

Correlation between Limb Muscle Endurance, Strength, and Functional Capacity in People with Chronic Obstructive Pulmonary Disease

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ABSTRACT

Purpose: To examine the correlation between limb muscle function (endurance and strength) and functional capacity in upper limbs (ULs) and lower limbs (LLs) of people with chronic obstructive pulmonary disease (COPD). **Method:** This article describes a secondary analysis of data from a randomized controlled trial. A stationary dynamometer was used to measure isokinetic muscle strength and endurance; the 6-minute walk test, the 6-minute pegboard and ring test, and the unsupported UL exercise test were used to measure functional capacity. **Results:** Participants were 44 adults with COPD. Muscle strength and endurance in ULs and LLs demonstrated a moderate to strong correlation with functional capacity. When controlling for muscle strength, muscle endurance was moderately correlated with functional capacity in ULs and LLs, but when controlling for muscle endurance, there was no positive and significant correlation between muscle strength and functional capacity for the ULs or LLs. **Conclusions:** Functional capacity seems to be more closely related to limb muscle endurance than to limb muscle strength in people with COPD.

Key Words: chronic obstructive pulmonary disease; exercise test; lower extremity; muscle strength; upper extremity.

RÉSUMÉ

Objet : Étudier le lien entre l'endurance, la force et la capacité fonctionnelle des muscles des membres supérieurs et inférieurs de personnes qui ont une maladie pulmonaire obstructive chronique (MPOC). **Méthode :** Cet article décrit une analyse secondaire de données provenant d'un essai contrôlé randomisé. On a utilisé un dynamomètre stationnaire pour mesurer la force et l'endurance isocinétiques des muscles, le test de marche de six minutes (TM6M), le test du tableau perforé et des anneaux de six minutes (TPA6M) et le test des membres supérieurs non supportés (TMSNS) pour mesurer la capacité fonctionnelle. **Résultats :** Les participants étaient 44 adultes atteints de MPOC. La force et l'endurance musculaires des membres supérieurs et inférieurs a révélé un lien variant de modéré à solide avec la capacité fonctionnelle. Compte tenu de la force musculaire, on a établi un lien modéré entre l'endurance musculaire et la capacité fonctionnelle des membres supérieurs et inférieurs, mais compte tenu de l'endurance musculaire, il n'y avait aucun lien positif et significatif entre la force musculaire et la capacité fonctionnelle des membres supérieurs ou inférieurs. **Conclusions :** Il semble y avoir un lien plus étroit entre la capacité fonctionnelle et l'endurance des muscles des membres qu'entre la capacité fonctionnelle et la force des muscles des membres chez les personnes qui ont une MPOC.

Limb muscle dysfunction is a well-known consequence of chronic obstructive pulmonary disease (COPD).^{1,2} Muscle dysfunction, including reduced maximal strength and endurance, occurs in both upper limbs (ULs) and lower limbs (LLs)^{2,3} and is associated with exercise intolerance; it may also be associated with poor quality of life, diminished activities of daily living, and increased mortality in people with COPD.^{2,4} People with COPD also have decreased functional capacity,⁵ and it has been suggested that the reduction is related to the muscle dysfunction.^{6,7} To fully understand the role of muscle

dysfunction in the functional capacity of people with COPD, we need to further investigate the relationship between these factors.

Limb muscle strength and endurance are two different components of limb muscle function: Whereas *limb muscle strength* refers to the force-generating capacity of the muscle, *limb muscle endurance* refers to the muscle's ability to sustain or repeat a specific task over time.⁸ Thus, we can anticipate that the importance of strength and endurance will vary depending on the functional activity performed. Extended knowledge of the roles

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played by muscle strength and endurance in functional capacity will guide clinicians in constructing exercise programmes aimed at improving functional capacity.

Previous studies have shown a correlation between limb muscle strength and functional capacity in both ULs and LLs in people with COPD.^{6,9–12} Three studies found moderate to strong correlations between maximal quadriceps strength and LL functional capacity^{6,9,10} measured using the 6-minute walk test (6MWT), the timed up-and-go test (TUG), the timed stair climb power test, and the 30-second sit-to-stand test (STS). Janaudis-Ferreira and colleagues¹¹ found a moderate to strong correlation between limb muscle strength and UL functional capacity measured using the unsupported UL exercise test (UULEX) and the 6-minute pegboard and ring test (6PBRT).

