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Home-based or remote exercise testing in chronic respiratory disease, during the COVID-19 pandemic and beyond: A rapid review

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Abstract

Objectives: To identify exercise tests that are suitable for home-based or remote administration in people with chronic lung disease. **Methods:** Rapid review of studies that reported home-based or remote administration of an exercise test in people with chronic lung disease, and studies reporting their clinimetric (measurement) properties. **Results:** 84 studies were included. Tests used at home were the 6-minute walk test (6MWT, two studies), sit-to-stand tests (STS, five studies), Timed Up and Go (TUG, 4 studies) and step tests (two studies). Exercise tests administered remotely were the 6MWT (two studies) and step test (one study). Compared to centre-based testing the 6MWT distance was similar when performed outdoors but shorter when performed at home (two studies). The STS, TUG and step tests were feasible, reliable (intra-class correlation coefficients >0.80), valid (concurrent and known groups validity) and moderately responsive to pulmonary rehabilitation (medium effect sizes). These tests elicited less desaturation than the 6MWT, and validated methods to prescribe exercise were not reported. **Discussion:** The STS, step and TUG tests can be performed at home, but do not accurately document desaturation with walking or allow exercise prescription. Patients at risk of desaturation should be prioritised for centre-based exercise testing when this is available.

Keywords

Exercise test, lung diseases, rehabilitation, home care services, telemedicine

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Introduction

As a result of the COVID-19 pandemic, many pulmonary rehabilitation programmes have transitioned rapidly to remote delivery models.[1,2] While studies have shown it is possible to deliver exercise training, physical activity counselling, education and self-management training remotely, with similar outcomes to traditional centre-based pulmonary rehabilitation,[3,4] all existing clinical trials have included an in person exercise test prior to programme commencement, to assess safety of exercise (e.g. degree of

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oxyhaemoglobin desaturation) and enable accurate exercise prescription.[3,5] During the COVID-19 pandemic centre-based or in person assessments of exercise capacity are not able to be performed in most centres. As a result, some pulmonary rehabilitation programmes have commenced exercise testing at home, using tests with minimal space requirements such as sit-to-stand (STS) or step tests, and with or without remote monitoring of oxyhaemoglobin saturation (SpO_2) and heart rate. Other programmes are not conducting any exercise testing prior to commencing patients on pulmonary rehabilitation programmes at home. It is not clear which of our current tests of functional exercise capacity are suitable for home and / or remote administration.

The research questions for this rapid review were:

1. Which functional exercise tests have been conducted in the home setting in people with chronic lung disease?
2. Which functional exercise tests have been conducted remotely in people with chronic lung disease?
3. What are the clinimetric properties of tests that have been conducted at home or remotely, including feasibility, reliability, validity and responsiveness to pulmonary rehabilitation?
4. Can these functional exercise tests be used to assess safety (particularly oxyhaemoglobin saturation) and prescribe exercise intensity, either in person or remotely?

Methods

The protocol was registered on PROSPERO (CRD42020182375) on 27 April 2020.

Types of studies: We included any study that reported conducting an exercise test at home or remotely in people with chronic respiratory disease. All exercise tests were eligible for inclusion; questionnaires and subjective reports of exercise capacity were excluded. We defined home exercise testing as any test conducted in the home setting by a health professional in person. We defined remote testing as any exercise test that had been conducted using information and communications technology, without in person supervision, regardless of setting. We also included studies conducted in any setting that report use of tests that were being conducted at home in people with chronic respiratory disease during the COVID-19 pandemic,[1] specifically step tests, sit-to-stand (STS) tests and the Timed Up and Go. These studies were included in order to report on their clinimetric properties (quality of measurement instruments e.g. reproducibility) and clinical properties (e.g. ability to detect desaturation and prescribe exercise). We did not include studies that reported the clinimetric properties of the 6-minute walk test (6MWT) in a centre-based setting, as these have been reported in detail in a previous systematic review.[6] There was no restriction on the functional domains measured during the test, which could include functional exercise capacity (e.g. walking tests, step tests) as well as tests of lower limb strength and endurance (sit-to-stand tests) and tests with components reflecting balance and frailty (e.g. Timed Up and Go).

We did not include case studies. Review articles were not included, but we reviewed their reference lists for studies that met our inclusion criteria. Otherwise there were no restrictions on study design. We included studies investigating clinimetric properties, descriptive studies and studies where the test was used to evaluate the effects of an intervention. Only studies published in English were included.

Participants: We included studies in which participants had any chronic lung disease including (but not limited to) chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), asthma, cystic fibrosis (CF), bronchiectasis or pulmonary hypertension. We did not exclude studies based on age, gender or physiological status of participants. We excluded studies that focused on participants who were mechanically ventilated.

Search methods for identification of studies: As this was a rapid review designed to respond to the emerging COVID-19 pandemic, we elected to search a single database (MEDLINE) from 1 January 2000 to 25 April 2020. We chose the MEDLINE database due to the availability of relevant MESH terms, and good coverage of clinical topic areas for the English language literature, as only studies in English were to be included. The search strategy for MEDLINE is in Supplementary Table S1. One author reviewed the title and abstract of the identified studies to determine their inclusion.

Data extraction and management: One author conducted data extraction using a standardised template, with random checks on accuracy by a second reviewer. The following information was extracted:

- Methods of study (date/title of study, aim of study, study design, primary outcome, other outcomes)
- Participants (diagnosis, age, sex, disease severity, inclusion criteria, exclusion criteria, method of recruitment of participants)
- Intervention (if applicable, description of the intervention)
- Exercise test – name, details of protocol (if provided), location of test (home, centre, other) and monitoring (in person, remote, none), variables monitored
- Outcomes pre/post intervention data where applicable, details of clinimetric properties if applicable
- Details of any physiological monitoring, including but not limited to pulse oximetry
- Whether the results of the test were used to prescribe exercise and if so, the methods used.

Assessment of risk of bias: We considered risk of bias according to study design and methods of analysis, and this was documented in the data extraction form. As this was a rapid review we did not conduct a formal assessment using a risk of bias tool.

