CHOOSING THE RIGHT BODY POSITION FOR ASSESSING TRUNK FLEXORS AND EXTENSORS TORQUE OUTPUT

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ABSTRACT

Purpose. The sitting position is generally adopted when measuring the torques produced by flexors and extensors of the trunk. Results of such measurements are influenced by the strength of both abdominal muscles and flexors of the hip joint. In order to assess the effect of exercises used to strengthen the abdominal muscles it was necessary to find such a measuring position which engaged mainly the abdominal muscles. The objective of the study was an assessment of EMG activity of abdominal and spinal muscles during the measurements of muscle torques in the sitting position, as well as in the lying position.

Basic procedures. Thirteen female students of the University School of Physical Education in Wrocław participated in the study. The methods of measuring muscle torques and surface electromyography (sEMG) were used under static conditions. The torques were measured on a multifunctional chair in the lying and sitting positions. The surface EMG electrodes were placed on the right and left hand sides of m. rectus abdominis (rA) and m. erector spinae (ES). Signals from both muscles were sampled at 1000 Hz.

Main findings. The maximal torques of trunk flexors in the sitting position and in the lying position were similar: 130.6 ± 31.7 Nm and 129.8 ± 37.9 Nm, respectively. by contrast, the torque of trunk extensors was significantly larger when the measurement was carried out in the sitting position (228.1 ± 76.4 Nm) as compared with the lying position (148.8 ± 25.3 Nm). The ratio of the maximal torques of flexors and extensors of the trunk in the women examined was 0.572 in the sitting position and 0.872 in the lying position. Both rA and ES showed higher EMG activity in the lying position than in the sitting position.

Conclusions. The higher EMG activity of the rA muscle in the lying position at the same values of the trunk flexors torque in both positions may suggest that in the sitting position flexors of the hip joint are more engaged than abdominal muscles. That is why, in order to assess the effects of abdominal muscles training, measurements of the trunk flexors torque should be performed in the lying position.

Key words: torque, EMG, measuring position, trunk muscles

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Introduction

Measuring muscle torques is one of the most frequently used methods of assessing the effects of training and of selecting the correct loads both in physiotherapy and in sports. While measurement methodology of flexor and extensor torques of the hip and knee joints is well defined [1 – 5], the torques of trunk flexors and extensors are measured either in a sitting or standing position. This is often a result of the way the measuring equipment is constructed. Flexion and extension of the trunk are characterized by many degrees of freedom and consequently engage many muscle groups. It is apparent for flexion of the trunk that its first phase is realized mainly by abdominal muscles (m. rectus abdominis, mm. external and internal obliques), which are then joined by hip flexors (m. iliopsoas, m. rectus femoris, m. tensor fasciae latae), the main actuators in the last phase of flexion. This is a result of the variation of the muscle lever arm and consequently of the torque produced. The external effects of muscle action, the torques produced, are the sum of all the actions of a given muscle group. The value of the maximal torque as a function of the joint angle is therefore different not only in individual joints but also at different angular positions of the same segment. There are a lot of experimental data concerning this effect for major joints of the upper and lower extremities [6].

The interest in measuring trunk muscle torques is a result of the constantly increasing number of people suffering from the low back pain syndrome (LBP) [7, 8]. A special role in preventing LBP should be attributed to strengthening the muscle groups which are jointly referred to in the literature as muscle corset. These muscle groups include, among others, abdominal muscles and m. erector spinae, and their role consists in...
stabilizing the spine during activity of the muscles responsible for appropriate execution of all the movements. The stabilizing function of muscles is based on their static activity when activated muscles do not change their length, which is a result of the muscular torque being equal to the external torque.

According to the literature cited in previous papers [9], exercises like curl-up may be safe and efficient in preventing LBP, because they engage m. rectus abdominis and mm. external obliques in their motor function. In order to assess the effects of training and to program the correct loads during exercises, reliable measurement of strength capabilities of these muscles must be carried out. This criterion is not fulfilled by the measurement of the torque of trunk flexors in the sitting or standing position, because beside abdominal muscles it engages also other muscle groups. That is why, we propose to perform the measurement of the maximal torque of trunk flexors in the lying position with such a range of trunk flexion that would keep the lower tips of scapulae on the support. Adequacy of this measuring position may be verified by electromyography. Therefore, the objective of this study was an assessment of EMG activity of abdominal and spinal muscles during the measurement of muscle torque carried out in the sitting and lying positions. This was helpful in finding the measuring position in which trunk flexion was realized more by abdominal muscles than by flexors of the hip.

