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CLINICAL ASSESSMENT

The assessment of the cervical spine. Part 2: Strength and endurance/fatigue

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Summary Quantitative documentation of physical deficits such as muscle strength and endurance/fatigue in the cervical spine may provide objective information, not only helping the diagnostic procedures, but also monitoring rehabilitation progress and documenting permanent impairments. The reliable and valid evaluation of muscle strength and endurance both in clinical and research environments are a difficult task since there are many factors that could affect the assessment procedure and the obtained values. The aim of the second part of this critical review is to identify the factors influencing the assessment of strength and endurance/fatigue of the muscles in the cervical spine.

Introduction

Neck muscle strength and endurance/fatigue has been evaluated in both clinical and laboratory settings. The assessment of these factors along with neck range of motion and proprioception (presented in part I of this review) has been proposed from many researchers and clinicians as an important component of a thorough evaluation of the cervical spine that could possibly contribute to the "cause and effect" justification of neck disorders (Jull et al., 1999; Hermann and Reese, 2001; Strimpakos and Oldham, 2001; Dumas et al., 2001; Nakama et al., 2003; Strimpakos et al., 2004; Puglisi et al., 2004; Lee et al., 2005; Strimpakos et al., 2005a, 2005b, 2006; Kapreli et al., 2007; Nordin et al., 2008; Vaillant et al., 2008; Dvir and Prushansky, 2008; de Koning et al., 2008; Kapreli et al., 2009). On the other hand, debate continues regarding the correlation between pain and strength or endurance/fatigue measurements (Jordan et al., 1997; Ryan et al., 1998; De Loose et al., 2009). It is often difficult to distinguish whether the muscular weakness is the cause of acute or recurrent injury and pain or is a result of the pain itself. One of the main reasons for this discrepancy among clinicians and researchers is the confounding reports in the literature.

The ability to measure neck muscle strength or their endurance/fatigue is challenging due to many methodological limitations. In most studies assessing neck muscle

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performance, there has been no uniform method or recommendation how to perform the test and/or report the results (Suryanarayana & Kumar 2005; Rezasoltani et al., 2008; Dvir and Prushansky, 2008; de Koning et al., 2008). In order, therefore, to determine the best protocol for measuring muscle strength and endurance/fatigue in the cervical spine this critical review aims to identify the factors influencing their assessments and estimates.

A computerised search was performed through the Medline, EMBASE, CINAHL and AMED databases from 1966 to March 2010 using broad as well as specific key words — individually or in combination. They included: cervical spine, neck, function, reliability, validity, intra-observer, inter-observer, strength, endurance and fatigue. This was followed by a search through references cited in the retrieved articles. Only English language articles were included. Reliability and validity studies were included if they reported at least one measurement tool concerning cervical strength, endurance and fatigue, regardless of whether the studies were in healthy or symptomatic subjects. Studies were excluded if measurements were limited to the electromyography-based method (EMG) as the plethora of parameters included in EMG studies highlights the need for a separate comprehensive analysis of this variable.

Strength

Neck muscle strength has been used as an indicator of neck dysfunction. Studies concerning the cervical spine have reported reduced muscle strength in patients with neck pain, headache and other neck—shoulder disorders (Silverman et al., 1991; Vernon et al., 1992; Levoska and Keinanen-Kiukaanniemi, 1993; Watson and Trott, 1993; Jordan and Mehlsen, 1993; Gogia and Sabbahi, 1994; Hamalainen et al., 1994; Nitz et al., 1995; Barton and Hayes, 1996; Jordan et al., 1997; Placzek et al., 1999; Dumas et al., 2001; Chiu and Sing, 2002; Jull et al., 2004; Ylinen et al., 2004a, 2004b; Prushansky et al., 2005; Cagnie et al., 2007; de Koning et al., 2008).

Nowadays, there is no consensus among clinicians and researchers regarding the correlation between pain and strength measurements (Ylinen et al., 2004b; De Loose et al., 2009). Much data exist reporting improvements in neck muscle strength and reduction of neck pain after rehabilitation (Highland et al., 1992; Jordan and Mehlsen, 1993; Berg et al., 1994; Ylinen and Ruuska, 1994; Randlov et al., 1998; Nelson et al., 1999; Kay et al., 2005; Falla et al., 2006; O'Leary et al., 2007a; Ask et al., 2009). On the other hand, some authors have stressed that quantification of spinal disease through strength measurements is not valid as strength is poorly correlated with pain and disability both before and after treatment. They also noted that strength measurements are not very reproducible in patients (Waddell et al., 1992; Jordan et al., 1997; Ryan et al., 1998; van den Oord et al., 2010). Recent studies however revealed that impairment, functional limitations (i.e. isometric strength, endurance, ROM) and disability correlated well with each other in patients with cervical spine disorders (Hermann and Reese, 2001; Kay et al., 2005; Lee et al., 2005; Nordin et al., 2008; de Koning et al., 2008).

In a review assessing trunk muscle strength Beimborn and Morrissey (1988) suggested that pain may interfere with the ability of a subject to produce a maximum voluntary contraction (MVC) (Beimborn and Morrissey, 1988). Patients fear that they may evoke their painful neck under maximum stress — as strength measurements often demand — thus making these measurements invalid. A number of studies however, have postulated that no serious adverse effects (i.e. pain or injury) have been noted in patients or healthy subjects after maximum isometric voluntary contractions of the neck muscles (Highland et al., 1992; Berg et al., 1994; Ylinen and Ruuska, 1994). Furthermore a more recent publication suggests that the presence of symptomatology in neck patients does not adversely affect the reliability of the physical outcome measures (Sterling et al., 2002). The psychological benefit to the patients after these contractions could also be a significant factor contributing to the pain reduction as they realise that they can use their neck in stressful tasks without fear. The possibility however, of adverse effects after a maximum contraction in patients with neck pain of discogenic origin cannot be eliminated at the moment, as no study has been found in the literature to examine this issue (Kay et al., 2005).

