Exercise testing for the evaluation of muscle strength/endurance and pulmonary rehabilitation

Prof. Dr. Rik Gosselink
Respiratory Rehabilitation and Respiratory Division, University Hospitals,
Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences
KU Leuven
Herestraat 49
3000 LEUVEN
BELGIUM
rik.gosselink@uz.kuleuven.ac.be

AIMS

- Demonstrate the clinical importance of muscle dysfunction in acute and chronic respiratory disease
- Present tools to evaluate limb muscle and respiratory muscle strength and endurance in clinical practice

SUMMARY

Dyspnea, impaired exercise tolerance and reduced quality of life are common complaints in patients with chronic respiratory disease. Several pieces of evidence point to the fact that these symptoms show only a weak relation to lung function impairment [1]. Prediction of exercise performance based solely on resting pulmonary function tests is inaccurate [2, 3, 4]. Other factors, such as peripheral and respiratory muscle weakness and deconditioning are now recognized as important contributors to reduced exercise tolerance [5, 6]. Respiratory muscle weakness contributes to hypercapnia [7], dyspnea [5, 8], weaning failure [9] and nocturnal oxygen desaturation [10]. A higher mortality rate was observed in patients with severe muscle weakness [11, 12]. Assessment of skeletal muscle function contributes to the evaluation of impairment of COPD patients and thus to the assessment in rehabilitation in several ways. Skeletal muscle function is an independent marker of disease severity [12] since it contributes to the abovementioned clinically relevant issues. Recently, ICU acquired muscle weakness has gained increasingly interest and consequently the tools to diagnose muscle weakness [13]. Muscle function assessment enables to diagnose muscle weakness and thus to state the indication for rehabilitation. Indeed, isometric muscle testing seems helpful in selecting candidates for exercise training in healthy subjects [14] and in COPD patients [15]. COPD patients with muscle weakness seem to be better responders to rehabilitation [15]. Measurement of isometric muscle strength and endurance was also found sensitive to detect changes in peripheral muscle function after rehabilitation [16-18].

Skeletal muscle strength is in general reduced in COPD. However, arm muscle strength is less affected than leg muscles and respiratory muscles [19, 20], while proximal arm muscles were more affected than distal arm and hand muscles [19]. This information is helpful to optimize training prescription in a rehabilitation program. Allowing to target muscle training more specific to more impaired muscle groups.

Assessment of peripheral skeletal muscle function will be discussed from the point of view of both strength and endurance capacity of the muscles.

Respiratory Muscle Strength Testing

Clinically, respiratory muscle strength is measured as PImax and maximum expiratory pressure (PEmax). These pressures are measured using a small cylinder that fits to the patient’s mouth with a
circular mouthpiece. A small leak in the cylinder (two mm diameter and 15 mm length) prevents high pressures due to the contraction of the cheek muscles [21]. Standardizing the lung volume at which the pressures are measured is crucial [22]. To prevent chest wall and lung recoil pressures from contributing to the pressure generated by the inspiratory muscles, measurements are recorded at functional residual capacity (FRC). This lung volume, however, is difficult to standardize. In clinical practice, PImax is measured from residual volume whereas PEmax is measured at total lung capacity (TLC). At least five repetitions should be performed. Respiratory muscle testing is described in detail in a American Thoracic Society/European Respiratory Society position statement [23].

Several groups of investigators have published norms for PImax and PEmax [21;24;25]. Regardless of the norms used, the standard deviation is typically large. Therefore, weakness is not easy to define [26]. Inspiratory weakness is defined as a PImax lower than 50% of predicted[27] in the presence of clinical signs (e.g., dyspnea, impaired cough, and orthopnea) consistent with reduced respiratory muscle strength. Other methods, such as the sniff maneuver, have been developed as tools to quantify global respiratory muscle function [28]. The results of the sniff maneuver have been reported to be highly reliable in children with neuromuscular disease. More invasive methods such as electric or magnetic diaphragm stimulation can provide more accurate and detailed information on diaphragmatic function [29] and are useful in the diagnosis of diaphragmatic paresis. For most clinical applications, however, the assessment of inspiratory and expiratory mouth pressures is sufficient.

**Limb Muscle Strength Testing**

Muscle strength, or, more precisely, the maximum muscle force or tension generated by a muscle or (mostly) a group of muscles, can be measured in several ways and with different equipment.

Manual testing with the 0-5 scale from the Medical Research Council is often used in clinical practice, but very insensitive to assess differences in muscle strength of values above grade 3 (active movement against gravity)[30]. Therefore several equipment was developed to measure muscle strength more accurately:

1. One-repetition maximum (1-RM) weightlifting for isotonic muscle force is a dynamic method for measuring the maximum amount of weight lifted for one time during a standard weightlifting exercise. In elderly people, 1-RM can be calculated from sub maximal efforts [31]. For untrained persons the calculated 1-RM (kg) = 1.554 * (7-10RM weight,kg) -5.181. In COPD patients, the 1RM tests have been shown to be safe [32] and sensitive to measure changes after training [16]. However, to the best of our knowledge no normative data exist for the 1-RM tests, and the obtained values are largely dependent on the equipment used. Measurement of the 1-RM is often used to guide a muscle training program [33;34].