The correlation between limb muscle endurance and functional capacity measurements, however, has been less well studied. To our knowledge, only one study¹² has examined the relationship between quadriceps muscle endurance, strength, and the 6MWT. This study found strong correlations both between muscle endurance and the 6MWT and between muscle strength and the 6MWT. The relationship between endurance and the 6MWT seemed to be stronger than that between strength and the 6MWT, but no analysis was performed to investigate this further.

To decrease this gap in our knowledge, research is needed to explore the importance of limb muscle endurance to functional capacity in COPD, preferably including both LL and UL measurements. The aim of our study, therefore, was to determine the correlation between limb muscle function (i.e., maximal strength and endurance) and functional capacity in ULs and LLs in people with moderate to severe COPD.

METHODS

This cross-sectional study was a secondary analysis of data collected during a multi-centre randomized controlled trial, described elsewhere,^{13,14} that examined the effects of an exercise programme with low-load-high-repetition elastic band resistance training in people with moderate to severe COPD. Ethical approval was obtained from the regional ethical board in Umeå, Sweden (Dnr: 2010–344–31 M), and written informed consent was obtained from all participants.

Participants

Potentially eligible participants were identified by screening medical records from three hospitals in Sweden (Norrlands University Hospital, Umeå; Karolinska University Hospital, Huddinge; and Örnsköldsvik Hospital, Örnsköldsvik) and primary-care centres in the vicinity of each hospital. Potential participants were eligible if they were adults aged 40 years or older; had stable moderate to very severe airflow obstruction (Global Initiative for

Chronic Obstructive Lung Disease stages 2–4)¹⁵; were ex-smokers; had stable medical treatment (no changes within 3 months); and lived less than 60 km from one of the three hospitals. Potential participants were excluded if they had a musculoskeletal, rheumatic, cardiac, or neurological disorder; had previously undergone lung surgery; were on long-term oxygen treatment; or had a body mass index of less than 18 (kg/m²).

Outcome measures

Measurements were performed at Umeå University Hospital and at Karolinska University Hospital. Measurements were assessed by the same researcher for all participants at each location and were performed on two occasions. Each test occasion lasted between 1 and 2 hours. Information and encouragement were standardized, and the tests were conducted in the same order for all participants.¹³ Measurements used in this analysis were performed at baseline, before the resistance exercise programme started.

6-minute walk test

The 6MWT was used to measure LL functional capacity. The walking course was 30 m in length, and participants were instructed to walk as far as possible in 6 minutes. To minimize the learning effect, participants first performed a practice test; standardized instructions and encouragement were given according to American Thoracic Society guidelines for the 6MWT.¹⁶ Test occasions were separated by more than 24 hours. The test with the longest distance walked was used for the analysis.

6-minute pegboard and ring test

Unsupported arm function was measured using the 6PBRT, which uses a pegboard with two pegs set at participants' shoulder level (lower pegs) and two pegs set 20 cm above shoulder level (upper pegs). The pegs are positioned shoulder width apart for each participant. Ten lightweight wooden rings (6 g each) were placed on each of the lower pegs, and participants then moved one ring at a time from each lower peg to the corresponding upper peg, using both hands simultaneously. After moving all 20 rings from the lower to the upper pegs, participants moved them back, one at a time, from the upper pegs to the lower pegs. The participants were asked to move as many rings as possible in 6 minutes; the total score was the number of rings moved during the 6-minute period. Standardized encouragement was given every minute. Before testing, participants were allowed to move 20 rings from the lower to the upper pegs and vice versa to familiarize themselves with the procedure.¹⁷

Unsupported upper limb exercise test

The UULEX was used to assess unsupported UL functional capacity. Participants sat on a chair with the

UULEX chart attached to the wall in front of them. The UULEX chart consisted of eight horizontal levels. Each level was 84 cm wide and 8 cm high, and the distance between the centers of the levels was 15 cm. The lowest was placed at the level of the participants' knees. Participants held a plastic bar (0.2 kg) with their hands shoulder-width apart and moved it from the hips to the different levels on the UULEX chart in front of them. Each movement began and ended with the bar on the participant's hips. After 2 minutes at the first level, participants changed to a higher level every 1 minute, always returning the bar to the hip, regardless of level. The bar was lifted at a rate of 30 beats per minute, guided by a metronome. When participants reached their individual maximum height, the 0.2 kg bar was replaced with a heavier one (0.5 kg), and they continued to lift the bar to the highest level. Thereafter, the weight of the bar was increased by 0.5 kg each minute up to 2 kg. Participants were instructed to continue the test until symptom limitation.¹⁸