As a result of these conflicting opinions about strength and pain correlations, some researchers have suggested that the classical gross measurements of strength and endurance may actually reflect a pain tolerance measure rather than an estimation of muscle function (Mannion et al., 1996). In each instance however, there is a general consensus among clinicians and researchers that strength measurements (regardless if they are primary or secondary outcomes) are of clinical value at least for determining training dosage and documenting rehabilitation efficacy (Leggett et al., 1991; Highland et al., 1992; Pollock et al., 1993; Berg et al., 1994; Ylinen and Ruuska, 1994; Hagberg et al., 2000; Nakama et al., 2003; Ylinen et al., 2004b; Kay et al., 2005).

There are many operational definitions of strength. Harris and Watkins (1999) have defined strength as "the ability of skeletal muscle to develop force for the purpose of providing stability and mobility within the musculoskeletal system, so that functional movement can take place". It has also been interpreted as "the magnitude of the torque exerted by a muscle or muscles in a single maximal isometric contraction of unrestricted duration" (Enoka, 2002) or as "the maximum force that muscles can exert isometrically in a single voluntary effort" (Caldwell et al., 1974; Fulton, 1989). Torque and force are different concepts with torque being the capability of a force to produce axial rotation and is equal to the magnitude of the force times the perpendicular distance between the line of action of the force and the axis of rotation. Force is measured in Newton (N) and torque is measured in Newton meter (N m) (Enoka, 2002).

In clinical and experimental settings strength is commonly measured in one of three ways: as the maximum force that can be exerted during an isometric contraction, the maximum load that can be lifted once, or the peak torque during an isokinetic contraction (Enoka, 2002). The isometric contraction task is usually referred to as a maximum voluntary contraction (MVC). The strength values retrieved from an individual therefore, depend on how strength is measured.

The measurement methods also vary among investigators and published studies. In clinical practice, manual muscle testing (MMT) is used very often most likely due to low cost and time effectiveness. However, the use of MMT for the assessment of muscular function has been criticised primarily due to the crude measurement scale and its low reliability (Dvir and Prushansky, 2008). On the other hand, the utility of hand-held dynamometers for measuring muscle strength in the cervical spine is also limited since the devices are unable to measure rotation and their reliability and validity are vulnerable to examiner bias (Strimpakos and Oldham, 2001; Dvir and Prushansky, 2008). Isokinetic devices have also been used for measuring cervical spine strength, but up to now manufacturers of isokinetic dynamometers do not supply specialised attachments. Although there are certain advantages for using isokinetic dynamometry the existence of several methodological drawbacks such as the difficulty in aligning the centre of rotation with the mechanical axes of the testing device, the fixation of the subjects on the device, the cost and expertise needed make their utility questionable. Fixed frame dynamometry has been used by the vast majority of investigators. Most of these devices are able to measure isometric strength in flexion, extension and lateral flexion of the cervical spine (Seng et al., 2002; Chiu and Sing, 2002; Garces et al., 2002; Rezasoltani et al., 2008) and some of them can also examine the rotation (Ylinen et al., 1999; Vasavada et al., 2001; Ylinen et al., 2003; Strimpakos et al., 2004; Salo et al., 2006). Unfortunately, there is a great discrepancy among reported values making any conclusion or clinical inference invalid.

Several studies have shown that muscle strength is dependant on the type of muscle fibres and is correlated with the cross-sectional area (Mayoux-Benhamou et al., 1989). Also, biomechanical internal and external factors (such as anatomical variation, muscular contraction type, muscle length, speed of contraction, etc) can compromise or enhance the muscles' ability to produce maximum force. It may also be influenced by factors arising during the measurement procedure such as the position and posture of the subjects, the use of stabilisation and isolation of the cervical spine, the number of repetitions as well as the diurnal variation and hormonal effect on strength production. The importance of each of these factors and their influence in neck muscles' strength assessment is discussed below.

Factors influencing strength measurements

Muscle fibre composition and muscle strength

Muscle fibre composition affects the capacity of a muscle to generate force. Based on their biochemical, physiological, and anatomical profiles, skeletal muscle fibres have been classified into two major fibre types: type I (slow-twitch oxidative), and type II which subdivide into type IIA (fast-twitch oxidative glycolytic), type IIB (fast-twitch glycolytic) or type IIC (intermediate or transitional) (Uhlig et al., 1995; Enoka, 2002). In general, fast-twitch (phasic) motor units, which are composed of large motoneurons, large axons and large muscle fibres, demonstrate the shorter time-to-peak tension and are capable of exerting the greatest tensions. Conversely, slow-twitch (tonic) units are composed of small motoneurons, slow transmitting axons, and slowly contracting muscle fibres. The latter are the most resistant to fatigue (Smidt and Rogers, 1982; Murphy, 1993; Harris and Watkins, 1999).