Outcomes: The main outcomes of interest were the number of reports of home or remote administration of each exercise test. Additional outcomes were patient variables monitored for each test (e.g. SpO_2, heart rate, symptoms, blood pressure); methods used to prescribe exercise training intensity; and clinimetric properties for each test – feasibility, reliability, validity and responsiveness, using the metrics reported by the authors.

Data synthesis: A narrative synthesis was performed for each exercise test separately. For each exercise test we reported whether it had been performed at home or with remote monitoring, including the number of reports. Patient variables monitored for each test (e.g. SpO_2, heart rate, symptoms, blood pressure) were reported descriptively. Any methods used to prescribe exercise training intensity were reported descriptively.

We reported clinimetric properties for each test, from all studies where these are reported, not just those performed at home. We reported feasibility (e.g. number of participants who could perform the test), reliability (e.g. intra-class correlation coefficient (ICC)), validity (e.g. correlation with gold standard exercise tests) and responsiveness to pulmonary rehabilitation (e.g. mean changes pre/post rehabilitation and measures of variability). Where possible we calculated an effect size to describe responsiveness.

We had intended to examine outcomes separately by subgroups with different lung diseases (e.g. COPD, ILD), but there were insufficient data for diseases other than COPD, so these analyses were not performed.

Results

The MEDLINE search identified 3778 studies (excluding duplicates) of which 3654 were excluded based on title and abstract. Of the 128 full text papers screened, 84 were included (85 reports). This included five studies examining the 6MWT,[7–11] 39 studies examining STS tests,[12–50] 35 studies examining step tests[19,24,50–82] and 17 studies examining the Timed Up and Go (TUG).[17,19,24,33,42,49,50,83–92] Ten studies examined more than one test, including four that examined STS and TUG,[17,42,48,49] four that examined two kinds of STS test,[29,32,44,45] and two studies (in three reports) that examined STS, TUG and step tests.[18,23,50] The PRISMA diagram is in Figure 1 and study characteristics are in Supplementary Tables S2-S5. An overall summary of the review findings is in Figure 2. No adverse events were reported in any studies.

Main outcome – home and remote use: Exercise tests that have been used at home in people with chronic lung disease were the 6MWT (two studies),[7,8] five times STS (5STS, two studies),[34,42] 10 times STS (10STS, one study, two reports),[19,24] 1-minute STS (1minSTS, one study),[50] 6-minute stepper test (6minStepper, two studies, three reports),[19,24,50] and TUG.[19,24,42,50,92] Exercise tests administered remotely were the 3-minute step test (3MST)[59] and 6MWT.[9,10]

6-minute walk test

Home: One randomised crossover trial (RXT) compared home and centre-based 6MWTs[8] and one RXT compared an outdoors to a centre-based 6MWT.[7] Both included people with moderate to severe COPD. The centre-based 6-minute walk distance was significantly longer than the distance recorded at home[8] (Table 1) with a mean difference that exceeded the minimal important difference of 30 metres.[93] The 6MWT track lengths were shorter at home (mean 17 metres) compared to the centre (30 metres) and 42% of tests were conducted indoors. Comparison of indoor vs outdoors 6MWT (conducted on a flat sidewalk), both using a 30-metre track, showed no difference in the distance walked (Table 1).[7]

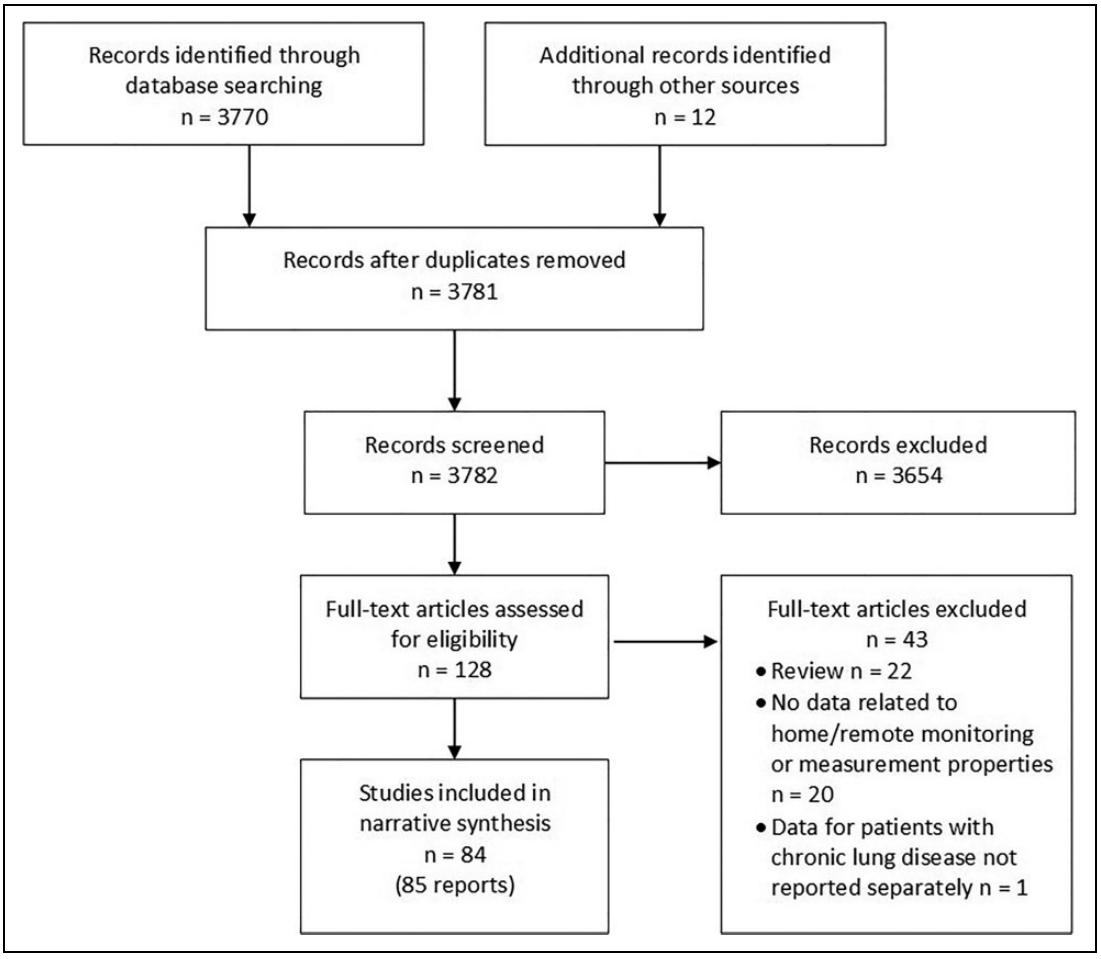

Figure 1. Study selection.

