Home-based and 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 properties.

Results: 84 studies were included. Tests used at home were the 6-minute walk test (6MWT, 2 studies), sit-to-stand tests (STS, 5 studies), Timed Up and Go (TUG, 4 studies) and step tests (2 studies). Exercise tests administered remotely were the 6MWT (2 studies) and step test (1 study). Compared to centre-based testing the 6MWT distance was similar when performed outdoors but shorter when performed at home (2 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.
Introduction

As a result of the COVID-19 pandemic, many pulmonary rehabilitation programs have transitioned rapidly to remote delivery models.\(^1\)\(^2\) Whilst studies have shown it is possible to deliver exercise training, physical activity counselling, education and self-management training remotely, all existing clinical trials have included an in-person exercise test prior to program commencement, to assess safety of exercise (e.g. degree of oxyhaemoglobin desaturation) and enable accurate exercise prescription.\(^3\)\(^4\) 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 programs 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 programs are not conducting any exercise testing prior to commencing patients on pulmonary rehabilitation programs 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\(^{th}\) April 2020. Inclusion criteria are presented in Box 1.

Types of studies: We included any study that reported conducting an exercise test at home or remotely in people with chronic respiratory disease. 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, specifically step tests and sit-to-stand (STS) tests.\(^1\) 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
des atu ration 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.5

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 MEDLINE from year 2000 to 25th April 2020. The search strategy for MEDLINE is in supplementary Table 1. 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. SpO₂, 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. SpO₂, 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, 39 studies examining STS tests, 35 studies examining step tests and 17 studies examining the Timed Up and Go (TUG). Ten studies examined more than one test, including three that examined three tests. The PRISMA diagram is in Figure 1 and study characteristics are in Supplementary Tables 2-5. An overall summary of the review findings is in Figure 2.

Main outcome – home and remote use: Exercise tests that have been used at home in people with chronic lung disease were the 6MWT (2 studies), five times STS (5STS, 2 studies), ten times STS (10STS, 1 study, 2 reports), 1-minute STS (1minSTS, 1 study), 6-minute stepper test (6minStepper, 2 studies, 3 reports), and TUG. Exercise tests administered remotely were the 3-minute step test (3MST) and 6MWT.

6-minute walk test:

Home: One randomised crossover trial (RXT) compared home and centre-based 6MW Ts and one RXT compared an outdoors to a centre-based 6MW T. Both included people with moderate to severe COPD. The centre-based 6-minute walk distance was significantly longer than the distance recorded at home with a mean difference that exceeded the minimal important difference of 30 metres. 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.

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). Both apps recorded the 6-minute walk distance using accelerometry, and one also provided voice and vibrating instructions. 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.

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

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

Exercise prescription: One study used the 6MWT for exercise prescription in 39 people with COPD. 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 (VO₂) with a steady state by the 4th 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 ten 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 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, 10STS, and the 1minSTS. Participants (n=381) had COPD, some were using home oxygen therapy and some were recovering from an acute exacerbation. 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. 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. One additional trial reported that 3 of 50 participants with COPD (6%) could not complete any repetitions of the 30secSTS. Of those participants who felt it was strenuous to undergo a STS (69%), most (93%) found the 30secSTS more strenuous than the 5STS. 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. 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. 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). Greater desaturation on 1minSTS than 30secSTS was reported in a second study in COPD (mean -2.6 (2) vs 2(1.8)). 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). 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).

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 VO2peak 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]). Symptom scores for dyspnoea and fatigue were variable, with some studies reporting that they were similar across the tests, higher on CPET than 1minSTS, or higher on 6MWT than 1 minSTS, or higher on 1minSTS than 6MWT. 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 program at home.\textsuperscript{18,23,49} 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.\textsuperscript{58} Remote supervision took place via videoconferencing and included measures of SpO\textsubscript{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\textsubscript{2}, pulse rate and rate of perceived exertion (Table 1). Nine of ten participants indicated no 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.\textsuperscript{56} 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.\textsuperscript{56} In contrast the entire 3MST at fixed cadence was completed by 97 of 101 adults with CF.\textsuperscript{67} One study reported that all participants (n=84 with ILD) could complete the 6minStepper test,\textsuperscript{63} however people using supplemental oxygen were not included. Some studies excluded participants with orthopaedic problems that would have prevented them undertaking the test,\textsuperscript{75} 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.\textsuperscript{54,57} 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 (SpO₂ 2.3 to 3% more desaturation on 6MWT, 4 studies). Desaturation on the 6MST with free cadence was not different to 6MWT or CPET. 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. A 6MST with free cadence caused a greater rise in heart rate and more lower limb fatigue than a 6MWT, with similar findings for the 6minStepper.