Previous studies have confirmed greater type I fibre size and composition in various back muscles (Johnson et al., 1973; Mannion et al., 1998) although few studies have described the histochemistry of human neck muscles, whether in health or disease. Of those studies undertaken, most of them showed that neck muscles (paravertebral group, trapezius, multifidus and longus colli) consist mainly of type I muscle fibres (Lindman et al., 1990; Wharton et al., 1996; Hannecke et al., 2001). Furthermore, differences were observed between the different portions of the trapezius for both genders (the most superior parts of the descending portion indicated a higher frequency of type IIB fibres) but the mean cross-sectional area of the fibres in female muscle was considerably smaller (Lindman et al., 1991). These observations may indicate a lower functional capacity in females which may be of importance in the development of neck and shoulder dysfunction. However, the huge intramuscular and intermuscular variations regarding fibre type composition as well as problems in obtaining cervical muscle biopsy samples make proving the associations between cervical muscle fibre type and force production difficult. Despite these limitations a loose relationship between muscle strength and fibre cross-sectional area is described (Jones and Round, 1990).

Functional biomechanics and muscle strength

The amount of force generated by the muscles depends on the mechanical factors of muscular contraction type, muscle length, and speed of contraction. A concentric contraction occurs when the force developed by a muscle exceeds the magnitude of the external applied force, resulting in shortening of the whole muscle. An isometric contraction occurs when the force developed by a muscle is equal to the external force. An eccentric contraction occurs when the external force exceeds the force developed by the muscle, resulting in a lengthening of the whole muscle. Muscle length affects the binding capacity between actin and myosin molecules of the component muscle fibres. Maximal force is generated at some midpoint in the range of motion, while less force is developed in either shortened or lengthened positions (Harris and Watkins, 1999). The speed of contraction also affects the binding capacity of actin and myosin. In concentric contractions, greater force is generated as the speed of shortening decreases, becoming maximal at zero velocity — which equates to a static isometric contraction. With eccentric contractions, increasing speed (to the extent permitted by voluntary and neuromotor control) can generate greater force than that generated during isometric contractions. These higher forces may reflect the contribution of the passive elastic components of muscle connective tissues in addition to the contractile mechanism (Harris and Watkins, 1999). These factors should be taken account during any muscle strength assessment and the use of stabilisation methods (such as torso stabilisation) is important for keeping muscle lengths constant in order to provide reliable measures of cervical function.

Moment arm and muscle strength

Another factor influencing muscular strength is the moment arm, or perpendicular distance from the line of application of the musculotendinous unit to the axis of rotation for the joint. Principles of mechanics dictate that the greater the musculotendinous moment arm, the greater the strength because the joint torque at a given instant is equivalent to the product of the force output of a muscle and the length of the moment arm. The moment arm of a muscle, and consequently the measured tension, may be altered with changes in joint angle. Many authors have shown that the total moment-generating capacity of the neck muscles change in different neck/head postures (Harms-Ringdahl et al., 1986; Queisser et al., 1994; Hamilton, 1996; Vasavada et al., 1998; Bonney and Corlett, 2002). Changes in posture alter the moment produced by the weight of the head by changing the location of the head's centre of gravity with respect to the point of rotation in the cervical spine (Figure 1). The length—tension relationship, combined with moment arm changes throughout the ROM, alters a muscle's moment or torque-generating capability. Biomechanical models showed that most of the cervical spine muscles maintain at least 80% of their peak force-generating capacity throughout full cervical ROM (Oatis, 2004) and many of them have the advantage of producing the maximum force in the neutral position of the head (Vasavada et al., 1998).

The complex anatomy of the head and neck musculoskeletal system make the direct estimation of muscles forces or moment arm impossible. Most efforts are therefore, limited to a gross estimation of neck muscle strength. For isometric strength testing, the magnitude of the force alone is a valid indicator of muscular strength if the point of application, line of application, direction of force, and segment position are kept constant between measurements. If any of these factors are not constant, the measurements should be obtained in the form of a moment or torque (Smidt and Rogers, 1982). The standardisation of the procedure and subject's position is the most effective way for optimal comparison of measures between sides, between examinations, and between subjects. Researchers and clinicians have to take into account therefore the above considerations and to employ measurement devices that are able to satisfy these requirements. Furthermore, comparisons between results obtained in different investigations can only be made between those utilised the same measurement units (peak force or moment ratios).

Maximum muscle activation

The ability of an individual to maximally activate a muscle by voluntary command seems to vary across muscles. Jakobi and Rice (2002) in a study comparing young and old volunteers demonstrated that for elderly men, elbow flexor maximal activation was achieved less frequently than for elbow extensors and muscle activation was more variable than in the young men. However, when sufficient attempts were provided, the best effort in order to achieve maximal voluntary muscle activation for the elderly men was not different from that of the young men for either muscle group (Jakobi and Rice, 2002). This supports the view that, at least for some muscles, maximal activation is theoretically possible through voluntary effort (Jones and Round, 1990). However, it appears that, although humans are capable of recruiting nearly all of the maximal force capability of muscles, there is a significant inter and intra-individual variation in this capability (Allen et al., 1995). If the voluntary command does not evoke the maximum force that the muscle can exert, then neuromuscular electrical stimulation can probably overcome some of the deficit (Enoka, 2002). Unfortunately, electrical stimulation of the neck muscles is not practical for the following reasons. Firstly, although the sensation of slight stinging or biting may be well tolerated in peripheral muscles, it may be difficult to accept in cervical muscles. Secondly, this method is applied only to superficial muscles so the deep synergistic muscles responsible for the contractions in neck