Remote: Two studies by the same group aimed to validate two different phone apps for remote monitoring of the 6MWT in people with chronic respiratory conditions (mostly COPD and asthma).[9,10] Both apps recorded the 6-minute walk distance using accelerometry, and one also provided voice and vibrating instructions.[9] Both apps included monitoring by pulse oximetry, however these data were not reported. The 6-minute walk distance measured by the apps was similar to that measured by the researchers in person (Table 1).

Feasibility: One study in participants with COPD reported that 58% of tests were conducted outdoors because a track of sufficient length was not available inside the home.[8]

Clinimetric properties: Home-based 6-minute walk distance was highly reliable when performed twice on the same day, with ICCs $\geq$ 0.99.[8] Intra-rater reliability was high for both outdoor and indoor tests (ICCs 0.97 and 0.99 respectively).[8]

Safety assessment: All studies reported monitoring the 6MWT using pulse oximetry and three also used symptom scales for dyspnoea and perceived exertion.[7,8,11]

Exercise prescription: One study used the 6MWT for exercise prescription in 39 people with COPD.[11] Walking exercise was prescribed at 80% of the average speed walked on the 6MWT. This exercise prescription was well tolerated over 10 minutes of walking, generally achieving more than 60% of peak oxygen uptake (VO_2) with a steady state by the fourth minute.

Sit-to-stand tests

Six different STS tests were used (Table S2). These were the five times sit to stand test (5STS, 14 studies), where the time taken to stand up and sit down five times from a standard height chair is recorded; the 10 times sit to stand test (10STS, 2 studies) using a similar protocol; the 30-second sit to stand test (30secSTS, 9 studies) where the number of sit-to-stand repetitions in 30 seconds is recorded; the

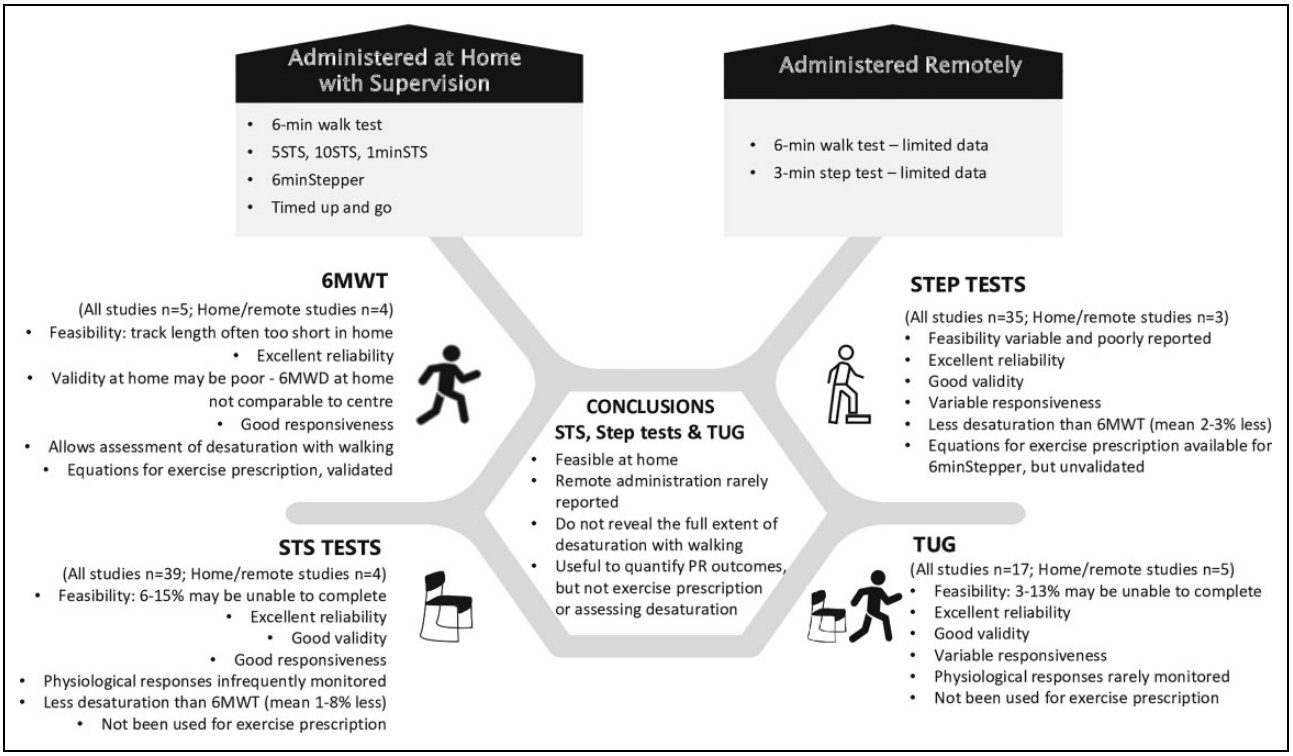

Figure 2. Summary of review findings.
6MWD = distance walked on 6-minute walk test, 6MWT = 6-minute walk test, STS = sit to stand, TUG = Timed Up and Go.

Table 1. Difference between centre-based and home or remote test administration.

Test	Study	Comparison	Difference
6MWT	Holland et al. 2015[8]	Centre vs home	6MWD mean 30.4 metres longer at the centre (95%CI 0.4 to 63.2 metres)
	Brooks et al. 2003[7]	Indoor vs outdoors	6MWD mean (SD) 394 (86) vs 398 (84) metres, p = 0.4
	Juen et al. 2014[9]	App vs in person	6MWD MD 0.3 m (95%CI – 73 to 72 metres) App absolute error for 6MWD 5.87%
	Juen et al. 2015[10]	App vs in person	App error for 6MWD 3.78%
3MST	Cox et al. 2013[59]	Remote supervision vs in person	Nadir SpO_2 MD 0.2% (LOA – 3.4 to 3.6%) Rate of perceived exertion MD 0.5 points (LOA – 1.1 to 2.1 points) Pulse rate MD - 0.6 beats/min (LOA – 11.3 to 10.1 beats/min).

