Pulmonary rehabilitation is now an evidence-based intervention for people suffering from chronic respiratory conditions. It consists of an individualised package of interventions that aim to accomplish two main objectives: 1) to improve the patient’s physiological and psychological well-being; and 2) to achieve long-term health-enhancing behaviour. As a minimum, the process of pulmonary rehabilitation requires a thorough assessment of the patient in order to establish their needs and the programme should contain exercise training, which is typically offered as group-based training, where patients receive an individually prescribed exercise programme.

While pulmonary rehabilitation can be offered using low-tech programmes that make use of simple forms of exercise, such as walking or stair climbing, technological advances are making inroads into rehabilitation programmes, such as those for patients with chronic obstructive pulmonary disease (COPD). Technology can be used to support pulmonary rehabilitation in various ways, both in the process of screening and in outcome assessment, as well as in the rehabilitation programme itself (in terms of the interventions made or monitoring methods used). In this article, methods of assessment that involve technology will be briefly highlighted, some of which are even now making their way outside the field of pulmonary rehabilitation. As there is relatively little evidence as to which tools are better than others, a top-level overview will be provided based on the long “consumer experience” we have gained in our centre in terms of the equipment used in exercise training programmes. Furthermore, the evidence regarding the use of activity monitors and step counters, as obtained in a large European Union project (the PROactive project from the Innovative Medicines Initiative (IMI)) will be summarised.

**ASSESSMENT OF PATIENTS**

Assessment of patients prior to starting rehabilitation entails physiologic assessment of exercise capacity and exercise limitation, as well as a functional exercise assessment.

Exercise capacity is typically assessed by incremental exercise testing, which in Europe is usually performed using an ergometer bicycle with electromagnetic braking. The peak work rate obtained from this test can be used to guide the load applied in training sessions, while the exercise limitation can help in guiding the type of training. For example, patients with a ventilatory limitation to exercise typically tolerate interval exercises (short bouts of up to 2–3 min) better at high intensity than long bouts of endurance exercise. Furthermore, patients with gas-exchange abnormalities may benefit from the administration of oxygen during training. Importantly, the load increments used during the incremental test determine to a large extent the peak work rate achieved. Indeed, patients...
achieve higher peak work rates when exercise testing protocols use steeper increments of load. Peak oxygen uptake ($V'\text{O}_2\text{peak}$) is less affected by the exercise protocol used and is therefore a more robust measure of a patient’s exercise capacity. Constant work rate tests, typically performed at 75–80% of the peak work rate, are excellent outcome measures that are sensitive to change after rehabilitation or pharmacotherapy interventions.

Functional exercise tests (e.g. the 6-min walk test (6MWT) or the incremental shuttle walk test (ISWT)) are less technology dependent; however, it is advised to have a transcutaneous oxygen saturation meter at hand. This is particularly important since desaturation can be more pronounced in a 6MWT, as in an incremental cycle test, and it is advised to stop the walking test if saturation drops below 80%. Importantly, transcutaneous saturation meters should be as resistant as possible to movement artifacts.

### Skeletal Muscle Function

Assessment of skeletal muscle function is increasingly being recognised as an important test even though it is not widely implemented at the present time. A recent statement on skeletal muscle function in COPD described ways to assess skeletal muscle force and endurance. Poor skeletal muscle strength and fatigability of muscles with exercise is predictive for a better exercise training response. In addition, skeletal muscle weakness is associated with poor prognosis in COPD and in other chronic respiratory diseases, as well as in chronic diseases more generally. As such, these assessments help in setting targets for exercise training and may provide benchmarks to assess training effects.

Assessment of skeletal muscle strength in particular is relatively easily implemented in clinical practice. A recent European Respiratory Society (ERS) and American Thoracic Society (ATS) statement on assessment of skeletal muscle function summarised current practice. While dynamometers are used in clinical practice, isokinetic dynamometers are often available in physical medicine departments, such as those in hospitals or rehabilitation centres. For patients with COPD these are typically used in isometric mode so movement does not limit the challenge to the ventilatory system. As an alternative to these expensive devices, isometric strain gauge measurements can be applied with equal validity and reliability. These measurements are advocated by the statement on muscle function and a simple chair can be built into a device to measure isometric quadriceps force. Hand-held dynamometers have also been used in the context of pulmonary rehabilitation. These devices are relatively cheap but require the technician to hold the tested limb while force is applied. The variability in results is relatively large and, while the test is valid to detect patients with muscle weakness, it is perhaps not the best method of detecting the effects of exercise training.