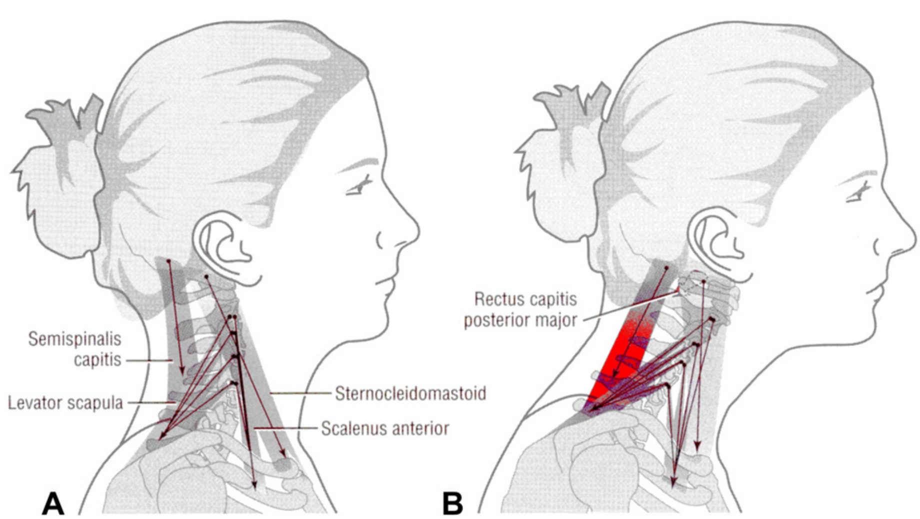

Figure 1 The change of the head posture changes the moment arms and the length—tension relationship (mechanical advantage) of neck muscles (From Neumann, 2002, with permission).

area cannot be stimulated (Herbert and Gandevia, 1999) resulting in false estimations. Thirdly, the presence of many arteries, nerves and muscles in this region may render the technique dangerous and thus inappropriate for use in the cervical spine. The use of voluntary contractions (isometric or dynamic) is therefore unavoidable in the assessment of neck maximal strength. The use of verbal encouragement has been suggested as an additional method for ensuring muscle maximal activation (Johansson et al., 1983; Bohannon, 1987).

Repetitions and maximum muscle contraction

It may be that many repetitions are necessary in order to permit subjects to generate a true maximal contraction (Gardiner, 2001; Jakobi and Rice, 2002). Allen et al. (1995) in a systematic study of the intra and inter-individual variability in assessing elbow flexor strength underlined the importance of several repeat measurements in order to determine a maximum contraction (Allen et al., 1995). The study highlighted the variability in maximum strength between contractions which can affect the reliability of repeated measurements. Many studies have reported that several sub-maximum and maximum contractions have to be employed before the actual measurements take place (Smidt and Rogers, 1982). No studies have evaluated the relative effect of the number of repetitions on the cervical muscles' strength. Some authors have argued that one repetition is enough for producing the maximum strength (Levoska et al., 1992; Peolsson et al., 2001) while in a study yielded by our research team no specific trend concerning the peak values amongst the repetitions was found (Strimpakos et al., 2004). Until future studies address this issue, maximal contractions should be repeated until three are within 10% of each other in order to ensure maximal activation and to avoid undesirable fatigue (Berg et al., 1994; Placzek et al., 1999; Strimpakos et al., 2004).

Warm-up and practice effect on muscle strength

In addition to the obvious value of acclimatising the patient to the particular assessment method, preparatory light exercises as a warm-up may induce a number of physiological changes that affect the assessment of muscular strength. A warm-up is associated with increasing muscle temperature, activating intermuscular energy sources, activating hormonal resources, alerting the nervous system (Smidt and Rogers, 1982), disrupting transient connective tissue bond and increasing core temperature (Enoka, 2002). The increase in core temperature will improve the biomechanical performance of the motor system and will enhance higher force production (Stienen et al., 1996; Saez et al., 2007). Conversely, reductions in muscle temperature decrease its work capacity (Wade et al., 2000). Furthermore, warm-up has a protective role in injury prevention and studies have shown that cold muscles are more stiff and possibly predisposed to injury (Best et al., 1997; Bishop, 2003; Woods et al., 2007). Although no clear-cut effects of warm-up on measurements of maximal strength have been established, some form of sub-maximal active warm-up is often recommended as a standard procedure (Smidt and Rogers, 1982). In neck strength measurements this should be routine to eliminate fear and increase confidence (Leggett et al., 1991; Highland et al., 1992; Berg et al., 1994; Strimpakos and Oldham, 2001; Valkeinen et al., 2002; O'Leary et al., 2005). It is also better to keep a constant room temperature during data collection in order to overcome any possible temperature influence.

In recent work of our research team, all reliability estimates were better and peak strength values were greater when the first test was excluded from the analysis (Strimpakos et al., 2004). In that study, a practice session preceded the first test and this may have also contributed to reduction of the learning effect. One practice or familiarisation test has been also used by several investigators in both cervical and lumbar spine (Graves et al., 1990; Berg et al., 1994) and seems to be needed even in healthy subjects to establish reliable strength estimates.