3MST – 3-minute step test, 6MWD – 6-minute walk distance, 6MWT – 6-minute walk test, 95%CI – confidence interval, LOA – limits of agreement, MD – mean difference, SD – standard deviation, SpO_2 – oxyhaemoglobin saturation.

1-minute sit-to-stand test (1minSTS, 13 studies) as well as small numbers of studies using 2-minute tests (2minSTS, 1 study) and 3-minute tests (3minSTS, 2 studies).

Home: Tests used at home were the 5STS,[34,42] 10STS,[19,24] and the 1minSTS.[50] Participants (n = 381) had COPD, some were using home oxygen therapy[50] and some were recovering from an acute exacerbation.[34] All home testing involved in person supervision from a researcher or clinician.

Remote: No studies reported remote administration or monitoring of a STS test.

Feasibility: In a study of patients with stable COPD (n = 475), 15% of participants were unable to

complete the 5STS.[27] Those who were unable to complete the test were significantly older (mean (SD) 73(10) vs 68(10) years), had higher levels of chronic dyspnoea (Medical Research Council scale 4.1(1.0) vs 3.3(1.1) points), lower quadriceps maximal voluntary contraction (44(13) vs 60(17)%predicted) and lower incremental shuttle walk distance (84(66) vs 224 (126) metres). A study comparing the 5STS to the 30secSTS in 128 people with moderate to severe COPD reported that all participants could complete the 5STS but 7% could not complete two trials of the 30secSTS.[45] One additional trial reported that 3 of 50 participants with COPD (6%) could not complete any repetitions of the 30secSTS.[26] Of those participants who felt it was strenuous to undergo a STS (69%), most (93%) found the 30secSTS more strenuous than the 5STS.[45] In a clinical trial of inpatient pulmonary rehabilitation including 60 participants with moderate to severe COPD, all could complete both the 30secSTS and the 1minSTS.[44] No feasibility data were reported for the 10STS, 2minSTS or 3minSTS.

Clinimetric properties: Reliability, validity and responsiveness of STS tests are in Table 2. Test-retest reliability was high for the 5STS, 30secSTS and 1minSTS. The 5STS, 30secSTS and 1minSTS had moderate to strong correlations with other measures of exercise capacity, with higher values for the 1minSTS than the other tests. There were moderate correlations with quadriceps strength and weak correlations with daily life physical activity. Predictive validity was demonstrated only for the 1minSTS, with lower values predicting increased mortality at 2 and 5 years.[21,36] Responsiveness to pulmonary rehabilitation was evident for 5STS, 30secSTS and 1minSTS, with moderate to large effect sizes.

Safety assessment: Most studies did not report using any monitoring during the STS test (24 / 40 studies, 60%, Table S2).

A comparison of three STS tests in people with COPD found significantly greater desaturation on the 1minSTS than the 30secSTS or 5STS (mean −3(SD 4) vs −1(2) and −1(2) respectively).[32] Greater desaturation on 1minSTS than 30secSTS was reported in a second study in COPD (mean −2.6 (2) vs 2(1.8).[44] The 1minSTS also gave rise to significantly greater increases in heart rate than the 30secSTS or 5STS (mean 22(13) vs 16 (10) and 7(7)) and higher fatigue scores (median 2 vs 0.5 vs 0).[32] Dyspnoea scores on 1minSTS did not differ from the 30secSTS but were significantly greater than 5STS (median 2.5 vs 1 vs 0) with a similar pattern of findings for systolic blood pressure (median 30 vs 20 vs 0 mmHg).[32]

In comparison to the 6MWT and cardiopulmonary exercise test (CPET), the 1minSTS provoked less oxyhaemoglobin desaturation and a smaller rise in heart rate (Table 3). The VO_2peak was also significantly lower during 1minSTS than during the CPET (median 1.68 [IQR 1.38, 2.29] vs 1.25 [1.03, 1.86]).[37] Symptom scores for dyspnoea and fatigue were variable, with some studies reporting that they were similar across the tests,[25,39] higher on CPET than 1minSTS,[37] higher on 6MWT than 1 minSTS,[35] or higher on 1minSTS than 6MWT.[16]

Exercise prescription: No studies used any of the STS tests for exercise prescription.

Step tests

Five different step tests were used (Table 3): 6-minute stepper test (6MStepper) (15 studies), using a hydraulic stepper; a 3-minute step test (3MST) (9 studies), most at a fixed cadence (7 studies); incremental step tests (5 studies), where the stepping rate increases regularly throughout the test, using either the Chester protocol (4 studies) or a version modified for patients with lung disease (modified incremental step test, MIST, 3 studies); a step oximetry test (4 studies) involving either stepping on and off a single step 15 times (3 studies) or for as long as possible (1 study); and a 6-minute step test on a single step at a free cadence (2 studies).

Home: Two studies (3 reports) used the 6MStepper to assess exercise capacity before and after a rehabilitation programme at home.[19,24,50] These tests used a hydraulic stepper with in person supervision in the home. Participants (n = 337) had moderate to severe COPD and some were using long-term oxygen therapy.

Remote: One study compared a remotely supervised 3MST to a 3MST monitored in person in 10 adults with CF and moderate lung disease.[59] Remote supervision took place via videoconferencing and included measures of SpO_2 and pulse rate via pulse oximetry, with the monitor visible to the health professional via videoconferencing. Measures of dyspnoea and perceived exertion were also collected. There was good agreement between the directly supervised and remotely supervised tests for nadir SpO_2, pulse rate and rate of perceived exertion (Table 1). Nine of 10 participants indicated no

Table 2. Clinimetric properties of sit-to-stand tests.