In our study, we included both 6PBRT and UULEX measurements of UL functional capacity because we expected them to measure somewhat different properties of functional capacity. Although the 6PBRT includes a small dynamic movement, it is mainly an isometric endurance test of the shoulders because it is performed with arms held in at least 90° of shoulder flexion. The UULEX is more of a dynamic measurement of functional capacity, including a large range of motion.

Limb muscle function

Muscle strength and endurance were measured during isokinetic knee extension and shoulder flexion, using two interchangeable stationary dynamometers: the Biodex Multi-Joint Systems 3 and 4 (Biodex Medical Systems Inc., Shirley, NY). The tests were performed on the self-reported dominant side and were undertaken after the 6MWT, which was considered a warm-up. Before the maximal tests, participants performed five submaximal contractions to familiarize themselves with the procedure, followed by 2 minutes of rest before the test started. In both maximal strength and endurance tests, shoulder flexion was performed between 0° and 100° with the elbow held extended, the forearm semi-pronated, and the handle of the dynamometer placed in the hand. Knee extension was performed between 90° of flexion and full extension minus 5° to lower the risk of passive resistance from the hamstring muscle. The maximal strength test measured peak torque (in Newton metres) from the highest contraction, generated during five maximal contractions.¹⁹ After 5 minutes of rest, participants performed the endurance test, which consisted of 30 repetitions measuring total work (in joules). Both tests were measured with an angular velocity of 60° per second, which is considered ideal for evaluating isokinetic muscle strength in COPD and has also been found to be reliable in endurance tests.^{19,20}

Data analysis

Assumption of normal distribution of parameters was assessed using the Shapiro–Wilks test, which revealed that some parameters were not normally distributed. These parameters were transformed logarithmically to stabilize the variance. To investigate the relationship between two parameters, we performed bivariate correlations using Pearson correlation analysis. Partial correlation analysis was used to examine the correlation between two parameters while controlling for a third (e.g., the correlation between walking distance and knee endurance while controlling for knee strength). The strength of the correlation coefficients was categorized as low (0–0.25), moderate (>0.25–0.50), strong (>0.50–0.75), or very strong (>0.75).²¹ Statistical analysis was performed using SPSS version 19 (SPSS Inc., Chicago, IL). Because we expected a strong correlation between limb muscle strength and endurance, we performed a linear regression to investigate the presence of multicollinearity, that is, the loss of power to measure for a variable when it occurs alongside other variables with similar properties. To avoid multicollinearity, the variance factor should be below 4, according to previous literature.²² Data are presented as means and standard deviations, with the threshold for significance set at $p < 0.05$.

RESULTS

The linear regression showed a variance factor of 3.6, which indicates no multicollinearity in the results. Participant characteristics are presented in Table 1.

Correlations between upper limb functional capacity, shoulder muscle strength, and endurance

We found no significant positive correlations between shoulder muscle strength and either 6PBRT or UULEX in either the bivariate or the partial correlations. The correlation between shoulder muscle endurance and the UULEX was only moderate in both bivariate and partial correlation analyses, and correlation between shoulder muscle endurance and the 6PBRT was significant only when we controlled for shoulder muscle strength. When we controlled for shoulder muscle endurance, we found a negative correlation between 6PBRT and shoulder muscle strength. UULEX and 6PBRT values were moderately correlated ($r = 0.414$, $p = 0.005$), and the correlation between UL muscle strength and endurance was very strong ($r = 0.806$, $p < 0.001$; see Figures 1 and 2).

Correlations between walking capacity, knee muscle strength, and endurance

Both knee muscle strength and knee muscle endurance were strongly correlated with 6MWT in the bivariate correlation analysis. When we controlled for knee muscle strength, the correlation between knee muscle endurance and 6MWT was moderate, but we found no significant correlation between knee muscle strength and 6MWT when we controlled for knee muscle endurance.

