PROCEEDINGS REPORT

Measuring skeletal muscle strength and endurance, from bench to bedside

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Peripheral muscle dysfunction is a recognized and important systemic consequence of many chronic diseases. Peripheral muscle weakness is associated with excess utilization of health care recourses, morbidity and /or mortality in patients with COPD, congestive heart failure, liver and frail elderly. In the latter group, muscle weakness was associated with significant increase in falling and falling related injury. Exercise training does enhance skeletal muscle function and exercise performance. In addition, patients who start a training program with impaired skeletal muscle function may be more likely to respond adequately to an exercise training program.¹ It is beyond the scope of the present review to discuss in detail the factors that may contribute to muscle dysfunction in chronic conditions. Clearly, muscle weakness is multi-factorial. Factors associated with skeletal muscle force are general factors (such as age, body weight, sex), disease related factors (such as inactivity) and disease specific factors (for example in COPD drug treatment, i.e. corticosteroid treatment, inflammation, oxidative stress

and hypoxia have been shown to contribute to muscle dysfunction).²

This review will focus on the different ways to assess skeletal muscle function in patients with chronic disease. More specifically, techniques to assess skeletal muscle strength, skeletal muscle endurance and skeletal muscle fatigue will be discussed. For the American College of Sport Medicine (ACSM) not only muscle strength but also muscle endurance are health-related fitness components.³ Loss in one of these muscle characteristics results in impaired muscle. Muscle function tests are very specific to the muscle group tested, the type of contraction, the velocity of muscle motion, the type of equipment and the joint range of motion. Results of any test are specific to the procedures used. Individuals should participate in familiarization sessions with the equipment, and adhere to a specific protocol in order to obtain a true and reliable score.

A change in one's muscular fitness over time can be based on the absolute value of the external force (Newton (N)), but when comparisons are made be-

tween individuals, the values should be expressed as relative values (percentage of a predicted normal value). In both cases, caution must be taken in the interpretation of the results because the norms may not include a representative sample of the individual being measured, a standardized protocol may be absent, or the exact test being used may differ.

Assessment of skeletal muscle strength

In 2007, 'muscle strength' was introduced as a medical subject heading by the National Library of Medicine and the National Institute of Health (PubMed database). 'Muscle strength' is there defined as the amount of force generated by muscle contraction. Muscle strength can be measured during isometric, isotonic, or isokinetic contraction.

Although muscle mass, as assessed by computer tomography, is related to muscle strength⁴, the general assessment of fat free mass, by whole body impedance, is a poor indicator of skeletal muscle strength. Many patients with a normal fat free mass index present with significant muscle weakness. By contrast almost all subjects with a low fat free mass index did show skeletal muscle weakness.

Classically, muscle force is often assessed using manual muscle testing. Manual muscle testing was first described by Wright in 1912.⁵ The five point Medical Research Council scale is undoubtedly the most commonly used scale. This scale assesses muscle force with five grades where zero means that no contraction is visible or can be felt, three means that a limb can be moved against gravity with no additional resistance. Five means that the subject can move the limb against a normal resistance over the full range of motion.

Although this scale is easy to use and allows assessment without the use of tools it has been shown that the scale lacks accuracy and responsiveness in ambulant patients with muscle weakness⁶. Hence it is advised to do more accurate measures of skeletal muscle strength which allow skeletal muscle force to

be expressed as a percentage of a predicted normal value. This normal value is generally predicted based on sex, age and weight.

Several techniques using dynamometers have been applied. Skeletal muscle strength (or better, skeletal muscle torque) can be assessed from isometric (no movement), dynamic (movement against fixed resistance) or isokinetic (movement against fixed angle speed) muscle contractions. Several techniques generally show good agreement, and allow the identification of patients with normal or abnormal muscle strength. In our laboratory, we have used maximum voluntary isometric quadriceps torque (in Nm) with the subject seated straight and the knee flexed 60°. Normal muscle torque is predicted with an equation using body weight, gender and age⁷. We have seen (unpublished observations) a good correlation between isometric testing and isokinetic testing in patients with COPD and in healthy controls.

Measurement on a dynamometer is not always feasible. In order to assess skeletal muscle strength bed-side, or when a large apparatus is unavailable hand held dynamometry has been suggested as an option. Hand held dynamometers are small light weight dynamometers that allow quick assessment of skeletal muscle strength⁸. Normal values exist for hand held dynamometry, but care must be taken that the age range and positioning is correct. Rigorous standardization is critical and the result may vary from the speed with which the force is applied by the investigator.⁹ Clearly, the most important caveat of hand held dynamometry is the underestimation of skeletal muscle strength in patients in whom their muscle force approaches or exceeds the ability of the investigator to break the force or to keep the limb fixed.¹⁰ It is fair to note that the variability (particularly between investigators) of hand held dynamometry is much larger than that of fixed dynamometry.⁸ This technique is therefore better reserved for clinical applications and to identify patients with muscle weakness rather than for research protocols and to evaluate small treatment effects.

FIGURE 1. Relationship between potentiated quadriceps twitch force (TwQ_{Potentialized}) assessed using magnetic stimulation and quadriceps maximal isometric voluntary contraction (MVC). There was a significant correlation between these two variables ($r = 0.61$, $p < 0.001$).

