesting that TUG performance is related mostly to the ability to generate high static forces and the ability to control the eccentric phase of muscle contraction. The strongest correlation with TUG performance was isometric peak torque.

SCPT performance was associated very strongly with SRAT performance and strongly or very strongly with all muscle torque variables except concentric contractions at 270°/sec. The anaerobic-based SRAT was the strongest determinant of SCPT performance.

The number of STS repetitions was also strongly associated with the SRAT and with all muscle torque variables except concentric contraction at 270°/sec, with eccentric contractions demonstrating the strongest correlation.

Discussion

The primary purpose of this study was to determine the association between muscle strength, functional performance, and physiological performance in patients with COPD. We found evidence supporting our first hypothesis that functional performance and physiological performance measures would be associated with certain qualities of muscle strength, but the strongest associations depended on the measure. For the TUG and STS, performance was best determined by isometric and eccentric torque, respectively. For the SCPT, performance was best determined by the anaerobic SRAT performance. This is the first study to show strong relationships between high-level functional performance, eccentric muscle contractions, and anaerobic exercise performance.

These findings support previous research demonstrating that isometric quadriceps strength is related to exercise performance in patients with COPD; however, most studies have examined measures of aerobic endurance such as the 6-minute walk test[29] and the incremental shuttle walk test.[30] Our measure of aerobic performance was of aerobic power (CPET) and not endurance, and our results suggest that isometric quadriceps strength is not significantly related to aerobic power. In assessing the role of concentric strength, Roig et al[9] found that slow-velocity quadriceps torque did not correlate with the 6-minute walk test or STS, and only to a small extent with the SCPT.[8] In addition, these authors found a much stronger association between eccentric strength and performance on the SCPT[8] – a finding supported by our study results. One key difference between our present study and previous studies was the expression of quadriceps torque as a function of body mass, which is more consistent with previous methodology and standardization.[28]

In support of our second hypothesis, eccentric contractions were strongly associated with performance of all three functional measures, indicating that eccentric strength is a strong contributor of functional performance in patients with COPD. Eccentric peak torque was a strong predictor of performance on the STS, presumably because of the utilization of multiple eccentric contractions in this test. This finding confirms that the rate of control of the eccentric phase of an activity involving a quick change of direction strongly determines performance on that activity.[11,31] Contrary to our expectations, however, high-velocity concentric contractions were not as strongly associated with functional or physiological performance as were slower-velocity concentric and eccentric contractions. There is some evidence in healthy adults that adequate functional performance is determined by fast-velocity contractions,[31] and using fast-velocity (power) exercise during training results in greater functional performance compared with slow-velocity training.[32,33] It is not apparent why these results are contradictory; however, because patients with COPD exhibit significant deficiencies in functional performance[6] and typically do not produce fast contractions in their daily life, it is possible that high-velocity torque production using an isokinetic dynamometer was extremely unfamiliar. We controlled for any learning effects by allowing a significant amount of time and standardized instruction during the familiarization procedures for the dynamometer; however, patients still may not have been fully accustomed.

Despite the lesser correlations between high-velocity concentric contractions and functional performance, there is some support for our hypothesis in regard to generating fast contractions. A high rate of torque development has been suggested to relate to an individual's ability to perform functionally at faster contraction speeds.[32,33] Our findings support the relationship between rate of torque development and performance of all three functional tests in patients with COPD.

In addition to these findings, the results supported our third hypothesis that measures of muscle strength and functional performance were more highly associated with anaerobic power (as determined by the SRAT) than aerobic power (as determined by the CPET). This finding supports previous assertions[34] that high-level functional performance is better determined by anaerobic energy utilization than the more typically measured aerobic energy utilization (through the standard CPET). As we[23] and others[22] have shown previously, the ability of the leg muscles to produce work in patients with COPD is grossly underestimated by the aerobically dominated CPET; however, when anaerobic performance is measured (by the SRAT, for example), this better reflects both high-level functional performance and qualities of muscle strength/power.

There are a few limitations of this study. First, our sample size may have contributed to some correlations being found nonsignificant. This limitation is less relevant given that the primary purpose was to examine which muscle strength and performance factors were most highly correlated. As hypothesized, the strongest correlations were, in every case, deemed to be statistically significant. A second limitation is our relatively homogeneous population of patients. Our patients were classified as mostly having moderate-severity COPD, and none required the use of supplemental oxygen. Previous research has demonstrated that patients with more severe COPD (independent of the use of supplemental oxygen) demonstrated reduced functional performance;[6] therefore, our results may not be generalizable to patients with more severe COPD. Nonetheless, we have demonstrated meaningful and statistically significant results in our described study population. Third, physiological measures were assessed on a cycle ergometer. The results of our study may not be generalizable to walking exercise, as it is well known that treadmill exercise usually results in maximal oxygen consumption about 10% higher than cycling.[15] Finally, this study was a cross-sectional, correlational study, and the results should not be interpreted to indicate any causal relationships between any of the muscle, functional, or physiological measures; they are merely associated with each other.

Conclusion

High-level functional performance in patients with COPD is best determined by eccentric and/or slow-velocity concentric (compared with fast-velocity) muscle contractions, and by anaerobic (compared with aerobic) performance. Exercise training studies that focus more on higher-intensity training (such as high-intensity interval training) or on changes in muscle strength/power should consider the addition of higher-level functional performance (such as the TUG, SCPT, or STS) tests and anaerobic power tests (such as the SRAT) as outcome measures.

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Disclosure

The authors report no conflicts of interest.

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