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, and there were no reports of their use to set training intensity in pulmonary rehabilitation programs. A third study developed reference equations for prescription of resistance training and compared actual vs predicted training load (70% of 1 repetition maximum (1RM)). The mean difference was 30kg, and the authors concluded this difference was not clinically acceptable and the prediction equation should not be used as a substitute for a 1RM measure.

**Timed Up and Go**

Home: The TUG was administered at home in 4 studies (5 reports), where it was used to evaluate the effects of a home pulmonary rehabilitation program or to evaluate change over 12 months. Participants (n=381) had moderate to severe COPD (FEV₁%predicted mean 27 to 42%) and some were using home oxygen therapy. 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).

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 VO₂) and peak quadriceps force, although one study reported no relationship between leg press and TUG time (data not reported). The TUG time was longer in fallers than non-fallers, and in
oxygen users vs non-oxygen users.\textsuperscript{82,84,85} 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, 6minStepper 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. Whilst delivery of pulmonary rehabilitation programs at home is feasible\textsuperscript{3,4} and international bodies are advocating for remote delivery,\textsuperscript{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. Whilst 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.\textsuperscript{54,57} Outdoors administration of a 6-min walk test may be possible in some settings,\textsuperscript{6} 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.

Limitations to this review relate to both the body of evidence and the review process. 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 small number of studies were available for patient groups other than COPD. A rapid review process was selected to ensure we could quickly address the immediate challenge facing the pulmonary rehabilitation community, but inherent limitations to this process must be acknowledged, including searching a single electronic database (Medline), a single author undertaking study selection, and a single author performing data extraction with accuracy checks on a random sample by a second reviewer. As this was a rapid review 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.

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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**Box 1. Inclusion criteria**

**Design**

- Any study that reported conducting an exercise test at home or remotely in people with chronic respiratory disease
- Any study reporting clinimetric properties of these tests
- Case studies, review articles and articles not in English were excluded

**Participants**

- People with chronic lung disease including (but not limited to) chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), asthma, cystic fibrosis, bronchiectasis or pulmonary hypertension