Material and methods

Subjects

Thirteen subjects were recruited from among female students of the Faculty of Physical Education of the University School of Physical Education in Wrocław. Their body height and body mass were, respectively, 168.5 cm and 55.5 kg on average. In order to make the results of this study as representative as possible, subjects were selected to be of the same sex (women), of a narrow age interval (21–25 years), and of similar level of motor activity and body type. All the subjects were informed about the aims and procedures of the experiment, and signed an informed consent statement. The experiment was approved by the commission for Ethics in Scientific research at the University School of Physical Education in Wrocław.

Experimental procedures

Methods of surface electromyography and measurements of muscle torques under static conditions were used in this study. Both signals were measured according to the rules and principles described in the literature [10, 11]. Synchronous measurements of static muscle torques and of EMG signals were carried out for muscles representing the groups of flexors and extensors of the trunk, i.e. for m. rectus abdominis (RA) and m. erector spinae (ES).

EMG measurements

Surface electrodes were placed on the right and left hand sides of m. erector spinae and m. rectus abdominis, and two more electrodes sites were additionally used on the latter in its upper and lower parts (Fig. 1a). This choice of EMG electrode sites, which included the right, left, but also the lower and upper parts of the muscle, was dictated by its specific shape. A similar approach to assessing activity of this muscle was used by some other authors [12, 13]. The two electrode sites on m. erector spinae were situated at a distance of 3.5 cm from the spinous process of the first lumbar vertebra [10] (Fig. 1b).

Figure 1. Electrode placement on m. rectus abdominis (a) and m. erector spinae (b)
The surface electrodes were placed according to the principles of best EMG signal reception described in the literature [12, 14, 15], and also based on the lines of action of muscles, which allowed us to take into account the individual anatomy of the subjects. The action potential of the muscles was recorded using solid gel Ag/AgCl surface electrodes (NORAXON Inc. USA) placed in a bipolar configuration on muscle bellies along muscle fibres. The electrode set included 6 pairs of active electrodes and 1 reference electrode, which was placed on the skin at an electrically passive location (anterior superior iliac spine). An 8-channel electromyographic device “Octopus” (Bortec Electronics Inc., Calgary, Alberta, Canada) was used, and signals were sampled at a frequency of 1000 Hz.

Normalization of the EMG signal

For normalization of the EMG signal, at the beginning of the experiment subjects were asked to perform a maximum voluntary contraction (MVC) [12], which required the help of two additional persons.

MVC of m. rectus abdominis (RA) was realized by counterbalancing the external load applied to the chest by the person who assisted in measurements. The subject attempted to lift the trunk from the floor. Her upper extremities were flexed in the elbow joints, and hands were placed at the back of the head. The second assistant was stabilizing the position by holding the feet at the ankles (Fig. 2).

For m. erector spinae (ES) MVC was produced during counterbalancing the external load applied near the scapulae by the person who assisted in measurements. The position of the upper extremities of the subject and trunk stabilization was the same as for m. rectus abdominis (Fig. 3).

The maximum values obtained in these measurements were assumed as reference values in the assessment of activity of abdominal and spinal muscles.

EMG signal processing

The raw EMG signal and the torque were recorded in a personal computer by using the “BioWare” software. Files with “tbd” extension were exported to the MATLAB environment, which was then used to process the EMG signals. Signal envelope was found by applying an algorithm available in the MATLAB environment in the program dspenvdet.mdl. The first step of these calculations was to square and double the EMG signal. Next, the result was filtered by a lowpass linear filter with finite impulse response. Parameters of the transfer function representing the filter were set up to 0, 0.03, 0.1, 1 and 1, 1, 0, 0 for the numerator and denominator, respectively. The envelope was calculated as the square root of the filtered output signal. The maximum of the envelope was the largest value of this square root (Fig. 4).
Measuring stand and experimental procedure

The measurements were carried out on a multifunctional chair (SUMER, Opole, UPR-01 A/S). To meet the needs of the experiment the chair was enhanced in a special way. The enhancement consisted in supplementing the single torque transducer by a second one, and in connecting both transducers with a transversal beam, which forced the subjects to push symmetrically on the measuring levers while producing the maximum torque. Technical characteristics of the measuring stand were described in Szpala et al. [16].