Test-retest reliability	Number of studies	Patient diagnoses and numbers	Outcome measure	Mean difference between tests	ICC	Studies
5STS	1	COPD (n = 50)	Time (seconds)	0.04 (−0.21 to 0.29)	0.97 (95%CI 0.95 to 0.99)	Jones et al. 2013[27]
10STS	0					
30secSTS	1	COPD (n = 50)	Repetitions	−0.2 (−0.5 to 0.3)	0.94 (95%CI 0.90 to NR)	Hansen et al. 2018[26]
1minSTS	3	COPD (n = 294), CF (n = 14)	Repetitions	Range 0.8 to 2.29	Range 0.90 to 0.98	Crook et al. 2017a,[20] Reychler et al. 2018,[39] Radtke et al. 2016[38]
2minSTS	0					
3minSTS	1	COPD (n = 40)			Range 0.82 to 0.92	Aguilaniu et al. 2014[12]

Validity	Number of studies	Patient diagnoses and numbers	Type of validity	Measure	Strength of relationship	Notes
5STS	1	COPD (n = 475)	Concurrent	ISWT	r = 0.59	Jones et al. 2013[27]
	1	COPD (n = 475)	Concurrent	Quadriceps force	r = 0.38	Jones et al. 2013[27]
	1	COPD (n = 23)	Concurrent	Daily walking time	r = 0.19	Morita et al. 2018[32]
	2	COPD (n = 297)	Concurrent	Identify poor 6MWD	AUC 0.71 (95% CI 0.48 to 0.93)	Morita et al. 2018,[32] Bernabeu-Mora et al. 2015[94]
		COPD (n = 44)	Known groups	Severe vs mild comorbidities on CCI	MD 2.72 (SD 1.35) repetitions, p = 0.013	Oliveira et al. 2018[34]
				Severe vs moderate comorbidities on CCI	MD 2.7 (SD 1.14) repetitions	
10STS	0					
30secSTS	1	COPD (n = 128)	Concurrent	6MWD	r = 0.528	Zhang et al. 2018[45]
	3	CF (n = 15) COPD (n = 141)	Concurrent	Quadriceps force	r = 0.398–0.810	Sheppard et al. 2019,[43] Zhang et al. 2018,[45] Butcher et al. 2012[17]
	1	COPD (n = 23)	Concurrent	Daily walking time	r = 0.46	Morita et al. 2018[32]
	1	COPD (n = 23)	Concurrent	Identify poor 6MWD	AUC (.85 (95% CI 0.70–0.10)	Morita et al. 2018[32]
	1	LT candidates (n = 15) LT recipients (n = 47)	Known groups	Lung transplant candidates vs recipients	Mean 7(SD 2.5) vs 10(4.4) (p < 0.001)	Bossenbroek et al. 2009[15]
1minSTS	4	ILD (n = 107), COPD (n = 349)	Concurrent	6MWD	r = 0.5 to 0.834	Briand et al. 2018[16] Crook et al. 2017,[20] Ozalevi et al. 2007,[35] Reyschler et al. 2018,[39]
	4	COPD (n = 349), CF (n = 25)	Concurrent	Quadriceps force	r = 0.064 to 0.65	Crook et al. 2017,[20] Gruet et al. 2016,[25] Ozalevi et al. 2007,[35] Reyschler et al. 2018,[39]
	1	COPD (n = 23)	Concurrent	Daily walking time	r = 0.40	Morita et al. 2018[32]
	1	CF (n = 14)	Concurrent	VO_2peak %predicted	r = 0.627	Radtke et al. 2016[38]
	1	COPD (n = 23)	Concurrent	Identify poor 6MWD	AUC 0.82 (95% CI 0.64–1.0)	Morita et al. 2018[32]

(continued)

Table 2. (continued)

Validity	Number of studies	Patient diagnoses and numbers	Type of validity	Measure	Strength of relationship	Notes
	1		Known groups	COPD vs healthy control	Mean 15 (5) vs 20 (4), p = 0.01	
	2	COPD (n = 371) COPD (n = 374)	Predictive	Mortality	At 5 years: HR per 3 more repetitions: 0.81 (95% CI 0.65 to 0.86). At 2 years: HR per one more repetition 0.90 (95% CI 0.83–0.97) HR per 5 more repetitions 0.58 (95%CI 0.40–0.85)	Crook et al. 2017[21] Puhan et al. 2013[36]
2minSTS	0					
3minSTS	0					

Responsiveness	Number of studies	Patient diagnoses and numbers	Interventions	Effect size	Studies
5STS	9	COPD (n = 591)	Endurance training, strength training, whole body vibration training	Median 0.53, range 0.29 to 1.79	Berry et al. 2018,[14] Chen et al. 2018,[18] Gloeckl et al. 2012,[22] González-Saiz et al. 2017,[23] Neves et al. 2018,[33] Jones et al. 2013,[27] Levesque et al. 2019,[29] Rietschel et al. 2008[41] Spielmanns et al. 2017[47]
10STS	2	COPD (n = 474)	Home-based pulmonary rehabilitation	Range 0.27 to 0.40	Grosbois et al. 2015,[24] Coquart et al. 2017[19]
30secSTS	3	COPD (n = 49), IPF (n = 32)	Endurance training, resistance training, home exercise programme	Median 0.81, range 0.25–0.82	Li et al. 2018,[30] Kongsgaarda et al. 2004,[28] Vainshelboim et al. 2014[48]
1minSTS	4	COPD (n = 400), CF (n = 14)	Endurance training, resistance training, pulmonary rehabilitation + inspiratory muscle training	Median 0.62, range 0.53 to 0.97	Crook et al. 2017,[20] Radtke et al. 2016,[38] Levesque et al. 2019,[29] Vaidya et al. 2016[46]
2minSTS	0				
3minSTS	1	COPD (n = 116)	Endurance and resistance training	0.67	Levesque et al. 2019[29]

Data are mean (95% confidence interval) except where specified.
1minSTS – 1-minute sit to stand test, 2minSTS – 2-minute sit to stand test, 3minSTS – 3-minute sit to stand test, 30secSTS – 30-second STS test, 5STS – five times sit to stand test, 6MWD – 6-minute walk distance, 95%CI – 95% confidence interval, AUC – area under the curve, CCI – Charlson Comorbidity Index, CF – cystic fibrosis; COPD – chronic obstructive pulmonary disease; HR – hazard ratio, ILD – interstitial lung disease; ISWT – incremental shuttle walk test, LT – lung transplant; MD – mean difference, NR – not reported, r – Pearson's correlation coefficient, SD – standard deviation, VO_2peak – peak oxygen uptake.