### Inspiratory Muscle Function

Assessment of inspiratory muscle function is important in the work-up of patients who have been referred for pulmonary rehabilitation and a technical standard is currently in preparation by the European Respiratory Society. Patients with inspiratory muscle weakness are the best candidates for inspiratory muscle training, which can be offered on top of classical exercise training. Assessment of respiratory muscle strength is possible using a variety of lung function equipment and measuring devices should allow for the capture of pressure differences of up to 30 kPa (~300 cmH₂O). The technology is also available as part of hand-held devices and allows easy assessment of respiratory pressures and “sniff pressures” when the assessor is well trained. It is important to mention that, for respiratory muscle pressure assessment, the measured values are to a large extent equipment dependent. As such, it is advised that a number of healthy subjects be tested prior to choosing reference values, to ensure that the values chosen are indeed consistent with normal. The orifice used and the “leak value” provided influence the outcome of the test to a large extent. If test results are abnormal, clinicians can decide to start inspiratory muscle training (IMT). For example, in the author’s own centre, IMT is started when maximal inspiratory pressure ($P_{\text{Imax}}$) is less than 50–60% of predicted. The equipment required to train the inspiratory muscles needs to be selected and should be suitable for isocapnic hyperpnoea training (although this is used less frequently in COPD cases). The most common training mode is that of threshold loading where the patient is required to breathe against a fixed submaximal threshold load for 15 min. However, newer protocols such as taking 30 breaths against a somewhat higher resistance have also been validated. While resistive breathing has been the dominant technique in the past it is currently being superseded by a new training mode, that of tapered-flow resistive breathing. This technology allows for considerably deeper inspiration against a fluctuating resistance and requires somewhat more advanced equipment (where resistance can be adjusted when patients are breathing towards the limit of their total lung capacity (TLC)). While this training mode seems to result in a somewhat larger improvement in $P_{\text{Imax}}$, it is not yet known whether any of these devices have benefits that are directly relevant to patients.

### Nutritional Status

The assessment of nutritional status, in addition to mapping exercise tolerance and muscle function, is an important part of the work-up of patients entering pulmonary rehabilitation. A recent ERS statement has summarised the state of the art in nutritional and body-composition assessment and attention is needed for patients that are underweight or overweight. However, it is important to note that even patients who have a normal body weight, or those who are overweight, may still present with low fat-free mass. Assessment of body composition is therefore imperative in patients referred for pulmonary rehabilitation in order to guide nutritional intervention. Body composition can be assessed using a dual
energy X-ray absorptiometry (DEXA) scan or by whole body bio-impedance measures. With a DEXA scan a more granular picture is obtained in terms of appendicular and central fat and lean mass, while whole body impedance allows for global assessment of fat mass and fat-free mass. Visceral fat, which is linked to a cardiovascular risk profile, has recently been assessed from a single slice of a computed tomography (CT) chest scan. In the ECLIPSE trial this was standardised as the inferior edge of the transverse process of the first lumbar vertebrae (L1). Similarly, CT scans can be used to assess subcutaneous fat or muscle cross-sectional area; however, while this may provide interesting insight into epidemiological questions, it is not the preferred method for clinical assessment.

**PHYSICAL ACTIVITY**

One last set of tools relevant to the assessment of patients for pulmonary rehabilitation are physical activity monitors. These monitors are designed to provide an accurate and reliable assessment of physical activity. As such, these unobtrusive wearable devices are used outside the context of the clinical laboratory in order to provide an assessment in the home setting. Since the values obtained are an example of “real-life information” sourced directly from the patient, there is increasing interest (including from regulatory agencies) in integrating these tools into the outcome assessment of pulmonary rehabilitation and for patients with chronic diseases more generally. Furthermore, a number of pharmacological trials have used activity monitoring as part of the outcome assessment.

Physical activity monitors typically use triaxial accelerometry to obtain raw objective data on a patient’s physical activity levels in terms of amount, type and intensity of activity. Dedicated (and often proprietary) software is needed to interpret the signals and convert the acceleration signals into meaningful units. Simple devices use acceleration signals from the vertical axis to detect the number of steps taken, while movement intensity (MI) is determined from the vector magnitude of the triaxial acceleration signal. An example of the number of steps taken by a patient over several days is illustrated in figure 1. Whilst this patient is active (>9000 steps day\(^{-1}\) on 4 days) they have insufficient steps on 3 days. However, none of their days drops below 5000 steps day\(^{-1}\) which would be considered sedentary. More complex devices recognise patterns of movement and classify the signals into activities such as walking, stair climbing, sitting, standing, shuffling *etc* before determining the average intensity of these different types of movement. A third type of monitor can be used to integrate other body signals (such as heart rate) to get a better estimate of the intensity of the movement in question. While several monitors are available, few are formally validated for use in COPD and, as patients with COPD walk much more slowly than healthy people, validation of activity monitors is absolutely required prior to their use. The IMI PROactive project reviewed and validated activity monitors for use in COPD. Monitors that were valid in both a laboratory and a field setting and still on the market included the Actigraph monitors (Actigraph, Pensacola, FL, USA) and the Dynaport monitors (McRoberts, The Hague, Netherlands). Physical activity monitoring needs to be performed for at least 4 days with at least 8 h of monitoring during waking hours. An example of the data collected during an assessment is given in table 1. In addition to a daily overview, the physical activity report generated can display a variety of summaries, activity profiles and session to session comparison charts. This overview can be discussed easily with patients and outcomes can be extracted for the patient rehabilitation report.