Position and movement effect

The initial body position for measuring neck muscle strength seems to be very important for the magnitude of the results. Despite the indications that different initial body positions revealed different strength values for both patients and healthy subjects (Gogia and Sabbahi, 1991; Vernon et al., 1992; Levoska et al., 1992; Strimpakos and Oldham, 2001; Kumar et al., 2001; Chiu and Sing, 2002; Strimpakos et al., 2004) only two studies examined the effect of different positions on strength exertion (Gogia and Sabbahi, 1991; Strimpakos et al., 2004). Unfortunately, the values of these studies cannot be compared because of different positions examined (prone versus sitting and sitting versus standing respectively). However, in both studies all positions yielded reliable results but different peak strength values with sitting position producing higher scores. One main reason for these results seems to be the stabilisation system and the compensation from parts of the body other than the cervical spine.

Neck extension yields the maximum strength following by flexion and lateral flexion irrespective of age or gender (Kumar et al., 2001; Strimpakos et al., 2004). The exact ratio between movements is not available since the discrepancy between published estimates is great due to the different methods and instruments used, the position of the head during measurements (offering physiologic and mechanical advantage), and the population studied. The placement of load cell especially in flexion can also affect the measurements (Figure 2). Weak deep neck flexors could permit chin protraction altering the muscle-length ratio and compromising the reproducibility and validity of the results (Dvir and Prushansky, 2008). A similar problem exists with the level of thoracic support during extension (Rezasoltani et al., 2008). Thus, one should consider the effect of initial body position and movement when examining the neck strength and comparing data with other investigations. Stabilisation of the trunk for minimizing compensation from other parts of the body is also essential for reliable and valid strength measurements in the cervical spine.

Diurnal variation and muscle strength

Many studies have shown that the ability of skeletal muscles to produce maximum force may be affected by time-of-day

Figure 2 Measuring neck strength during flexion in sitting (Arch. Phys. Med. Rehabil., 2004; 85:1309—1316, with permission from Elsevier).

influences (Sedliak et al., 2007, 2008). Wyse et al. (1994) demonstrated that peak values during isokinetic leg testing were different throughout the same day and suggested that reliable comparisons between strength values have to be based on data obtained within 30 min of the same time of the day (Wyse et al., 1994). Coldwells et al. (1994) in back and leg strength measurements observed also diurnal variations with the smaller values obtained at the early morning (Coldwells et al., 1994). Currently there are no available studies investigating diurnal variations on cervical muscles but most researchers suggest the measurements should take place the same time on the day to avoid any time-of-day effect (Strimpakos and Oldham, 2001).

Hormonal influences on muscle strength

Hormones are involved in many functions of the body and affect the ability of muscles to produce force (Hoffman, 1999). Growth hormone (GH) has widespread physiological activity because it promotes cell division and cellular proliferation throughout the body. GH facilitates protein synthesis, muscle growth and contributes to one's ability to perform endurance exercise. Insulin, and its antagonist glucagon, regulates total body glucose metabolism and stimulates the process of gluconeogenesis. Both hormones however, seem to have a greater effect during prolonged exercise than during maximum strength development. The adrenal gland hormones (catecholamines, mineralocorticoids, glucocorticoids) have a profound influence on free fatty acid and carbohydrate metabolism which in turn can affect muscle strength and endurance (Astrand and Rodahl, 1986). Gonadotropic hormones (FSH and LH) stimulate the male and female sex organs to grow and secrete their hormones at a faster rate and thus have an indirect effect on muscle strength production. The androgen testosterone (high concentration in males, low in females) is believed to be responsible for increases in muscle mass and strength and also decreases in body fat (McArdle et al., 1991). Hormone influences may therefore play a major role in assessing skeletal muscle function and factors that influence their production should be taken into account.

Studies of the effect of women's reproductive hormones during their menstrual cycle on muscle strength have demonstrated conflicting results. Sarwar et al. (1996) tested skeletal muscle strength, relaxation rate and fatigability of the quadriceps during the menstrual cycle (Sarwar et al., 1996). They found no changes in these parameters for women taking oral contraceptives. For women not taking oral contraceptives, the quadriceps were stronger, more fatigable and had a longer relaxation time at mid-cycle (day 12—18). Phillips et al. (1996) reported a higher adductor pollicis strength during the follicular phase than during the luteal phase, with a rapid decrease in strength around ovulation (Phillips et al., 1996). They suggested that oestrogen has a strengthening action on skeletal muscle, although the underlying mechanism is not clear. Other studies have found no changes in skeletal muscle strength over the menstrual cycle (Lebrun et al., 1995; Gur, 1997). Janse de Jonge et al. (2001) using the twitch interpolation method for ensuring maximal activation of the quadriceps muscle suggested that the fluctuations in female reproductive hormone concentrations throughout the menstrual cycle do not affect muscle contractile characteristics (Janse de Jonge et al., 2001). No studies have been found in the literature regarding the relationship between neck muscles' contractile properties and different phases of the menstrual cycle. It is recommended that this variable is better controlled during strength assessments by avoiding testing during menstruation. However, more research is needed in order to clarify this issue since, as mentioned above, there is also some evidence for a significant mid-cycle effect.

Implications for clinicians and researchers regarding neck strength assessment

Similar to the assessment of neck ROM, the evaluation of neck strength is influenced by the complexity of the cervical spine. The use of a stabilisation system in order to ensure the same subject torso and head position in any measurement is important. Neck extensors can produce higher forces than flexion or lateral flexion muscles and this trend can be used as an indicator for valid results. All assessments should also be performed after undertaking warm-up exercises and a full practice session at the same time of the day and preferably not early morning. Hormonal influences such as the menstrual cycle have to be considered in muscle strength evaluation in women. Finally, giving motivation of the subjects with loud and consistent commands is essential for obtaining maximum activation of the muscles.