Table 1 Participant Characteristics (*N* = 44*)

Characteristic	Mean (SD)*
Anthropometrics	
Age, y	69 (6)
Female, no. (%)	23 (52)
BMI, kg/m ²	26 (4)
Disease severity	
GOLD II, no. (%)	10 (23)
GOLD III, no. (%)	33 (75)
GOLD IV, no. (%)	1 (2)
VC, % predicted	100 (19)
FEV ₁ , L	1.5 (1)
FEV ₁ , % predicted	57 (13)
FEV ₁ /FVC	45 (10)
TLC, % predicted	112 (17)
RV, % predicted	141 (33)
Functional capacity	
6MWT, min	505 (95)
6PBRT, no. of rings	264 (51)
UULEX, s	568 (142)
Limb muscle function	
Shoulder flexion strength, Nm (<i>n</i> = 43)	34 (13)
Shoulder flexion endurance, J	472 (246)
Knee extension strength, Nm	101 (29)
Knee extension endurance, J	1,939 (581)

*Unless otherwise indicated.

BMI = body mass index; GOLD = Global Initiative for Chronic Obstructive Lung Disease; VC = vital capacity; FEV₁ = volume exhaled during the first second of a forced expiration; FVC = forced vital capacity; TLC = total lung capacity; RV = residual volume; 6MWT = 6-minute walk test; 6PBRT = 6-minute pegboard and ring test; UULEX = unsupported upper limb exercise test; Nm = Newton metres; J = joule.

The correlation between muscle strength and endurance was very strong ($r = 0.852$, $p < 0.001$; see Figure 3).

DISCUSSION

The most important finding of this study is that for people with moderate to severe COPD, functional capacity seems to be more closely related to limb muscle endurance than to limb muscle strength. This result highlights the importance of assessing limb muscle endurance, as well as strength, before beginning pulmonary rehabilitation. It also suggests that when designing exercise training programmes to improve functional capacity of people with COPD, clinicians should include limb muscle endurance training to a greater extent.

Functional capacity in people with COPD seems, as expected, to be correlated with both limb muscle strength and limb muscle endurance. Interestingly, the positive correlation with functional capacity only remained for limb muscle endurance when controlling for limb muscle strength. In fact, when controlling for limb muscle endurance, there was no longer any correlation between muscle strength and the 6MWT or UULEX, and the correlation between limb muscle strength and the 6PBRT was negative.

The negative correlation between muscle strength and the 6PBRT was unexpected, but a likely explanation is that those participants with better shoulder muscle strength measurements also had larger or heavier arms. It is known that muscle cross-sectional area is important for muscle strength in COPD,² but although a large and heavy arm may be an advantage for muscle strength, it is likely to be a disadvantage for 6PBRT performance, which requires holding the arms almost static in at least 90° of shoulder flexion throughout, with only a small dynamic movement. However, arm size and weight were not measured in the original study, so we could not confirm this speculation with the measurements available. Ours is the first study to examine the correlation between limb muscle endurance and functional capacity in both ULs and LLs in people with COPD, and the results need to be confirmed in additional studies. The relationship and importance of limb muscle strength and endurance for functional capacity have also been demonstrated in people with chronic heart failure.²³

Previous studies have reported a correlation between limb muscle strength and functional capacity,^{6,9–11} but only a few have also measured limb muscle endurance. Leite Rodrigues and colleagues⁹ found that LL muscle strength was the only variable that could predict the distance walked in the 6MWT. Butcher and colleagues⁶ found strong to very strong correlations between LL muscle strength and functional capacity as measured with the TUG and STS; this finding is in line with the results of our bivariate correlation analysis between LL muscle strength and functional capacity as measured with the 6MWT. But neither of these studies measured or controlled for limb muscle endurance. Vilaro and colleagues¹² found strong relationships between LL muscle endurance and 6MWT performance as well as between LL muscle strength and 6MWT performance, consistent with the results of the bivariate correlation analysis in our study. Although Vilaro and colleagues did not perform the further analysis that, in our study, suggested that limb muscle endurance may be more closely related to functional capacity, both their findings and ours highlight the need for separate assessments of muscle strength and endurance.