**Intervention:**

- No intervention was necessary for inclusion

**Outcome measures**

- Main outcome was the number of reports of home or remote administration of each exercise test
- Clinimetric properties for each test - feasibility, reliability, validity and responsiveness
- Patient variables monitored for each test (e.g. $\text{SpO}_2$, heart rate, symptoms, blood pressure)
- Methods used to prescribe exercise training intensity
| Test   | Study       | Comparison       | Difference                                                                 |
|--------|-------------|------------------|-----------------------------------------------------------------------------|
| 6MWT   | Holland 2015 | Centre vs home   | 6MWD mean 30.4 metres longer at the centre (95% CI 0.4 to 63.2 metres)      |
|        | Brooks 2003  | Indoor vs outdoors | 6MWD mean (SD) 394 (86) vs 398 (84) metres, p=0.4                          |
|        | Juen 2014   | App vs in-person | 6MWD MD 0.3m (95% CI -73 to 72 metres)                                      |
|        | Juen 2015   | App vs in-person | App absolute error for 6MWD 5.87%                                            |
| 3MST   | Cox 2013    | Remote supervision vs in-person | Nadir SpO₂ 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, SpO₂ - oxyhaemoglobin saturation.
| Test-retest reliability | Number of studies | Outcome measure | Mean difference between tests | ICC | Studies |
|-------------------------|-------------------|-----------------|-------------------------------|-----|---------|
| 5STS                    | 1                 | Time (seconds)  | 0.04 (-0.21 to 0.29)          | 0.97 (95% CI 0.95 to 0.99) | Jones 2013\(^{26}\) |
| 10STS                   | 0                 | Repetitions     | -0.2 (-0.5 to 0.3)            | 0.94 (95% CI 0.90 to NR)   | Hansen 2018\(^{25}\) |
| 30secSTS                | 1                 | Repetitions     | Range 0.8 to 2.29             |     | Crook 2017\(^{19}\), Reychler 2018, Radtke 2016\(^{37}\) |
| 1minSTS                 | 3                 |                 |                               |     |         |
| 2minSTS                 | 0                 |                 |                               |     |         |
| 3minSTS                 | 1                 |                 |                               |     |         |
| **Validity**            | **Number of studies** | **Type of validity** | **Measure** | **Strength of relationship** | **Notes** |
| 5STS                    | 1                 | Concurrent      | ISWT                          | \(r = 0.59\)              | Jones 2013\(^{26}\) |
|                         | 1                 | Concurrent      | Quadriiceps force             | \(r = 0.38\)              | Jones 2013\(^{26}\) |
|                         | 1                 | Concurrent      | Daily walking time            | \(r = 0.19\)              | Morita 2018\(^{31}\) |
|                         | 2                 | Concurrent      | Identify poor 6MWD           | AUC 0.71 (95% CI 0.48 to 0.93) | Morita 2018, Bernabeu-Mora 2017\(^{93}\) |
|                         | Known groups      | Severe vs mild comorbidities on CCI | MD 2.72 (SD 1.35) repetitions, \(p = 0.013\) | | Oliveira 2018\(^{33}\) |
|                         | Known groups      | Severe vs moderate comorbidities on CCI | MD 2.7 (SD 1.14) repetitions | | |
| 10STS                   | 0                 | Concurrent      | 6MWD                          | \(r = 0.528\)              | Zhang 2018\(^{44}\) |
|                         | 1                 | Concurrent      | Quadriiceps force             | \(r = 0.398 – 0.810\)      | Sheppard 2019,\(^{42}\) Zhang 2018,\(^{44}\) Butcher 2012\(^{36}\) |
|                         | 2                 | Concurrent      | Daily walking time            | \(r = 0.46\)               | Morita 2018\(^{31}\) |
|                         | 1                 | Concurrent      | Identify poor 6MWD           | AUC (0.85 (95% CI 0.70–0.10) | Morita 2018\(^{31}\) |
|                         | Known groups      | Lung transplant | Mean 7(SD 2.5) vs 10(4.4) (\(p < 0.001\)) | | Bossenbroek 2009\(^{14}\) |
| Responsiveness | Number of studies | Interventions | Effect size | Studies |
|----------------|-------------------|---------------|-------------|---------|
| 1minSTS        | 4                 | Concurrent    | r = 0.5 to 0.834 | Briand 2018, 15 Crook 2017a, 19, Ozalevi 2007, 34 Reyschler 2018, 38 |
|                | 4                 | Concurrent    | r = 0.64 to 0.65 | Crook 2017a, 19, Gruet 2016, 24 Ozalevi 2007, 34 Reyschler 2018, 38 |
|                | 1                 | Concurrent    | r = 0.40 | Morita 2018 31 |
|                | 1                 | Concurrent    | AUC 0.82 (95% CI 0.64 –1.0) | Crook 2017b 20, Puhan 2013 35 |
|                | 1                 | Known groups  | Mean 15 (5) vs 20 (4), p = 0.01 | |
|                | 2                 | Predictive    | Mortality | |
| 2minSTS        | 0                 |               |             |         |
| 3minSTS        | 0                 |               |             |         |

### Interventions

| 1minSTS        | 4                 | Concurrent    | 6MWD        | r = 0.5 to 0.834 | Briand 2018, 15 Crook 2017a, 19, Ozalevi 2007, 34 Reyschler 2018, 38 |
| 1minSTS        | 4                 | Concurrent    | Quadriceps force | r = 0.64 to 0.65 | Crook 2017a, 19, Gruet 2016, 24 Ozalevi 2007, 34 Reyschler 2018, 38 |
| 1minSTS        | 1                 | Concurrent    | Daily walking time | r = 0.40 | Morita 2018 31 |
| 1minSTS        | 1                 | Concurrent    | VO2peak %predicted | AUC 0.82 (95% CI 0.64 –1.0) | Crook 2017b 20, Puhan 2013 35 |
| 1minSTS        | 1                 | Known groups  | COPD vs healthy control | Mean 15 (5) vs 20 (4), p = 0.01 | |
| 1minSTS        | 2                 | Predictive    | Mortality | |