Table 3. Fall in oxyhaemoglobin saturation and rise in heart rate on 1-minute sit-to-stand test compared to conventional exercise tests.

		Oxyhaemoglobin desaturation or nadir (SpO_2%)			Maximum heart rate		
Study	Patient group	1minSTS	6MWT	CPET	1STS	6MWT	CPET
Briand et al. 2018[16]	ILD	92 (5)	90 (7)		112 (17)	112 (16)	
Crook et al. 2017[20]	COPD	90 (3)	86 (6)		107 (11)	107 (15)	
Gruet et al. 2016[25]	CF	−4 (3)	−5 (4)	−7 (5)	131 (18)	141 (16)	171 (14)
Ozalevi et al. 2007[35]	COPD	0 (1)	−3 (3)		98 (22)	110 (20)	
Radtke et al. 2017[37]	CF	−6 [−3 to −9]		−9 [6 to 11]	154 [148 to 159]		169 [166 to 178]
Reyschler et al. 2018[39]	COPD	−1 (3)	−8 (5)		14 (10)	20 (15)	

Data are mean (SD) or median [interquartile range). Data are decrease in SpO_2 from baseline, with the exception of Briand et al and Crook et al, which are nadir SpO_2.
1minSTS – 1-minute sit-to-stand test; 6MWT – 6-minute walk test; CF – cystic fibrosis, COPD – chronic obstructive pulmonary disease, CPET – cardiopulmonary exercise test; ILD – interstitial lung disease.

preference for in person or remote supervision, with one participant preferring in person supervision.

Feasibility: Feasibility varied across the different step tests. One study reported that in patients with bronchiectasis the Chester Step Test was not as well tolerated as the MIST, which starts at a lower cadence and increases more slowly.[57] The Chester Step Test was stopped more frequently than the MIST by the examiner (58% vs 41% of tests), either because the participant could not maintain the cadence, or due to desaturation.[57] In contrast the entire 3MST at fixed cadence was completed by 97 of 101 adults with CF.[68] One study reported that all participants (n = 84 with ILD) could complete the 6minStepper test,[64] however people using supplemental oxygen were not included. Some studies excluded participants with orthopaedic problems that would have prevented them undertaking the test,[76] making it difficult to assess the feasibility of tests across the population of people with chronic lung disease.

Clinimetric properties: Reliability, validity and responsiveness of step tests are in Table 4. The 6minStepper, MIST and Chester step tests demonstrated good test-retest reliability, with limited data for other tests. Although the ICC for the 6minStepper was high (0.94) the second test recorded up to 42 steps more than the first test, due to warming of the hydraulic jacks in the stepper device.[55,58] There was some evidence of criterion validity for all tests, with moderately strong correlations to other important measures such as 6-minute walk distance or physical activity in daily life. Data for responsiveness to pulmonary rehabilitation was only available for the 6minStepper and 3MST (free cadence), with variable effect sizes.

Safety assessment: All studies reported monitoring step tests with pulse oximetry and most also used symptom scales for dyspnoea and perceived exertion (Table S3). Several studies reported that the degree of desaturation was less on the 6minStepper than on 6MWT (SpO_2 2.3 to 3% more desaturation on 6MWT, 4 studies).[64,71,76,81] Desaturation on the 6MST with free cadence was not different to 6MWT[52] or CPET.[62] A 15-step oximetry test resulted in similar desaturation to a 6MWT in patients with idiopathic pulmonary fibrosis (mean nadir SpO_2 86(SD 8)% vs 86 (7)%).[77] In contrast, an incremental step test (MIST) resulted in greater desaturation than a CPET (−7(5)% vs −3(3)%), but with similar rise in heart rate and similar symptoms.[61] A 6MST with free cadence caused a greater rise in heart rate and more lower limb fatigue than a 6MWT,[52] with similar findings for the 6minStepper.[64]

Exercise prescription: Three studies of the 6minStepper had developed equations for exercise prescription. Two studies generated reference equations for prescribing aerobic training based on heart rate during the 6minStepper, but the equations were not validated.[54,65] and there were no reports of their use to set training intensity in pulmonary rehabilitation programmes. A third study developed reference equations for prescription of resistance training and compared actual vs predicted training load (70% of 1 repetition maximum (1RM)).[53] The mean difference was 30 kg, and the authors concluded this difference

Table 4. Clinimetric properties of step tests.

Test-retest reliability	Number of studies	Patient diagnoses and numbers	Outcome measure	Mean difference between tests	ICC	Studies
6MStepper	3	COPD (n = 113)	Number of steps	Range 6 to 42 steps more on second test	0.94	Borel et al. 2010,[55] Coquart et al. 2015,[58] da Costa et al. 2014,[60]
MIST	2	COPD (n = 34), Bronchiectasis (n = 17)	Number of steps	1 step	0.99	Dal Corso et al. 2013,[61] Camargo et al. 2013[57]
Chester	2	Bronchiectasis (n = 17), COPD (n = 10)	Number of steps	Range 0.17 to 1.1 steps	NR	Camargo 2013,[57] Karloh 2013[70]
3MST	2	CF (n = 10), CF (n = 28)	Lowest SpO_2	0 to 2%	NR	Cox et al. 2013,[59] Aurora et al. 2001[51]
6MST	1	ILD (n = 31)	Number of steps	1.1	NR	Dal Corso et al. 2007[62]
Step oximetry	0					
Validity	**Number of studies**	**Patient diagnoses and numbers**	**Type of validity**	**Measure**	**Strength of relationship**	**Studies**
6MStepper	7	COPD (n = 368)	Concurrent Validity	6MWD	r = 0.42 to 0.71	Bonnevie et al. 2017,[54] Borel et al. 2010,[55] Delourme et al. 2012,[64] Fabre et al. 2017,[65] Grosbois et al. 2016,[67] Pinchon et al. 2016,[76] Chehere et al. 2016[81]
	1	COPD (n = 39)	Concurrent Validity	Steps/day	r = 0.48	Mazzarin et al. 2018[50]
MIST		Bronchiectasis (n = 17), acute lung disease (n = 77)	Concurrent Validity	6MWD	r = 0.54 to 0.64	Camargo et al. 2013,[57] Jose et al. 2016[69]
	1	COPD (n = 34)	Known groups – FEV_1 ≥50% predicted vs <50%	Steps	Mean 142(SD 66) vs. 84(40) steps	Dal Corso et al. 2013[61]
Chester	3	Bronchiectasis (n = 17), COPD (n = 42)	Concurrent validity	6MWD	r = 0.60 to 0.76	Camargo et al. 2013,[57] Camargo et al. 2011,[63] Karloh et al. 2013[70]