In contrast to Janaudis-Ferreira and colleagues,¹¹ who found moderate to strong correlations between shoulder flexion strength and the 6PBRT and UULEX, we found no positive correlations in either bivariate or partial correlation analysis; 6PBRT and UULEX performances were moderately correlated with shoulder flexion endurance, but not with shoulder flexion strength. These contradictory results may to some extent be explained by the angle used in the strength measurements: Whereas Janaudis-Ferreira and colleagues¹¹ reported isometric peak measurement in 90° of shoulder flexion, our isokinetic peak torque values were obtained much earlier

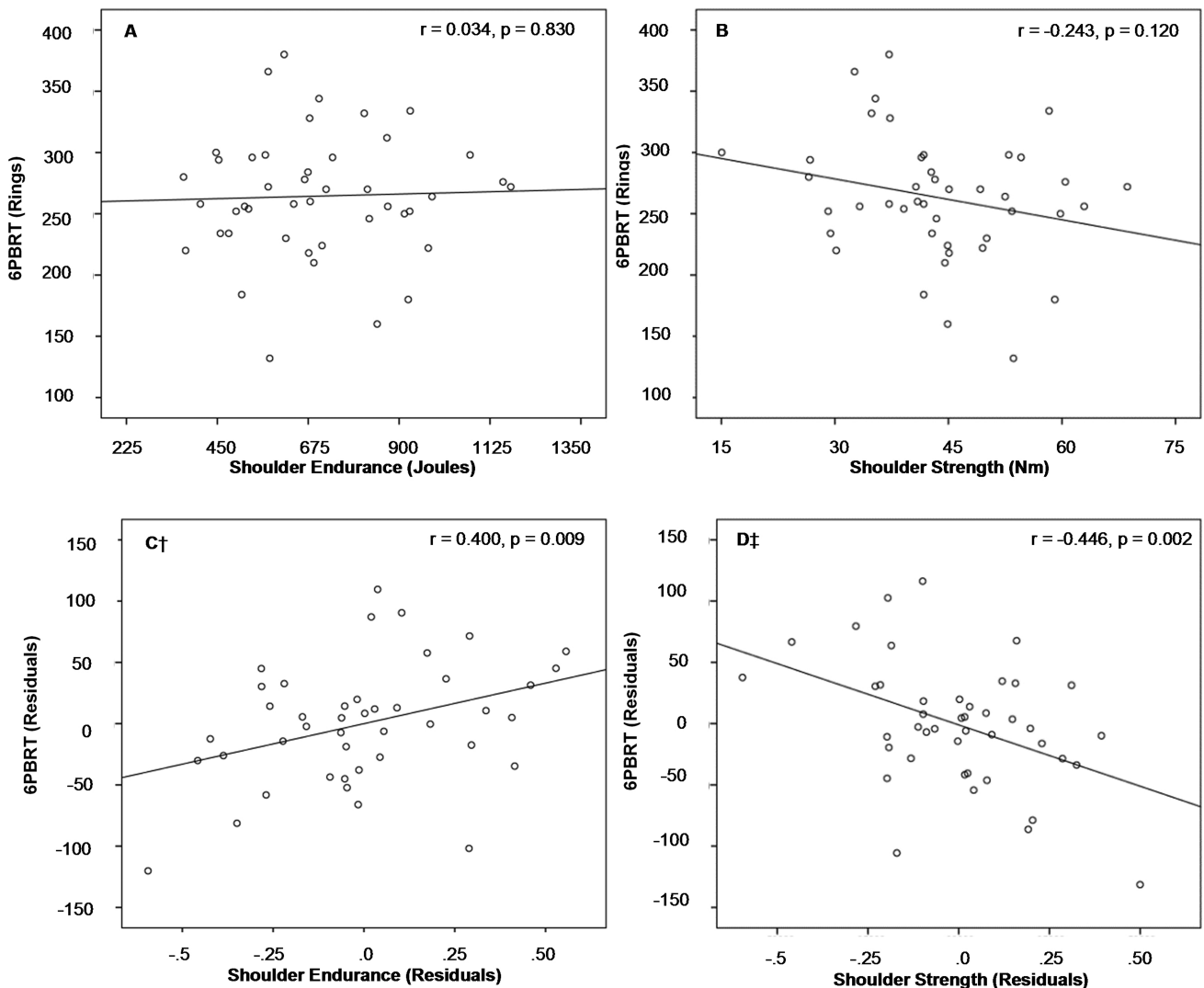


Figure 1 Bivariate (A–B) and partial correlations (C–D) between shoulder muscle strength, endurance, and rings moved on the 6PBRT.