Endurance/fatigue

Neck pain is usually associated with sustained static loading and the function of neck muscles depends on their strength and endurance. Studies have shown that a lower endurance ability and reduced neuromuscular efficacy of the neck muscles (especially of deep neck flexors) is a common finding in patients with neck pain, headache and chronic cervicobrachial syndrome (Hagberg et al., 2000; Alricsson et al., 2001; Jull et al., 2004; Falla et al., 2004a; Falla et al., 2004c; Lee et al., 2005; Peolsson and Kjellman, 2007; Nordin et al., 2008; de Koning et al., 2008; Jull et al., 2009; Kalezic et al., 2010).

Although strength and endurance are separate phenomena, they are interrelated. Muscle endurance is defined as the ability of muscle to sustain forces repeatedly or to generate forces over a period of time (Guide to physical therapy practice, 2001). The endurance time (the time that the subject can successfully contract the muscle at the assigned relative level of force) is inversely related to the relative workload (the higher the force of contraction, the lower the time of force maintenance) (Agre, 1999). At 100% of maximum force, the endurance time is usually well under 1 min although in reality, the time an individual can truly hold a maximum static muscle contraction is less than one second (Mundale, 1970). The endurance capacity of a muscle can be partly explained by the relative muscle fibre composition (Gogia and Sabbahi, 1990; Jones and Round, 1990; Watson and Trott, 1993; Uhlig et al., 1995; Mannion et al., 1998; Jull et al., 1999). Some other time-dependent physiological processes as well as psychological factors could also alter the means for generating force during sustained constant-force contractions (De Luca, 1993; Gardiner, 2001; Enoka, 2002).

Endurance essentially means avoiding the effects of fatigue (Jones and Round, 1990) although most times both fatigue and endurance are used interchangeably. Muscular fatigue is a loss of the ability to generate force, but such a simple definition is complicated by the fact that the extent of fatigue may vary according to the method of testing. The extent of fatigue may appear greater for voluntary contractions than for tetanic stimulation, or may differ according to whether the muscle is tested at one frequency of stimulation compared to another, or if the muscle is involved in a concentric rather than eccentric or isometric contraction. It is important therefore, in each situation to specify the type of change in muscle function and the contraction undertaken in describing "fatigue".

Although fatigue can be confused with muscle weakness and is a common general complaint in patients with a variety of clinical disorders, the term has a much more focused meaning in experimental studies. Because the physiological processes involved in performance extend from the central nervous system to the cross-bridge formation, numerous factors can contribute to the development of muscle fatigue (Enoka, 2002). These include the level of subject motivation, the neural strategy (pattern of muscle activation and motor command), the intensity and duration of the activity, the speed of a contraction, and the extent to which an activity is sustained (Enoka, 2002).

Methods for assessing neck endurance/fatigue

Although often tested for research purposes, endurance is rarely assessed in the clinical setting. The assessment of neck endurance/fatigue is quite complicated and the factors that contribute to their estimation require particular attention. Typically, endurance/fatigue measurements have been conducted by employing three methods, the electromyography-based method (changes occurring in the EMG signal and in the action potential velocities during a contraction), methods (usually questionnaires) that measure perceived effort during sustained contractions (subjective estimation of fatigue) and clinical tests that measure time-dependent changes (mechanical fatigue). Each of these methods has certain advantages but also serious shortcomings.

EMG methods

The muscles of the cervical spine have been studied electromyographically to a much lesser extent than those of the thoracic and the lumbar spine or the limbs (Gogia and Sabbahi, 1990; Sommerich et al., 2000; Falla et al., 2002; Falla et al., 2003; Thuresson et al., 2005; Strimpakos et al., 2005a; Kallenberg et al., 2009). The lack of adequate information on cervical EMG values is due partly to the multiplicity of neck muscles, making the EMG recording a difficult task for the investigator. A comprehensive review and recommendations of surface EMG application on neck muscles has been offered by Sommerich et al. (2000) as a result of a consensus panel. Nowadays, there is no consensus among researchers regarding the reliability of neck muscle EMG measurements (Falla et al., 2002; Falla et al., 2004d; Thuresson et al., 2005; Strimpakos et al., 2005a; Kallenberg et al., 2009) although there are reports indicating that this method is able to differentiate between healthy and patients with neck pain (Falla et al., 2004c; Kallenberg et al., 2009). The plethora of parameters included in EMG studies, as well as the amount of data available from neck mobility studies, highlights the need for a separate comprehensive analysis of these variables; this approach is precluded from the objectives of this review.

Subjective estimation of fatigue

An alternative method of fatigue estimation is the use of subjective scales such as the Borg scale of perceived exertion (Dedering et al., 2000; Elfving et al., 2000; Alricsson et al., 2001; Thuresson et al., 2005; Strimpakos et al., 2005a; Harrison et al., 2009). Although this method is easily applicable, the fact that different subjects may have different perceptions of effort does not permit valid extrapolation of conclusions (Strimpakos et al., 2005a). In any case, the use of subjective scales for fatigue perception can give a gross estimation of this parameter and could be utilised as an indication of subjects' opinion for their effort.