(continued)

Table 4. (continued)

Validity	Number of studies	Patient diagnoses and numbers	Type of validity	Measure	Strength of relationship	Studies
3MST	1	CF (n = 101)	Predictive validity	Desaturation<90%	Greater FEV_1 decline at 12 months than those who did not (mean difference 117 mL, 95% CI −215 to −19 mL).	Holland et al. 2011[68]
3MST	1	COPD (n = 32)	Concurrent Validity	6MWD	r = 0.733–0.777	Pessoa et al. 2014[62,75]
6MST	1	ILD (n = 31)	Concurrent Validity	VO_2peak	r = 0.52	Dal Corso et al. 2007[62]
	1	Asthma (n = 19)		Weekly moderate physical activity	r = 0.5	Basso et al. 2010[52]
Step oximetry	2	COPD (n = 50), PH (n = 86)	Concurrent Validity	6MWD	r = 0.13 to 0.77	Fox et al. 2013,[66] Starobin et al. 2006[79]
	1	PH (n = 86)	Concurrent Validity	TLCO	$r_S = -0.27$	Fox et al. 2013[66]
	1	IPF (n = 51)	Predictive validity	Lowest saturation	Lowest saturation a significant predictor of survival over 3 years (odds ratio 1.044, 95%CI 1.016 to 1.092)	Shitrit et al. 2009[78]

Responsiveness	Number of studies	Patient diagnoses and numbers	Interventions	Effect size	Study
6MStepper	4	COPD (n = 510), IPF (n = 13)	Home pulmonary rehabilitation	0.31 to 1.38	Grosbois et al. 2015,[24] Coquart et al. 2017[19] Mararra et al. 2012,[71] Rammaert et al. 2011[82]
	2	COPD (n = 92)	Centre-based pulmonary rehabilitation	0.2 to 0.36	Pichon et al. 2016,[76] Coquart et al. 2015[58]
MIST	0				
Chester	0				
3MST	1	COPD (n = 26)	Home pulmonary rehabilitation	1.07	Murphy et al. 2005[72]
6MST	0				
Step oximetry	0				

3MST – 3-minute step test, 6MST – 6-minute step test at free cadence, 6minStepper – 6-minute step test on hydraulic stepper equipment, 6MWD – 6-minute walk distance, 95%CI – 95% confidence interval, AUC – area under the curve, CF- cystic fibrosis, COPD – chronic obstructive pulmonary disease, HR – heart rate, ICC – intra-class correlation coefficient, ILD – interstitial lung disease, IPF -idiopathic pulmonary fibrosis, PH – pulmonary hypertension MD – mean difference, NR – not reported, PH – pulmonary hypertension, r – Pearson's correlation coefficient, r_S - Spearman's rho, SD – standard deviation, TLCO – diffusing capacity for carbon monoxide, VO_2peak – peak oxygen uptake.

was not clinically acceptable and the prediction equation should not be used as a substitute for a 1RM measure. No other step tests had been used for exercise prescription.

Timed Up and Go

Home: The TUG was administered at home in 4 studies (5 reports),[19,24,42,50,92] where it was used to evaluate the effects of a home pulmonary rehabilitation programme[19,24,42,50] or to evaluate change over 12 months.[92] Participants (n = 381) had moderate to severe COPD (FEV_1%predicted mean 27 to 42%) and some were using home oxygen therapy.[50] All home testing involved in person supervision from a researcher or clinician.

Remote: No studies reported remote administration or monitoring of the TUG.

Feasibility: Two studies reported excluding participants who could not perform the TUG (13% and 3% of those recruited).[89,90]

Clinimetric properties: Reliability, validity and responsiveness of the TUG are in Table 5. Test-retest reliability was high. Concurrent validity was demonstrated by moderate to strong relationships between TUG time and other measures of exercise capacity (6-minute walk distance, peak work, peak VO_2) and peak quadriceps force, although one study reported no relationship between leg press and TUG time (data not reported).[49] The TUG time was longer in fallers than non-fallers, and in oxygen users vs non-oxygen users.[83,85,86] Responsiveness varied, with effect sizes ranging from small to large, and the minimal detectable change (95%) ranging from 14 to 33.5%.

Safety assessment: Only one out of 16 studies (6%) reported any monitoring of physiological variables during the TUG (Table S4).

Exercise prescription: No studies used the TUG to prescribe exercise.

Discussion

This rapid review identified a range of exercise tests that have been used at home with supervision in people with chronic lung disease (6MWT, STS, 6min-Stepper and TUG) and a more limited range of tests that have been administered remotely (6MWT, 3MST). Administration of the 6MWT at home may be limited by short track lengths inside the house, although outdoors administration may provide a valid alternative where this is possible. The STS, step tests and TUG are feasible to perform in the home environment but do not reveal the full extent of desaturation with walking. These tests are useful to quantify improvements in physical function with home-based pulmonary rehabilitation but a gap remains in exercise prescription. Consideration should be given to identifying patients at risk of desaturation in whom centre-based exercise testing should be prioritised when local circumstances allow this to be performed safely.