†Correlation between rings moved on the 6PBRT and isokinetic shoulder endurance (J) while controlling for shoulder strength (Nm).

‡Correlation between rings moved on the 6PBRT and isokinetic shoulder strength (Nm) while controlling for shoulder endurance (J).

6PBRT = 6-minute pegboard and ring test; J = joules; Nm = Newton metres.

in the movement, at approximately 30°–40° of shoulder flexion. However, participants who are strong at 30°–40° of shoulder flexion are also arguably strong at 90° of shoulder flexion, which would minimize the importance of shoulder angle to the results.

UL muscle endurance was more closely related to UULEX than to 6PBRT performance, which may be explained by a greater resemblance in arm movements between the UL muscle endurance test and the UULEX than between the UL muscle endurance test and the 6PBRT. The differences between movements in the tests and the moderate correlation between the 6PBRT and UULEX indicate that, as expected, they probably measure somewhat different properties. Whereas the UULEX seems to measure dynamic endurance capacity, the 6PBRT appears to reflect isometric endurance capacity.

If this is the case, the stronger correlation we found between UULEX performance and isokinetic limb muscle endurance is not surprising. It is important to note that instruments designed to measure similar constructs can generate different results if they were designed for different purposes. A low correlation between tests underscores the fact that each instrument is providing unique information. Lack of strong correlation between tests does not imply that they are not valuable outcome measures in COPD.²⁴ When clinicians are choosing an appropriate test to evaluate UL function, our findings may guide them to choose the UULEX if they are targeting dynamic functional endurance capacity or the 6PBRT if isometric endurance is of interest.

The strengths of our study are the comprehensive standardization of the testing procedure, with all tests