The task of the subjects consisted in producing maximum static torque in response to a cue. The measurements of the torque and the EMG signal from the muscles examined were carried out in both sitting and lying positions.

The sitting position was defined by fixing the hip and knee joint angles at 90°. The axis of the hip joint was aligned with the axis of the dynamometer. In order to eliminate the influence of other muscle groups through the so called muscle torque transfer, upper extremities were held crossed on the chest, and pelvis, thighs and shanks near ankle joints were immobilized with stabilizing belts. The resistance of the measuring device was applied to the front of trunk near the chest for the measurement of the torque of trunk flexors (Fig. 5a), and to the rear of trunk near the scapulae – for the measurement of the torque of trunk extensors (Fig. 5b).

The lying position was defined by the requirement that during the measurement of the torque of trunk extensors the subject was lying on the measuring chair and the hip joint axis was aligned with the axis of the dynamometer. Lower extremities were straight at hip and knee joints and stabilized at the ankles by the assisting person. Hands were placed behind the head. The resistance of the measuring device was applied as in the sitting position (Fig. 6a). During the measurement of the torque of trunk flexors the subject was lying on the measuring chair with shoulders raised up to such a trunk flexion angle that allowed the lower tips of the scapulae to still contact the support. Attention was paid during the measurement to make sure that the head was in its anatomical position and was not pressed towards the chest. The hip joint axis was aligned with the axis of the dynamometer, lower extremities were flexed in the hip and knee joints by 90°, and they were stabilized by the assisting person at the ankles. Upper extremities were held straight along the trunk. The resistance of the measuring device was applied as in the sitting position (Fig. 6b).

The lever arm of the external force was individually selected for each measurement to take into account possible differences in the physical build of the subjects. This approach is in agreement with the generally ac-
cepted principles of muscle torque measurements under static conditions [11].

All the measurements within this project were carried out in the Laboratory of Biomechanical Analyses of the Department of Biomechanics of the University School of Physical Education in Wrocław (certificate PN-EN ISO 9001:2001).

Results

In order to assess which measuring position engages abdominal muscles to a greater extent, the amplitudes of action potential and the torque produced by the muscles examined were analyzed. The analysis included both the EMG signals expressed in natural units and the normalized EMG signals (the MVC value was adopted as a reference value during the assessment of activity of abdominal and spinal muscles).

Measuring position and muscle torque output

In order to verify if there is a difference in magnitude between torques measured in the sitting and lying positions, the mean values obtained in those positions were compared.

The maximal muscle torque of trunk flexors in the sitting position (130.6 ± 31.7 Nm) was similar to that obtained in the lying position (129.8 ± 37.9 Nm). Student’s t-test for independent data did not show significant difference between the means (t = –0.0883 for df = 56 and p = 0.93). By contrast, the torque of trunk extensors was significantly larger in the sitting position (228.1 ± 76.4 Nm), compared to that measured in the lying position (148.8 ± 25.3 Nm). Student’s t-test for independent data confirmed the significance of the differences between the means (t = –5.09 for df = 61 and p = 0.00004). The statistical analysis was carried out at the significance level of α < 0.05.

An analysis of flexors to extensors ratio was subsequently performed and it showed that the resultant torque of trunk extensors exceeded by 70% the resultant torque of trunk flexors in the sitting position and by 14% in the lying position. This means that the ratio of the maximal torque of trunk flexors and the maximal torque of trunk extensors in the women examined amounted to 0.572 and 0.872 in the sitting and lying positions, respectively.