### Effect Size

| 5STS            | 9                 | Endurance training, strength training, whole body vibration training | Median 0.53, range 0.29 to 1.79 | Berry 2018, 13 Chen 2018, 17 Gloeckl 2012, 21 Gonzales-Saes 2017, 22 Neves 2018, 23 Jones 2013, 26 Levesque 2019, 28 Reitschel 2008, 40 Spielmans 2017, 46 Grosbois 2015, 23 Coquart 2017 18 |
| 10STS           | 2                 | Home-based pulmonary rehabilitation | Range 0.27 to 0.40 | |
| Test   | Duration | Description                                                                 | Median (Range) | Reference |
|--------|----------|-----------------------------------------------------------------------------|----------------|-----------|
| 30secSTS | 3        | Endurance training, resistance training, home exercise program              | 0.81 (0.25 – 0.82) | Li 2018, Kongsgaard 2004, Vainshelboim 2014 |
| 1minSTS | 4        | Endurance training, resistance training, pulmonary rehabilitation + inspiratory muscle training | 0.62 (0.53 to 0.97) | Crook 2017a, Radtke 2016, Levesque 2019 |
| 2minSTS | 0        | Endurance and resistance training                                            | 0.67           | Vaidya 2016 |
| 3minSTS | 1        | Endurance and resistance training                                            |                | Levesque 2019 |

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, HR – hazard ratio, ISWT – incremental shuttle walk test, MD – mean difference, NR – not reported, r – Pearson’s correlation coefficient, SD – standard deviation, VO2peak – 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

| Study          | Patient group | 1minSTS | 6MWT | CPET     | 1STS | 6MWT | CPET |
|----------------|---------------|---------|------|----------|------|------|------|
| Briand 2018    | ILD           | 92 (5)  | 90 (7)|          | 112 (17) | 112 (16) |
| Crook 2017     | COPD          | 90 (3)  | 86 (6)|          | 107 (11) | 107 (15) |
| Gruet 2016     | CF            | -4 (3)  | -5 (4)| -7 (5)   | 131 (18) | 141 (16) | 171 (14) |
| Ozalevi 2007   | COPD          | 0 (1)   | -3 (3)|          | 98 (22) | 110 (20) |
| Radtke 2017    | CF            | -6 [-3 to -9] | -9 [6 to 11] | 154 [148 to 159] | 169 [166 to 178] |
| Reyschler 2018 | COPD          | -1 (3)  | -8 (5)|          | 14 (10) | 20 (15) |

Data are mean (SD) or median [interquartile range]. Data are decrease in SpO₂ from baseline, with the exception of Briand et al and Crook et al, which are nadir SpO₂.

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
Table 4. Clinimetric properties of step tests

| Test-retest reliability | Number of studies | Outcome measure | Mean difference between tests | ICC | Studies |
|-------------------------|-------------------|-----------------|------------------------------|-----|---------|
| 6MStepper               | 3                 | Number of steps | Range 6 to 42 steps more on 2nd test | 0.94 | Borel 2010, 54 Coquart 2015, 57 da Costa 2014, 59 Dal Corso 2013, 56 Camargo 2013, 56 Karloh 2013, 59 Cox 2013, 58 Aurora 2001 50 Dal Corso 2007 51 |
| MIST                    | 2                 | Number of steps | 1 step                       | 0.99 |         |
| Chester                 | 2                 | Number of steps | Range 0.17 to 1.1 steps      | NR  |         |
| 3MST                    | 2                 | Lowest Sp O₂     | 0 to 2%                      | NR  |         |
| 6MST                    | 1                 | Number of steps | 1.1                         | NR  |         |