Time-dependent methods

Muscle endurance can be assessed with several time-dependent methods, statically, dynamically or isokinetically. Tests that measure the time a subject can maintain a maximum static contraction or a specific relative level of maximal effort have been developed to assess the absolute or relative static endurance respectively. The dynamic endurance is assessed similarly with static endurance by measuring the number of repetitions a subject can perform a task (either requiring maximal or sub-maximal effort), usually through the full range of motion at a specific cadence. The isokinetic assessment of muscle endurance employs several tests such as: a) the 50% decrement test (the number of successful repetitions of maximum muscle contraction at a specific angular velocity until the peak torque fails to reach 50% of the initial peak torque); b) the predetermined time bout endurance test (as many maximal repetitions as possible at a predetermined angular velocity for a predetermined period of time); c) the predetermined repetitions bout endurance test (the individual performs a predetermined number of repetitions at a predetermined angular velocity and the total work performed by the muscles is the index of endurance); d) the 50-repetition decrement test (50 consecutive maximal isokinetic efforts at a predetermined angular velocity and the percent decrement of the average torque between the last three contractions and the first three contractions is used as a measure of endurance) (Agre, 1999).

These tests provide a gross estimation of muscle endurance/fatigue and most of them are easily applicable in clinical settings and do not require specific or expensive instruments. On the other hand, although the measurement of the time or the number of repetitions or the work produced by the muscles provide inherently objective values, all these endurance tests are subjective in nature as they are dependent on subjects motivation to give their maximal effort or to maintain a contraction until exhaustion and indeed if MVC is not attained initially or sustained during a contraction then a false estimate of fatigue may be obtained. It is not possible to determine from reported studies how MVC was ascertained and interpreting the results from time dependant methods remains questionable. In addition, the requirement to sustain a contraction until complete fatigue may be contraindicated in many patients because of the possible risks of such an effort. Most studies evaluating neck muscle endurance have employed this method to investigate their subjects and reviews on reliability reports of these tests have been recently published (Strimpakos and Oldham, 2001; de Koning et al., 2008).

Whole cervical spine versus deep neck flexor endurance measurement

The importance of neck flexors and especially the deep neck flexors (DNF) in patients with neck pain and headache is highlighted by many authors (Jull et al., 2004; Falla et al., 2004b; Lee et al., 2005; Falla et al., 2006; de Koning et al., 2008; Jull et al., 2008, 2009). It is proposed that the anterior cervical muscles are analogous to weak abdominal muscles in the production of low back discomfort (Krout and Anderson, 1966). Two tests in the literature have been employed in order to examine the endurance of these muscles, the craniocervical flexion test (upper cervical flexion is measured with an inflatable pressure biofeedback unit placed behind the neck, with the patient in a supine position) (Figure 3). and the conventional cervical flexion, a test that instruct the subjects to "tuck in their chins" (craniocervical flexion) and then to raise their heads from supine position. Although both tests are reliable and assess the DNF they have been developed for different purposes (de Koning et al., 2008; James and Doe, 2010). The craniocervical flexion test evaluates only the DNF while the second test (conventional flexion) assesses both superficial and deep flexor muscles. Recently, a study compared the isometric craniocervical flexion and conventional cervical flexion, did not found any significant differences between these two tests in the activation of the deep cervical flexion muscles (O'Leary et al., 2007b). However, when using these tests investigators have to be aware that the activity of superficial muscles (SCM and AS muscles) may mask impaired performance of the deep cervical flexor muscles and only the craniocervical flexion test can give specific information about deep neck flexors (Vasavada et al., 1998; Cagnie et al., 2008; Jull et al., 2008).

Figure 3 The clinical application of the craniocervical flexion test. The patient is guided to each progressive pressure increment of the test by feedback from the pressure sensor. The clinician analyses the movement and detects the presence of any activity in the superficial flexors (J. Manipulative Physiol. Ther., 2008; 31:525—533, with permission from Elsevier).

Factors influencing endurance—fatigue measurements and estimates

Differences in fatigue mechanisms during maximal and sub-maximal contractions

Maximal and sub-maximal contractions have different durations, involve different recruitment strategies and may as a consequence involve different fatigue mechanisms. While contractile activity of a supramaximally electrically stimulated muscle provides an objective measure of fatigue, the notion of fatigue in an exercising organism can include an increased effort necessary to maintain a sub-maximal contractile force at an unchanging level. Thus, the individual keeps exercising at the same performance level while experiencing an increase in the amount of excitation of the motor pool necessary to maintain the performance, with a simultaneous decrease in the maximal capacity of the contractile system (Gardiner, 2001). Differences in fatigue characteristics during maximal and sub-maximal contractions are partly explained by differences in motor unit recruitment, motor unit rate coding, blood flow and muscle activation patterns. These are briefly discussed in subsequent sections.

Motor unit recruitment

Muscle fibre types are dictated by the motor neuron supplying them. Motor units become active at characteristic levels of force. The normal sequence of motor unit activation calls upon the smaller units first, therefore, with weak effort, the type I motor units are recruited. As the demand for higher force levels increases, the type II motor units become active (Jones and Round, 1990; Gardiner, 2001). This phenomenon is known as the "size principle of recruitment" and can be affected by several factors such as joint pain and swelling. This in turn may interfere with the abilities to perform high-intensity levels of contraction, resulting of recruitment of only type I fibres (Harris and Watkins, 1999).

The recruitment pattern described above has advantages in that the most frequently used units are small, slow and fatigue resistant and can provide fine control for the majority of everyday activities such as postural adjustments which require relatively small forces. The large fast and rapidly fatigable units are only used for occasional high force contractions where fine control is not necessary (Jones and Round, 1990). During sub-maximal contractions metabolic product accumulation may decrease performance and require additional temporal and spatial recruitment of motor units in order to achieve the same force output (Blei et al., 1999). As a consequence, the increase in EMG during a fatiguing contraction held at a sub-maximal force is largely due to recruitment of additional motor units (Gardiner, 2001).