Measuring position and EMG activity

In order to identify which measuring position engages abdominal muscles to a greater extent the normalized EMG amplitudes in the two measuring positions were compared. Action potentials of the muscles on both sides of the body were summed up at this stage of analysis, and their levels of engagement were evaluated in all the measuring positions. This approach allowed us to conclude that both muscle groups demonstrated higher electromyographic activity in the lying position (RA: 83.50 ± 8.27%, ES: 87.40 ± 19.0%) than in the sitting position (RA: 60.98 ± 16.39%; ES: 41.00 ± 17.35%). Student’s t-test for independent data identified statistically significant differences between activities in the lying and sitting positions for m. rectus abdominis (t = 6.61, for df = 56 and p = 0.00001) and m. erector spinae (t = 10.05 for df = 61 and p = 0.00001).

The next stage of analysis considered electromyographic activity of the muscles examined against the background of torque produced. It turned out that both muscle groups showed higher action potentials in the lying position, but higher torques were found in the sitting position (Fig. 7).

Measuring position and symmetry of muscular activity

An analysis of symmetry of muscular activity was performed next. Comparing bioelectric activity of the right and left hand sides of the muscles examined showed symmetry in the EMG amplitude for m. rectus abdominis (RA) and asymmetry for m. erector spinae (ES) in the positions analyzed, which followed from Student’s t-test for independent data (Tab. 1). The statistical analysis was carried out at the significance level of α < 0.05.

The specific shape of m. rectus abdominis required placing the surface electrodes not only on its right and...
left hand sides, but also on its upper and lower parts. Analysis of symmetry between the upper and lower parts, but on the same side of the muscle, identified significant differences in activity of m. rectus abdominis in all the positions considered (Tab. 2).

In this part of the experiment the analysis was based on raw data, instead of those related to the value of the maximum isometric voluntary contraction (MVC). Signals should be normalized when one compares activity of different muscles in different motor tasks. As humans show dynamic asymmetry manifesting itself in differences between the strength of the right and left hand sides of the body, it can be assumed that this asymmetry will manifest itself in EMG activity as well. If normalized EMG signals were used, then possible differences between the sides would not be visible. A similar approach to the analysis of EMG signals from muscles of the right and left hand sides of the body was employed by other authors [17].

**Table 1. Results of symmetry analysis between the right and left hand sides of the muscles examined in the adopted measuring positions (t – Student’s t-test, df – number of degrees of freedom, p – probability level, RA – rectus abdominis, ES – erector spinae).**

| Measuring position | Muscle      | Amplitude 1 (mV) | Amplitude 2 (mV) | t     | df | p   |
|--------------------|-------------|------------------|------------------|-------|----|-----|
| Lying position     | RA          | 0.856            | 0.902            | –1.505 | 28 | 0.143 |
| Sitting position    | RA          | 0.744            | 0.711            | 1.224  | 28 | 0.231 |
| Lying position     | ES          | 0.708            | 0.638            | 2.039  | 28 | 0.051 |
| Sitting position    | ES          | 0.468            | 0.444            | 0.887  | 28 | 0.382 |

**Table 2. Results of symmetry analysis between the upper and lower parts on the right and left hand sides of m. rectus abdominis (RA) in the adopted measuring positions (t – Student’s t-test, df – number of degrees of freedom, p – probability level).**

| Measuring position | M. rectus abdominis (RA) | Amplitude 1 (mV) | Amplitude 2 (mV) | t     | df | p   |
|--------------------|--------------------------|------------------|------------------|-------|----|-----|
| Lying position     | right side – upper part vs. right side – lower part | 0.856 | 0.744 | 2.133 | 28 | 0.041 |
| Sitting position    | right side – upper part vs. right side – lower part | 0.902 | 0.711 | 3.886 | 28 | 0.0006 |

**Discussion**

Electromyography has been applied in increasingly sophisticated biomechanical analyses aiming at trunk muscle force assessment mainly in LBP prevention. Stokes [18] analyzed dependence of EMG signals on trunk muscles effort under isometric conditions. Using an apparatus to stabilize the pelvis, influence of increasing versus decreasing effort on the EMG-effort relationship in the standing position was quantified. It was found that the EMG/effort relationship had a statistically significantly greater gradient as the effort was increasing than when it was decreasing. Gardner-Morse et al. [19] noticed that many problems with the lumbar spine can be attributed to instability. The ligamentous spine (without muscles) is unstable at very low compressive loads. They examined the hypothesis that instability of the lumbar spine is prevented under normal circumstances by the stiffness of spinal musculature, without active responses from the neuromuscular control system. The effect of muscle activity on the stability of the lumbar spine was analyzed for maximum voluntary extension efforts with different spinal postures in the sagittal plane. Ng et al. [8] examined the effect of fatigue on torque output as well as electromyographic frequency and amplitude values of trunk muscles during isometric axial rotation in back pain patients and compared the results with a matched control group of healthy persons. They found that low back patients demonstrated a different activation profile of the trunk muscles during the exertion.