| Validity                | Number of studies | Type of validity | Measure                     | Strength of relationship | Studies |
|-------------------------|-------------------|-----------------|-----------------|--------------------------|---------|
| 6MStepper               | 7                 | Concurrent Validity | 6MWD             | r=0.42 to 0.71           | Bonnevie 2017, 53 Borel 2010, 54 Delourme 2012, 63 Fabre 2017, 64 Grosbois 2016, 65 Pinchon 2016, 75 Chehere 2016 52 Mazzarin 2018 59 |
| MIST                    | 1                 | Concurrent Validity | Steps/day         | r=0.48                   | Camargo 2103, 56 Jose 2016 68 Dal Corso 2013 |
|                         | 1                 | Known groups – FEV₁ ≥50% predicted vs <50% | Steps per day | Mean 142(SD 66) vs. 84(40) steps | Camargo 2103 56, Camargo 2011, 52 Karloh 2013 59 |
| Chester                 | 3                 | Concurrent validity | 6MWD             | r=0.60 to 0.76           |         |
| 3MST                    | 1                 | Predictive validity | Desaturation<90%   | Greater FEV₁ decline at 12 months than those who did not | Holland 2011 57 |
| 3MST | 6MST | Concurrent Validity | 6MWD | VO_{2peak} | Concurrent Validity | Weekly moderate physical activity | 6MWD | Concurrent Validity | 6MWD | VO_{2peak} |
|------|------|---------------------|------|------------|---------------------|---------------------------------|------|---------------------|------|------------|
| 1    | 1    | 1                   | 1    | 1          | 1                   | 1                               | 1    | 1                   | 1    | 1          |

(mean difference 117 mL, 95% CI -215 to -19 mL).

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, HR – heart rate, ICC – intraclass correlation coefficient, MD – mean difference, NR – not reported, r – Pearson’s correlation coefficient, SD – standard deviation, VO_{2peak} – peak oxygen uptake.
### Table 5. Clinimetric properties of Timed Up and Go

| Test-retest reliability | Number of studies | Outcome measure | Mean difference between tests | ICC | Studies |
|-------------------------|-------------------|-----------------|-------------------------------|-----|---------|
|                         | 3                 | Time            | 0.06 to 0.82 seconds          | 0.85 to 0.96 | Albarrati 2016, Marques 2016, Mesquita 2013 |

| Validity | Number of studies | Type of validity | Measure | Strength of relationship | Studies |
|----------|-------------------|------------------|---------|--------------------------|---------|
|          | 4                 | Concurrent       | 6MWD    | r = -0.61 to -0.74        | Albaratti 2016, AlHaddad 2016, Mesquita 2016, Vainshelboim 2019 |
|          | 2                 | Concurrent       | Quadriceps peak torque        | r = -0.61 to -0.74 | Butcher 2012, Mesquita 2016 |
|          | 1                 | Concurrent       | Steps /day                      | r = -0.33 | Mazzarin 2018, Albaratti 2016 |
|          | 2                 | Known groups     | Longer time in COPD vs controls | Mean 2.2 to 3.2 seconds longer | AlHaddad 2016, Albaratti 2016 |
|          | 2                 | Known groups     | Longer time in fallers vs non-fallers | Mean 3.0 to 3.5 seconds longer | AlHaddad 2016, Albaratti 2016 |
|          | 2                 | Known groups     | Longer time in oxygen users vs non-users | Mean 1.3 to 4.7 seconds longer | Beaugenhain 2009, Beaugenhain 2009, Butcher 2004, Vainshelboim 2019 |
|          | 1                 | Predictive validity | Time ≥ 6.9 seconds               | 14.1-fold increased risk of hospitalisation, 55.4-fold increased risk of mortality | |

| Responsiveness | Number of studies | Interventions | Effect size | SEM | MDC95% | Studies |
|----------------|-------------------|---------------|-------------|-----|--------|---------|
|                | 6                 | Centre-based PR, Median 0.4, range 0.09 to 0.8 | 0.79 to 0.947 | 14 to 33.5% | Grosboi 2015, |
|            | home-based PR, whole body vibration training | Neves 2018, \(^{33}\)  
Marques 2016, \(^{36}\)  
Mesquita 2013, \(^{13}\)  
Mesquita 2016, \(^{49}\)  
Mazzarin 2018, \(^{49}\) |

6MWD – 6-minute walk distance, 95% CI – 95% confidence interval, AUC – area under the curve, COPD – chronic obstructive pulmonary disease, ICC – intraclass correlation coefficient, 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\(_2\)peak – peak oxygen uptake.
Figure 1. Study selection

Records identified through database searching
n = 3770

Additional records identified through other sources
n = 12

Records after duplicates removed
n = 3781

Records screened
n = 3782

Records excluded
n = 3654

Full-text articles assessed for eligibility
n = 128

Full-text articles excluded
n = 43
• Review n = 22
• No data related to home/remote monitoring or measurement properties n = 20

Studies included in narrative synthesis
n = 84 (85 reports)

• Data for patients with chronic lung disease not reported separately n = 1
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