This rapid review addresses an important challenge for pulmonary rehabilitation clinicians during the COVID-19 pandemic. While delivery of pulmonary rehabilitation programmes at home is feasible[3,5] and international bodies are advocating for remote delivery,[1,2] assessment of exercise capacity remains a key gap for many services. This review identifies a number of simple exercise tests that can be performed at home with supervision, when social distancing restrictions allow. These tests allow quantification of pulmonary rehabilitation outcomes, which is particularly important to evaluate in the context of a rapidly changing model of care. The small number of studies on remote administration of the 6MWT and 3MST provides some evidence that this approach would be feasible in selected patients (e.g. those not at risk of falls), but more data are required. While the 6minStepper has been used to prescribe exercise in a small number of studies, reliability of this test may be limited by the equipment required, which appears to require a variable warm up period for the hydraulic jacks.[55,58] Outdoors administration of a 6-min walk test may be possible in some settings,[7] depending on local weather and physical environment, which would allow both assessment of desaturation and prescription of exercise. This approach may prove more acceptable to some patients than an in-home or centre-based test, allowing social distancing to be better maintained. Important considerations for home administration of exercise tests include those specific to the pandemic, including availability of personal protective equipment, as well as those pertinent to all home testing including availability of equipment (standard height chairs and steps) and ensuring a safe testing environment for patients and health professionals.

Limitations to this review relate to both the body of evidence and the review process. A rapid review process was selected to ensure we could quickly address the immediate challenge facing the pulmonary rehabilitation community. We used accepted

Table 5. Clinimetric properties of Timed Up and Go.

Test-retest reliability	Number of studies	Patient diagnoses and numbers	Outcome measure	Mean difference between tests	ICC	Studies
	3	COPD (n = 274)	Time	0.06 to 0.82 seconds	0.85 to 0.96	Al Haddad et al. 2016,[83] Marques et al. 2016,[87] Mesquita et al. 2013[89]
Validity	Number of studies	Patient diagnoses and numbers	Type of validity	Measure	Strength of relationship	Studies
	4	COPD (n = 1136), IPF (n = 34)	Concurrent	6MWD	r = −0.61 to −0.74	Albaratti et al. 2016,[84] AlHaddad et al. 2016,[83] Mesquita et al. 2016,[90] Vainshelboim et al. 2019[91]
	2	COPD (n = 465)	Concurrent	Quadriceps peak torque	r = −0.61 to −0.74	Butcher et al. 2012,[17] Mesquita et al. 2016[90]
	1	COPD (n = 39)	Concurrent	Steps /day	r = −0.33	Mazzarin et al. 2018,[50]
	1	COPD (n = 520)	Concurrent	Identify poor 6MWD <360m	AUC 0.826 (95% CI 0.783 to 0.870)	Albarrati et al. 2016[84]
	2	COPD (n = 639)	Known groups	Longer time in COPD vs controls	mean 2.2 to 3.2 seconds longer	AlHaddad et al. 2016,[83] Albarrati et al. 2016[84]
	2	COPD (n = 670)	Known groups	Longer time in fallers vs non-fallers	mean 3.0 to 3.5 seconds longer	AlHaddad et al. 2016,[83] Albarrati et al. 2016[84] Beauchamp et al. 2009[85]
	2	COPD (n = 69)	Known groups	Longer time in oxygen users vs non-users	mean 1.3 to 4.7 seconds longer	Beauchamp et al. 2009,[85] Butcher et al. 2004[86]
	1	IPF (n = 34)	Predictive validity	Time ≥ 6.9 seconds	14.1-fold increased risk of hospitalisation 55.4-fold-increased risk of mortality	Vainshelboim et al. 2019[91]

Responsiveness	Number of studies	Patient diagnoses and numbers	Interventions	Effect size	SEM	MDC95%	Studies
	6	COPD (n = 722)	Centre-based PR, home-based PR, whole body vibration training	Median 0.4, range 0.09 to 0.8	0.79 to 0.947	14 to 33.5%	Grosbois et al. 2015,[24] Neves et al. 2018,[33] Marques et al. 2016,[87] Mesquita et al. 2016,[90] Mazzarin et al. 2018,[50] Rosenbek et al. 2015[42]

6MWD – 6-minute walk distance, 95% CI – 95% confidence interval, AUC – area under the curve, COPD – chronic obstructive pulmonary disease, ICC – intra-class correlation coefficient, IPF – idiopathic pulmonary fibrosis, MD – mean difference, MDC -minimal detectable change at 95% confidence level, NR – not reported, r – Pearson's correlation coefficient, PR – pulmonary rehabilitation, SD – standard deviation, VO_2peak – peak oxygen uptake.

methodological approaches for a rapid review in order to speed up the process, including searching fewer databases; restricting the types of studies included (e.g. English only); a limited time frame for article retrieval (year 2000 onwards); limiting dual review for study selection and data extraction; and limiting risk of bias assessment.[95] Inherent limitations to our review must therefore be acknowledged. These include searching a single electronic database (Medline) and only including studies published in English, which may have resulted in relevant studies being missed. A single author undertook study selection, and a single author performed data extraction with accuracy checks on a random sample by a second reviewer; this may have increased the risk of error and reduces confidence in the findings. We did not perform a formal quality assessment, although data extraction included risk of bias related to study design and analysis, which was considered during data synthesis. A formal risk of bias assessment may have identified important limitations to study conduct and reporting that were not evident during this rapid review process, which may also reduce the strength of conclusions that can be drawn. The included studies often included a small number of participants and used a wide variety of testing protocols, which limited data synthesis. Feasibility of the tests was poorly documented and key patient groups were often excluded from studies (e.g. those using oxygen therapy or those who could not perform the test). Clinimetric properties of tests were rarely assessed in the home setting, but given the nature of the tests (STS, step and TUG) and the use of face-to-face supervision, these seem unlikely to vary substantially from those properties documented in centre-based testing. A wide variety of testing protocols were used across the included studies, with reports of six different variants of STS and five variants of step tests, sometimes with differences in protocols between studies of the same test. This is a limitation to consistent clinical application. We only evaluated tests where we identified reports of their use in the home or remotely, so other tests that may be feasible in the home setting (e.g. treadmill testing, gait speed tests) were not included. A small number of studies were available for patient groups other than COPD.

In conclusion, pulmonary rehabilitation clinicians can confidently perform STS, step and TUG tests at home in people with chronic lung disease, where in person supervision is possible. Remote supervision may also be possible in selected patients, although few data are available. These in-home tests are useful to quantify the outcomes of home-based pulmonary rehabilitation, but do not reveal the full extent of desaturation on exercise, and validated methods to prescribe exercise intensity are not available. Consideration should be given to identifying patients at risk of desaturation in whom centre-based exercise testing should be prioritised, when local circumstances allow this to be performed safely.

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Supplemental material

Supplemental material for this article is available online.

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