FIGURE 2. Illustration of the decreased quadriceps strength (white columns) and endurance (black columns) in patients with COPD. Data are adapted from Serres ; Chest, 1998, Couillard; Am J Respir Crit Care med, 2003, Coronell; Eur respire J, 2004, Koechlin; Am J Respir Crit Care med, 2004, Allaire; Thorax, 2004, Van 't Hull; muscle & Nerve, 2004, Malaguti; Eur J Appl Physiol, 2006 and are expressed as a percentage of the respective control groups reported in these papers.. As illustrated, skeletal muscle endurance is more impaired than skeletal muscle force in patients with COPD.

All techniques mentioned, so far, consist of maximum voluntary contraction assessment. Non-volitional assessment of skeletal muscle strength using electrical or magnetic stimulation has been developed. In the last decades, magnetic stimulation of peripheral nerves has been used in COPD to obtain non volitional 'twitch force' of respiratory and skeletal muscles.^{11;12} Magnetic stimulation is relatively non-invasive and much less painful compared to electrical stimulation. Femoral nerve stimulation results in reliable assessments of twitch force if a supra-maximal stimulation is ensured.¹³ A twitch contraction can be obtained in a rested muscle (unpotentiated twitch) or can be preceded by a maximum voluntary contraction (potentiated twitch). The latter is larger and somewhat more sensitive to the assessment of fatigue.¹⁴ Using this technique in our laboratory, we have seen a good correlation between quadriceps twitch tension and maximum voluntary contraction in patients with COPD (figure 1).

Assessment of skeletal muscle endurance

Muscle endurance was defined by the ACSM as the ability of a muscle group to execute repeated contractions over a period of time sufficient to cause muscular fatigue, or to maintain a specific percentage of the maximum voluntary contraction for a prolonged period of time.³ In general, skeletal muscle endurance is more impaired than skeletal muscle force in many chronic diseases, including COPD (figure 2). Outcomes used to indicate skeletal muscle endurance are: time to force decline below a threshold level targeted, number of contractions or percentage of force decline for a given period of time. Almost all devices described before for measuring muscular strength can be used with the same recommendations to assess muscular endurance. The dynamic measurement of muscle endurance uses free weights. More complex machines can be used to assess the number of repetitions patients can achieved using a weight that is a fraction of the maximum weight. As a comparative test be-

tween groups of individuals, the relative dynamic endurance test is a reliable test of muscle endurance when standard guidelines are used for testing. Also, Dynamic muscular endurance assessment can be done using isokinetic motions and based on the capacity of the muscle to produce force at constant velocity over multiple repetitions. The test-retest reliability in isokinetic measures have been shown to provide good results on normal population¹⁵ and was already used in patients with COPD as a fatigue index.

The measurement of isometric muscle endurance requires the maintenance of a single contraction over an extended period of time to observe at which time strength declines. Similar to the maximal isometric force measures, these tests can be performed using computerized methods to track the decay in force production or simply the time to observe a decline in strength below a threshold level. Standard testing parameters required to perform a sustained MVC lasting 10-30 seconds are similar to those of the MVC to assess strength. Likewise, recovery between repeat contractions requires between 3 and 5 minutes of rest. With all muscular endurance tests, the results obtained are most reliable if a full and maximum voluntary effort is provided.

Unfortunately, several muscular endurance protocols have been developed and few muscle endurance tests control for repetition duration, (speed of movement) or range of motion, thus reference values are missing and results are difficult to interpret. Endurance tests therefore are suitable to answer specific research questions or may be used to evaluate effects of interventions on local muscle endurance within a subject. In patients with COPD local muscle endurance tests have the additional benefit that they do not impose a large burden on the ventilatory system. Hence they allow to study muscle function regardless of the ventilatory limitation and symptoms of dyspnea.¹⁶

Assessment of skeletal muscle fatigue

Whereas muscular endurance refers to the capacity of the muscle to maintain a given level of force or work for a period of time, muscular fatigue is defined as a reversible reduction in the force generated by the muscle itself for a given neural input.¹⁷ Muscle strength is assessed before and after a given task and the decline in strength is indicative of skeletal muscle fatigue. Muscle force is preferably assessed using non-volitional techniques to exclude motivational aspects. The 'task' may be a bout of isolated skeletal muscle work, whole body exercise or a combination of both. Standardization of the task is critical in terms of duration intensity and modality. For example fatigue is less after walking compared to cycling at similar relative intensity.

Although the technique to assess muscular fatigue is technically demanding and not widely used in clinical setting, some studies have found a link between muscular fatigue and the exercise related fatigue symptoms of patients. This suggests that contractile fatigue is reflected in the symptoms perceived by patients after exercise.

Conclusion

To gain complete insight in the skeletal muscle properties clinicians and scientists should be interested in muscle strength, endurance and fatigability. Many standardized protocols have been designed to assess muscle strength for clinical and research domains. These protocols are valid and reliable. Reference values are available for isometric muscle testing, which facilitates to exchange results. Recently, it has become clear that skeletal muscle endurance may be even more impaired than skeletal muscle strength. There is currently no gold standard to assess skeletal muscle endurance in clinical practice. Efforts to develop valid and reliable muscular endurance protocols for chronic disease are welcomed and reference values are needed to increase the clinical use of these tests. Skeletal muscle contractile fatigue proved to be an important

factor directly contributing to exercise intolerance. This skeletal muscle property, however, can only be addressed using rather complex research tools, involving magnetic stimulation. Symptoms of muscle fatigue, however, seem to be somewhat associated to contractile fatigue, and therefore may guide clinicians.

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