Individual Cervical Muscle Function in Biomechanical Studies: A Review of Literature

ASGHAR REZASOLTANI, PhD, PT1)

1)Faculty of Rehabilitation, University of Sh. Beheshti: Damavand St., Faculty of Rehabilitation, Dept. of Physiotherapy, Tehran-Iran. E-mail: agreza@medscape.com

Abstract. The human cervical structure is a complex arrangement in which an important array of bones, soft tissues and vital organs are collected in a closely-packed area. There are numerous small and large muscles which act together to induce head and neck motion in a certain direction. The cervical muscles are also involved in many audiovisual reflexes, which are a complicating factors in clinical evaluations. Because of this anatomical compaction and the complexity of the upper motor neuron reflexes involving the cervical muscles, there is as yet no general understanding of the anatomy and function of the neck muscles. This gap in our knowledge may in part be due to a lack of proper examination tools or to a failure to examine the applicability of the present methods for evaluating cervical muscle function. Today the field of biomechanical evaluation of the cervical spine needs an easy and practical method which would also be replicable in follow-up studies such as rehabilitation assessments. Within the last decade, parallel to methods like electromyography and muscle strength tests, a few imaging techniques, particularly computerized tomography, magnetic resonance imaging and ultrasonography have been used to evaluate the function of the cervical muscles. In the present article, the application of the current biomechanical methods in the assessment of the individual cervical muscle function is discussed.

Key words: Individual, Cervical, Muscle, Function.

INTRODUCTION

Biomechanics is the science that examines the action and interaction of various forces upon and within a biological structure (Nigg and Herzog 1996). According to Miller and Nelson (1973), the main aim of developing biomechanical components (models) is to provide a simple and accurate estimation of the force exerted on different biological structures. Nigg and Herzog (1996) stated that biomechanics involves studies of disabled, non-disabled, athletic and non-athletic subjects.

Clinical biomechanical methods have already been used to analyse the mechanisms behind cervical injuries and to gain an understanding of the instability caused by cervical trauma (Yoganandan and Pintar 1997). Grauer et al. (1997) examined the mechanism of whiplash injury by monitoring the motion of individual spinal vertebrae during whiplash trauma. The authors found that during a whiplash injury the cervical spine was bent into a s-shaped curve and subjected to hyperextension deformities.

BIOMECHANICAL PROPERTIES OF HUMAN CERVICAL MUSCLES

In vitro laboratory studies of cervical biomechanics have been undertaken with both
human and animal subjects (Nolan and Sherk 1988, Dickman et al. 1994, Chen et al. 1994). Dickman et al. (1994) compared and analysed the function of the upper cervical spine in baboons and humans. The authors concluded that as regards the anatomy and biomechanics of their upper cervical spine, these two species resembled each other. Kamibayashi and Richmond (1998) provided descriptive morphometric data on individual cervical muscles in humans. Basing their model on a microdissecting approach, the authors evaluated the muscle mass, pennation angle, fascicle length and sarcomere length of the fourteen cervical muscles. Drawing on Kamibayashi and Richmond’s (1998) results from cadaver studies, Vasavada et al. (1998) developed a computer-graphic model of the cervical muscles and calculated the movement-generation properties of individual neck muscles for a range of head and neck positions. According to the authors, neck muscles with similar action may have some essential differences in their neural activation patterns, moment arm and their force generation capacity.

*In vivo* indirect biomechanical methods such as surface electromyography and muscle force measurements have been employed in studies of the biomechanical properties of the cervical muscles (Harms-Ringdahl et al. 1986, Schüldt et al. 1988, Mayoux-Benhamou et Revel 1993, Queisser et al. 1994). Using surface electrodes, Queisser et al. (1994) measured the myoelectrical signals generated by four cervical muscles, the semispinalis capitis muscle, the splenius capitis muscle, the levator scapula and the trapezius muscles during MVC in cervical extension at four head and neck positions. The authors reported a linear relationship between the electromyographic signals of the semispinalis capitis muscle and external torque, whereas the splenius capitis muscle results suggested that the relationship between the signals generated by the splenius capitis muscle and external extension torque tends to be non-linear. The authors suggested the effect on EMG signals of the shifting of the end plates in different head and neck positions as a possible source of error. Schüldt et al. (1988) applied a similar vector line to estimating cervical muscular moment. The authors used surface EMG and reported a non-linear EMG/moment relationship for the erector spine/trapezius, splenius, and levator scapula muscles.

Staudte and Dühr (1994) measured cervical extension force and neck length and calculated torque by multiplying cervical extension force by neck length in men and women aged between 14 and 74. They found that torque declined with increasing age because the neck became shorter and the neck muscles weaker. In the other studies, Ylinen and Ruuska (1994), Ylinen et al. (1998), Julin et al. (1998), and Ylinen et al. (1999) measured absolute neck maximal extension force and reported higher values for athletes than for non-athletes or cervical patients.

Load sharing among the cervical muscles during isometric contraction has been studied by EMG, MRI and computer motion analysis (Steen 1966, Mayoux-Benhamou et al. 1989, Conley et al. 1995, Vasavada et al. 1998). While a few authors have granted that measurements based on the external torque of the cervical muscles have some applicability in EMG studies, others have more faith in absolute neck force measurements. Harms-Ringdahl et al. (1986) calculated the cervical load moment induced by the weight of the head and the neck about the bilateral axis of the C7-T1 spinal motion segment. The authors located the centre of cervical motion (the fulcrum) at a site halfway between the spinous process of C7 and the upper margin of the manubrium sterni. They reported that with the head and neck in flexion, the load moment of the cervical extension force for the C7-T1 joint was 3.6 times as high as the value for the neutral position of the head. Queisser et al. (1994) calculated the external torque of the post-cervical muscles by multiplying the absolute force and the external lever arm for cervical extension. These authors estimated the external lever arm (moment arm) by determining the distance between the centre of pressure under the head and the C7-T1 spinous process.