Rate coding

An alternative way of modulating force is to vary the frequency of stimulation. This is known as rate coding. It is not known to what extent the two methods of varying force, recruitment and rate coding are used during a normal voluntary contraction. It is possible that in large muscles such as the quadriceps, where fine control is not generally required, force is adjusted by recruitment of motor units which, once recruited, continue firing at a fixed rate. In small muscles like those of the hand where fine control is essential, rate coding may be more important (Jones and Round, 1990). There are no available reports in literature regarding rate coding in neck muscles.

Blood flow and muscle fatigue

Among the mechanisms that could contribute to fatigue is the impairment of blood flow to active muscle. An increase in muscle blood flow with motor activity is necessary for the supply of substrates, the removal of metabolites, and the dissipation of heat. When a muscle is active however, there is an increase in intramuscular pressure that compresses blood vessels and occludes blood flow when it exceeds systolic pressure. Blood flow decreases with an increase in the level of the sustained force but only for tasks that involve more than 15% of the MVC force (Enoka, 2002). This is more pronounced during isometric contractions because the blood flow within the muscle is maintained during the dynamic contraction by enhanced venous return from the contracting muscle (Masuda et al., 1999). It would not be appropriate therefore to compare the extent of fatigue between different types of contraction as the mechanisms of fatigue will differ between them depending on the extent of blood flow.

Muscle activation patterns and fatigue

A resultant muscle force about a joint can be achieved by a variety of muscle activation patterns. This flexibility certainly exists amongst groups of synergist muscles such as the cervical spine muscles (Tamaki et al., 1998; Semmler et al., 1999). Because of this possibility, one option the motor system has for delaying the onset of force decline (fatigue) is to vary the contribution of synergist muscles to the resultant muscle force enabling different muscles to rest and therefore prevent fatigue. This is a complementary muscle recruitment strategy of the body in order to maintain a constant force. Although this possibility is available only when the task requires sub-maximal forces (Enoka, 2002), it applies to most activities of daily living that involve such forces. Especially in cervical spine, we have to keep this principle in mind since during endurance assessment patients could differentiate their patterns activating more the strongest superficial muscles in contrast to weaker deep neck muscles resulting thus in wrong estimation of this parameter. Low load tests and supervision for performing the right movement patterns during assessment may be used in order to overcome this limitation.

Implications for clinicians and researchers regarding neck endurance/fatigue assessment

Neck muscle endurance and fatigue can be assessed by using either clinical methods (time dependent and subjective) or more sophisticated (EMG-based) methods. Moreover the assessment of fatigue could involve the whole cervical spine or only its upper part. Many authors have suggested that the lower endurance of deep neck flexors seems to be important factor for the development of neck pain and headache. Regarding the clinical assessment of endurance, some precautions have to be taken to ensure valid results. Low load tests are essential for assessing the deep neck muscles' endurance together with isometric evaluation since the main function of small neck muscles is the stabilisation of cervical structures. Sometimes, clinical tests performed until exhaustion are not preferable, especially in acute situations. Tests that use incremental levels of effort (i.e. subject aims to sustain a nominated pressure for as long as possible) could be employed in these situations. Furthermore, the position of the subjects (sitting, standing or lying) can change the resulting values since the load in each test may be different. Test position has to be kept constant between measurements and torso stabilisation could help in this way. Aforementioned issues for strength assessment such as warm-up, diurnal variations, hormonal influences, etc could also be applied for endurance measurements. Finally, investigators must be aware that muscle activation patterns could be changed during assessment as a result of fatigue making more prominent the superficial neck muscles resulting in invalid estimates and conclusions.

Conclusion

Physical factors such as strength and endurance/fatigue have been considered as significant parameters for the normal function of the cervical spine along with neck ROM and proprioception (presented in a previous paper). The presence of physical impairments in the neck may lead to the development of chronic neck pain and headache. However, the complicated nature of the cervical spine requires the awareness of the multiple factors a clinician or researcher has to take into account throughout their evaluation. For these reasons presently there is no consensus among clinicians and researchers for the best method and protocol for assessing neck strength and endurance. The best way to obtain reliable and valid values is to keep a constant assessment procedure in all measurements, to isolate as much as possible the cervical spine from the rest of the body by using stabilisation frames, to test the reliability of all instruments being used, and to motivate subjects to give their best efforts. Issues such as warm-up and familiarisation sessions before measurements, diurnal variations and hormonal influences, are all essential for reliable and valid results in both neck strength and endurance/fatigue assessments. Low load tasks with close monitoring of muscle activation patterns are also important components in cervical spine endurance assessments.

Text box

Neck strength and endurance/fatigue evaluation have been used extensively in clinical research and practice. Their assessment however, is compromised by many factors concerning either the cervical spine as a structure or the strength and endurance variables themselves. It is important for obtaining valid and reliable values to maintain consistent assessment procedures in all sessions, to isolate the cervical spine movement from the rest of the body, to ensure maximum efforts from the subjects by motivating them, and also to assess at the same time-of-day after undertaking a warm-up and familiarisation session. It is also essential to use low load tests to evaluate the endurance of small neck muscles (especially the deep neck flexors) and to supervise closely the test in order to ensure the proper performance and to avoid compensation from other muscles.

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