The author’s research group has looked into the “sensitivity to change” of physical activity monitor outcomes and found that the number of steps day\(^{-1}\) is the most sensitive. Other outcomes are typically more variable and require larger sample sizes in order to obtain statistically significant differences. The science around activity monitoring is relatively new and there is much progress still to be made in the post-processing of physical activity signals and in the manner of outcome reporting. Indeed, it is not known at this time which outcomes are the most clinically meaningful or whether bouts of activity, their duration and their intensity are relevant outcomes in COPD. Monitoring does offer patients a concrete starting point for a discussion with their clinician on physical activity.

**Table 1. Data obtained from a small triaxial activity monitor worn on a belt**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total time</th>
<th>Average time(^{a})</th>
<th>Relative time(^{b})</th>
<th>Average MI(^{c})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>61:03</td>
<td>8:43</td>
<td>36.3</td>
<td>0.018 g</td>
</tr>
<tr>
<td>Lying</td>
<td>47:43</td>
<td>1:54</td>
<td>7.9</td>
<td>0.007 g</td>
</tr>
<tr>
<td>Sitting</td>
<td>13:20</td>
<td>6:49</td>
<td>28.4</td>
<td>0.021 g</td>
</tr>
<tr>
<td>Active</td>
<td>47:01</td>
<td>6:43</td>
<td>28.0</td>
<td>0.101 g</td>
</tr>
<tr>
<td>Standing</td>
<td>30:10</td>
<td>4:19</td>
<td>18.0</td>
<td>0.048 g</td>
</tr>
<tr>
<td>Locomotion</td>
<td>13:53</td>
<td>1:59</td>
<td>8.3</td>
<td>0.210 g</td>
</tr>
<tr>
<td>Shuffling</td>
<td>2:58</td>
<td>0:25</td>
<td>1.8</td>
<td>0.138 g</td>
</tr>
<tr>
<td>Not worn</td>
<td>59:57</td>
<td>8:34</td>
<td>35.7</td>
<td>0.000 g</td>
</tr>
<tr>
<td>Overall Total</td>
<td>168:01</td>
<td>24:00</td>
<td>100.0</td>
<td>0.035 g</td>
</tr>
<tr>
<td>Steps n</td>
<td>71,659</td>
<td>10,236</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Data is presented as h:min or %, unless otherwise stated. A breakdown of the different physical activities of the patient in the categories of lying, sitting, standing, locomotion and shuffling is given, as well as the time the device was not on the patient’s body.

\(^{a}\): Average duration over 24 h; \(^{b}\): Duration as a proportion of the whole period; \(^{c}\): The movement intensity (MI) of an activity is the average body acceleration (in g) during this activity.
and, when finalising rehabilitation, a second assessment can provide an idea as to whether physical activity requires further specific attention in a patient.

Tools have been developed and validated to assess a patient’s experience of physical activity. The Patient Reported Outcome (or PROactive) tool is a hybrid tool that combines physical activity monitoring with classical items to capture how patients with COPD experience physical activity. In order to do so, two domains are captured: the amount of physical activity and the difficulty the patient experiences with physical activity. The tool has been developed in two versions, one for use on a daily basis (with a 1-day recall period) and one for use during clinical visits (with a 1-week recall period). In both cases the tool requires physical activity to be monitored in parallel using a validated activity monitor. Steps and vector magnitude units are converted to item scores and integrated in the “score for” amount. The tool is now ready for use in clinical trials and has been used successfully on two occasions in the pharmaceutical industry where physical activity was an end point. This tool will also be of value in investigating the impact of pulmonary rehabilitation programmes and other interventions on an outcome with direct relevance for patients.

Once patients have been fully assessed the treatment programme can be given shape for use either inside or outside a rehabilitation centre. It is beyond the scope of this article to discuss the set-up of a pulmonary rehabilitation programme in much detail and the reader is referred to the document on pulmonary rehabilitation published jointly by the ERS and the ATS. Figure 2 provides a top level overview of how the different assessments described herein contribute to shaping the rehabilitation programme in individual patients. Obviously the tests described in this article are further complemented by measurements of lung function, various symptoms and health-related quality-of-life. Based on this comprehensive assessment, an individualised programme is designed.

**SUMMARY**

Comprehensive patient assessment beyond just lung function is required to determine whether rehabilitation is indicated, as well as whether exercise training or other components of the

**SHAPING THE REHABILITATION PROGRAMME**

**Figures**

**Figure 1.** Record of the number of steps taken by a patient on a given day over a period of several days.

**Figure 2.** Examples of relevant tests in pulmonary rehabilitation assessment, their outcomes and the consequences of the results for the set-up of rehabilitation programmes. MID: minimally important distance; Wmax: maximal (peak) work rate in an incremental exercise test; CWT: constant work rate test; 6MWD: 6-min walk distance; FM: fat mass; FFM: fat-free mass; FFMi: fat-free mass index; BMI: body mass index.
rehabilitation programme are needed. Novel technologies have been introduced to aid this assessment and physical activity monitoring has made much progress. Indeed, such monitoring is increasingly being used beyond pulmonary rehabilitation, in respiratory medicine more broadly.

**CONFLICT OF INTEREST**

Dr Troosters reports fees from Boehringer Ingelheim and Astra Zeneca outside the scope of the submitted work.

**RECOMMENDED READING**