**CERVICAL MUSCLE DIMENSIONS AND MUSCLE FORCE**

Imaging methods such as computerized tomography scanning and MRI have been used to estimate the relationship between cervical muscle force and size in humans (Mayoux-Benhamou et al. 1989, Conley et al. 1995). Mayoux-Benhamou et al. (1989) measured the total cross-sectional area of the posterior cervical muscles and absolute neck extension force. The highest correlation found by
these authors was between absolute neck extension force and the cross-sectional area of the semispinalis capitis muscle. They suggested that because of individual anatomical and physiological differences, using any vectorial construction might lead to an oversimplified picture of the actual muscle strength.

In studies of muscle size and related muscle force, muscle size has been measured separately from maximum voluntary contraction (Mayoux-Benhamou et al. 1989, Freilich et al. 1995, Ikai and Fukunaga 1968). The first simultaneous measurement of muscle response and muscle force was reported by Hicks et al. (1984). The authors found a significant decrease in the echo amplitude of the quadriceps muscle during MVC as compared to measurements taken with the muscle at rest. Furthermore, Henriksson-Larsen et al. (1992) scanned the vastus lateralis muscle at rest and during the MVC force of knee extension. The authors also revealed a significant increase in the angle of the muscle fascias during MVC as compared to a state of rest. Likewise, in another ultrasonographic study, the mean fiber angle pennation of the vastus lateralis and vastus intermedius muscles decreased as the muscles first contracted or shortened and then stretched. (Rutherford and Jones 1992). The same authors also reported a significant positive correlation between the fiber angle and the CSA of the vastus lateralis and vastus intermedius muscles.

In this regard, muscle outline and dimensions may be altered during muscle contraction. The result of our recent study revealed a significant variation in the lateral and antero-posterior dimensions of the neck semispinalis capitis muscle when subjects supported the weight of their heads in a prone position and muscle size was measured simultaneously (Rezasoltani et al. 1998a). Our other results also showed a significant correlation between the dimension of the muscle at rest and cervical extension force during MVC (r=0.82, p<0.001) in a group of males and females (Rezasoltani et al. 1998b).

DISCUSSION

In biomechanical studies, there are a few authors who have modelled the musculature of the human cervical spine as a single equivalent force vector (Harms-Ringdahl et al. 1986, Queisser et al. 1994). Regarding the literature, such a single-vector model may not work satisfactorily or produce inaccurate results since there are many other factors not considered in it (Mayoux-Benhamou et al. 1989, McGill and Sharratt 1990). McGill and Sharratt (1990) assumed that a single vector may not adequately represent the strength of the spinal extensor muscles since the force generated by the muscles is parallel to the axis of compression, with the result that it may cancel the shearing force. In addition, a single equivalent vector cannot enable a comprehensive perspective on the mechanics involved because of the intervertebral disc load, facet joint reaction forces, the force of gravity and the multitude of ligaments and muscles.

Using an external lever arm, Schüldt et al. (1988) and Queisser et al. (1994) gained contradictory results on the relationship between EMG activity and cervical extensor torque. Regardless of the limitations of EMG recording of the cervical muscles, the discrepancies might be partly due to the complexity of modelling the moment arm for muscle force prediction. The contradictory findings regarding EMG and cervical extension torque may also be a result of different biomechanical models being applied by different authors. In a spinal muscle strength study, Rantanen et al. (1994) came to paradoxical results when they compared maximal trunk flexion and extension force and torque using a different level of the fulcrum. The authors concluded that trunk flexion and extension torque increased in direct proportion to the height of the fulcrum. The authors further stated that lowering the fulcrum (increasing the external lever arm) may allow the hip flexor and extensor muscles to also contribute to the generation of torque in back flexion and extension.

Another factor which must be taken into account in the force production of a single muscle are the special biomechanical characteristics of the muscle studied. Vasavada et al. (1998) found that in certain movements some cervical muscles, such as the sternocleidomastoid, may provide two moment arms. The semispinalis capitis muscle consists of two medial and lateral parts named as a digastric of the neck (Kapandji 1974), and each part may have different physiological and mechanical characteristics in maximal and submaximal contraction. Both parts of the semispinalis capitis muscles have a common insertional attachment to the occipital bone. The lateral part originates from
C3-C4 and the medial part from the transverse process of the lower cervical and upper thoracic spine. The location as such may provide the lateral part of the muscle with a special function as a head and upper cervical extensor, but the medial part which runs parallel to the semispinalis cervicis muscle may function as a spinal extensor, concentrated mainly on the lower part of the cervical and the upper part of the thoracic spine.

In general, in the cervical area the application of current force estimation methods based on dynamometry and EMG or direct methods of force measurement may prove inapplicable in the evaluation of the action of individual deep muscles, while needle electromyography and transducer implantation may, in the context of cervical muscle measurement, be an invasive method. In cadaver studies it is difficult to encircle the muscles, and it is not easy to draw conclusions about the actual condition of healthy and young individuals either.

The simultaneous measurement of muscle force and muscle size may be of special importance in gaining a lucid understanding of the action of the individual muscles in such a complex structure as the cervical spine. Monitoring muscle contraction in vivo may be a useful method to study the biomechanical property of the cervical individual muscle. Further studies are required regarding applications of the technique of muscle size measurement in the field of biomechanical research, physiotherapy and rehabilitation.

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