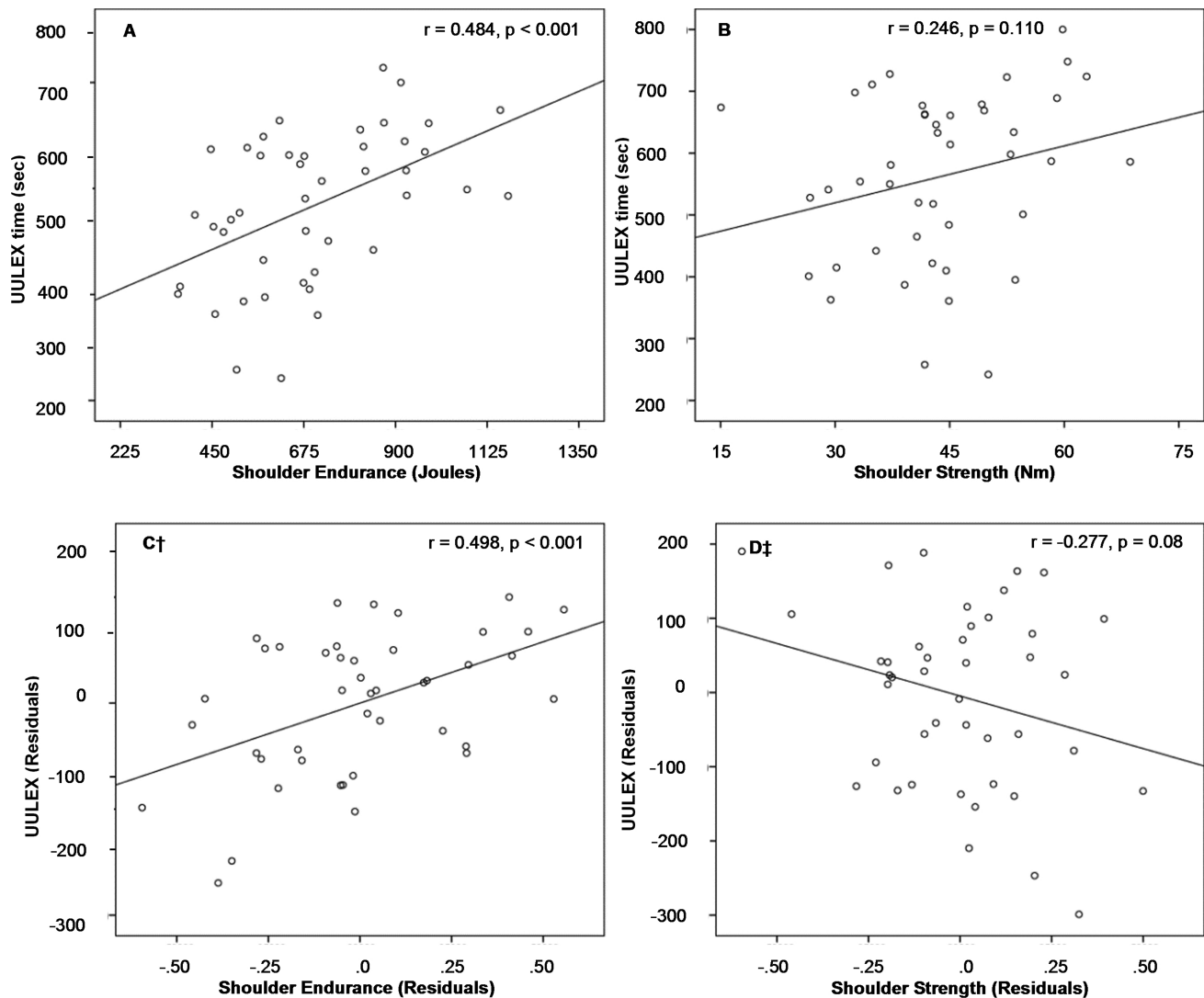


Figure 2 Bivariate (A–B) and partial correlations (C–D) between shoulder muscle strength, endurance, and exercise time on the UULEX.

†Correlation between total time on the UULEX and isokinetic shoulder endurance (J) while controlling for shoulder strength (Nm).

‡Correlation between total time on the UULEX and isokinetic shoulder strength (Nm) while controlling for shoulder endurance (J).

UULEX = unsupported upper limb exercise test; J = joules; Nm = Newton metres.

led by the same researcher, at the same time of the day, with the same interval between testing occasions for all participants. The investigated tests are reliable, valid, and commonly used in research with this population.^{17–20,25} Apart from the isokinetic limb muscle and endurance test, clinicians can easily use all measures because as they do not require expensive equipment or time.

Although the correlation between limb muscle strength and functional capacity has been demonstrated before, no study has reported the correlation between limb muscle endurance, strength, and functional capacity in both ULs and LLs in COPD.

Our study has some limitations. First, our results are valid only for patients with moderate to severe COPD; to broaden their applicability, it would be interesting to investigate whether the same relationship obtains for

patients with more severe disease, especially given that limb muscle weakness is more prevalent with more severe disease.²⁶ Second, although assessment of limb muscle strength and endurance in our study targeted muscles that most likely play an important role in the functional tests performed, other potentially important muscles, such as the biceps brachii muscle and the soleus muscle, for which results might differ, were not assessed.¹¹

CONCLUSION

Our study found moderate to strong correlations between functional capacity and muscle strength and endurance in both ULs and LLs. When we controlled for muscle strength, muscle endurance was moderately correlated with functional capacity in both ULs and LLs.