2. Dynamometry with mechanical or electrical equipment is used to measure isometric muscle force. In mechanical equipment mostly a steel spring is compressed, which moves a pointer on a scale, for example the handgrip dynamometer [35]. Handgrip dynamometry has been shown to be reliable and reference values are available [35;36]. It has been used in several studies in COPD patients [6;37-39]. For other upper and lower extremity muscle groups handheld devices have been developed. This electrical equipment consists of an electronic force transducer connected to a computer. Two methods of isometric testing are described: the make-test and the break-test. In the make-test the maximal force of the subject is equal to the force of the observer. In the break-test, the force of the examiner exceeds the force of the patient slightly. Both tests are reproducible, but higher values were found during break-tests [40]. The hand-held dynamometry is a viable alternative to more costly modes of isometric strength measurements, provided the assessor’s strength is greater than that of the specific muscle group being measured [40;41]. References values are available, also for elderly healthy subjects [42]. Hand-held devices for muscle testing have been applied in COPD patients [19;43].
3. Computer-assisted dynamometers to measure isokinetic or isometric muscle strength have the advantage of measuring maximal muscle strength over a wide range of joint positions and velocities. This also takes into account the force-velocity characteristics of the muscle contraction. However, the equipment is very expensive and not available to many practitioners. References values are available for isometric [11] and isotonic [44] muscle testing. In healthy subjects isometric and isokinetic measurements were well correlated [45;46]. Although direct comparison between these measures was not performed in COPD patients, two studies may suggest such a relationship also in COPD. Both isokinetic muscle strength [5;47] and isometric muscle strength [6;48] were significantly lower in COPD patients compared to healthy subjects.

The limitation of the use of maximal voluntary contractions is the potential to observe sub maximal contractions due to sub maximal cortical drive [49;50]. The use of superimposed electric or magnetic twitch contractions anticipates this potential variation in voluntary activation [49]. The technique of electrically superimposed twitch contractions was developed in 1954 by Merton [51]. Twitch stimulation, however, is not suggested for routine clinical evaluation of muscle force. When standardized, and maximal encouragement is given, isometric muscle strength results in reliable, and maximal data [50]. To answer specific research questions, however, magnetic or electrical nerve stimulation may be useful. Magnetic stimulation has nowadays become a validated research procedure. It is less painful than electrical stimulation, and the ‘twitch’ stimulations are relatively reproducible [52].

In addition, measurement of muscle mass with ultrasound has become increasingly popular as a reproducible and effort independent measure[13;53].

**Limb Muscle Endurance Testing**

The evaluation of lower limb muscle performance in patients with COPD has focused mainly on muscle strength. In addition to reduced muscle fiber cross sectional area [20], changes in fiber type composition resulting in a decrement of fatigue-resistant slow fibers [54-56] and a reduction in oxidative enzymes [57-59] are the main morphological and histochemical alterations found in lower limb skeletal muscles. Following these morphological and histochemical alterations in muscle biopsies, it may be hypothesized that lower limb muscle endurance is decreased more than muscle strength in patients with COPD. Newell et al.[60] observed only a slight reduction in endurance capacity (torque reduction over 18 contractions) of elbow flexors in COPD patients compared to healthy subjects. The same was concluded for Triceps and Deltoid sustained contractions which were not different between healthy subjects and patients with mild COPD [47]. Along the same lines endurance (time to maintain 80% of peak torque) of the quadriceps muscle in hypoxemic COPD patients was normal [61]. In contrast, others found a mean reduction of 50% in quadriceps muscle endurance at sub maximal (20-40% of peak) torque) in patients with moderate to severe COPD [62;63].

Isolated muscle endurance can be measured in several ways. First, the time of a sustained maximal isometric muscle contraction until 60% of the initial maximal strength is left can be measured [64]. During this test blood supply is profoundly reduced and muscle contraction is very much dependent on anaerobic metabolism. Second, the decline in maximal force after a fixed number (18) of repetitive contractions with a fixed contraction (10sec) and relaxation time (5sec) can be assessed [65]. A third protocol consists of repeated contractions of 20% of the maximal voluntary contractions at a pace of 12 contractions per minute up to exhaustion [63;66]. The latter two are probably more related to oxidative capacity, as these dynamic muscle contractions at a low percentage of peak torque do not induce closure of capillaries in the muscle and thus do not deprive the muscle from oxygen supply. After a specific muscle endurance training program, significant improvements in the number of repetitions of loaded and unloaded isotonic contractions of upper and lower extremities over a 30 second period were observed [67]. Although no data were shown on the reproducibility of this
measurement, control subjects performed fairly reproducible results at their second visit after 12 weeks [67].

REFERENCES