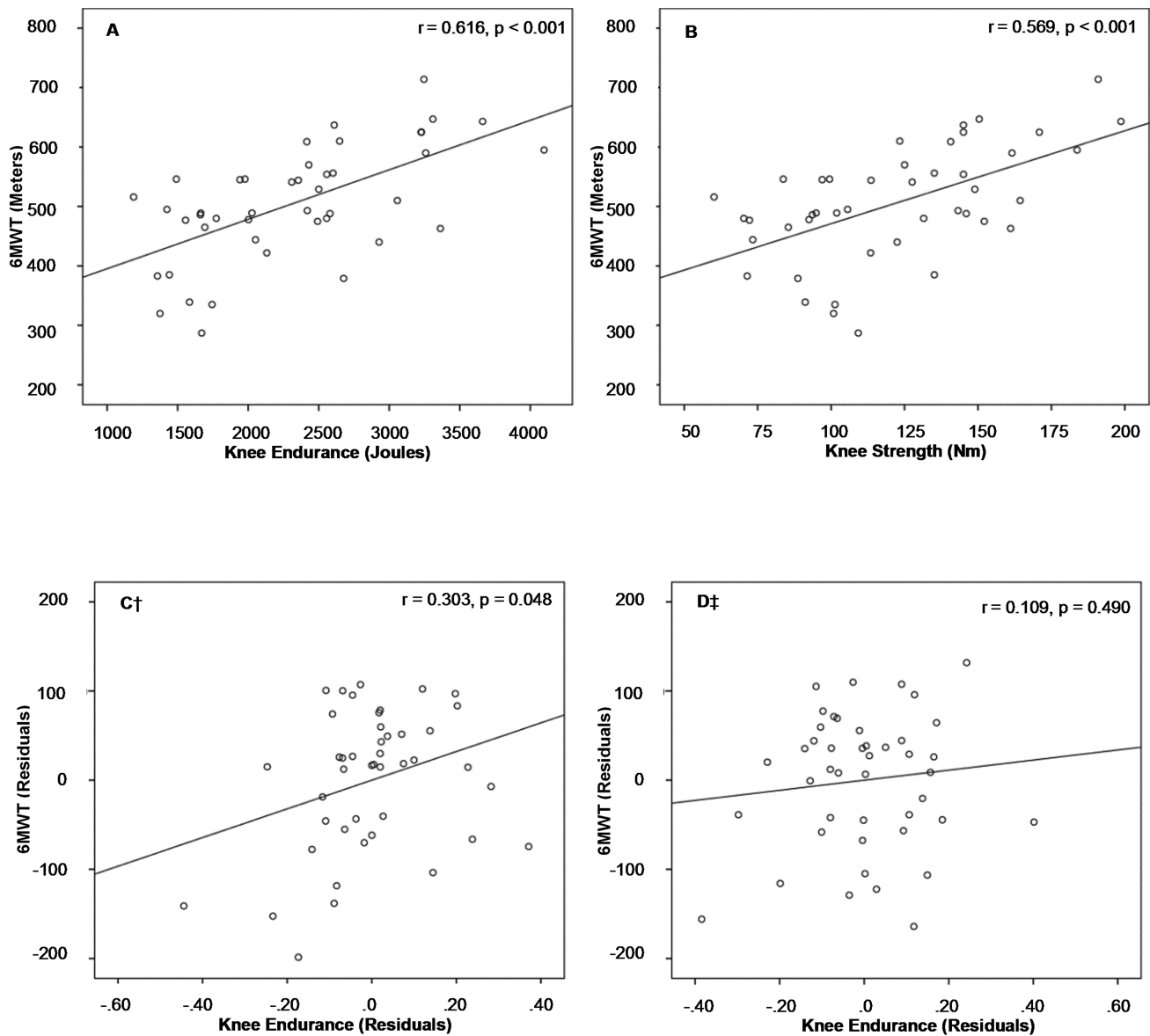


Figure 3 Bivariate (A–B) and partial correlations (C–D) between knee muscle strength, endurance and walking distance in COPD.

†Correlation between metres walked on the 6MWT and isokinetic knee endurance (J) while controlling for knee strength (Nm).

‡Correlation between metres walked on the 6MWT and isokinetic knee strength (Nm) while controlling for knee endurance (J).

6MWT = 6-minute walk test (distance); Nm = Newton metres; COPD = chronic obstructive pulmonary disease; J = joules.

When we controlled for muscle endurance, however, we found no significant positive correlation between muscle strength and functional capacity in either ULs or LLs. Functional capacity thus seems to be more closely related to limb muscle endurance than to limb muscle strength. Our findings emphasize the importance of assessing limb muscle endurance and of incorporating limb muscle endurance training when designing exercise training programmes in pulmonary rehabilitation for people with COPD.

KEY MESSAGES

What is already known on this topic

Limb muscle dysfunction, including reduced maximal muscle strength and endurance, is a well-known consequence in people with chronic obstructive pulmonary disease (COPD). A correlation between limb muscle strength and functional capacity has been reported in several previous studies, but very few of them have measured muscle endurance.

What this study adds

One primary goal of exercise training for people with COPD is to improve functional capacity. The results of this study suggest that functional capacity is more closely related to limb muscle endurance than to limb muscle strength. Clinicians may need to place more focus on increasing limb muscle endurance to improve functional capacity in this population.

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