The EMG/torque output relationship is analyzed for trunk muscles, and in many cases this is done under dynamic and not static conditions [7, 20]. However, in accordance with Hill’s curve, the maximal strength capabilities can well be quantified under static conditions. Such an assessment is necessary if one wants to identify the effects of a training program both in physiotherapy.
and in competitive sports. Our experiment concerned the problem of choosing the most appropriate measuring position for assessment of muscle groups being strengthened in back pain prevention programs. The obtained results showed that mm. rectus abdominis and erector spinae demonstrated higher action potential in the lying position, and larger torque output in the sitting position. This information may also be important for rehabilitation procedures in which choosing the lying position can be significant for persons suffering from low back illnesses. The constantly increasing number of scientific publications testifies to the growing interest of researchers in the role of various exercise and training programs in LBP prevention.

In our opinion, it is the flexors to extensors torque ratio that is more significant to LBP prevention than the actual values of the torques of individual muscle groups. Many papers present trunk muscles torque output against the background of the general strength profile of the major muscle groups [21, 22]. However, such an assessment is not useful for LBP prevention. It seems justifiable to adopt an assessment based on agonist to antagonist strength ratio, as it is done for flexors and extensors of the knee joint in competitive sport (in prevention of m. biceps femoris injuries). Such an approach based on using the flexors to extensors ratio for the trunk is suggested by Trzaskoma [21] for injury prevention in competitive sport and for diagnosing patients with different disorders. It follows from the research published in another paper [23] that the flexors to extensors ratio can have similar values even though the maximal torque outputs of flexors and extensors of the trunk differ significantly in women and men with different spinal disorders. For persons with different disorders the flexors to extensors ratio evaluated based on measurements of maximal torque output in the sitting position amounted to 0.445 for women with L4–S1 discopathy, 0.692 for persons using a wheelchair, and 0.818 for patients with rheumatoid arthritis in an early stage. Trzaskoma [21] compared these values with the flexors to extensors ratio for healthy women in the same measuring position, which turned out to be equal to 0.739. In our research, which was carried out using a different measuring apparatus, the flexors to extensors ratio obtained for the same measuring position was equal to 0.572.

The present work brings also an analysis of symmetry of electromyographic activity of the muscles examined as a function of the measuring position adopted. Activity was analyzed of those muscles which normally fulfill motor functions, but can also engage in stabilizing functions while producing maximal forces [24]. That is why, it was assumed that during maximal static effort of m. rectus abdominis and erector spinae the activity of these muscles should be characterized by symmetry between their right and left hand parts. The statistical analysis indicated a symmetric pattern only in the amplitude of the EMG signal of m. rectus abdominis (RA). A similar characteristic of activity of these muscles (i.e. symmetry of m. rectus abdominis and asymmetry of m. erector spinae) was found when activity was examined under static conditions, but muscles did not have to produce maximal forces [9]. Asymmetry for spinal muscles was also found by Furjan-Mandić et al. [25] when they examined EMG activity of m. erector spinae and trapezius, and detected more pronounced electric activity in the right hand parts of these muscles in the analyzed exercises. By contrast, Axler and McGill [26] found asymmetry in activity of m. rectus abdominis characterized by a predominance of the left hand side.

Conclusions

Higher EMG activity of m. rectus abdominis in the lying position together with the same values of trunk flexors torque output in both measuring positions may suggest that hip joint flexors are more engaged than abdominal muscles in producing maximal torque during measurements performed in the sitting position. That is why, for a reliable assessment of training effects of abdominal muscles, we recommend to carry out the measurement of trunk flexors torque output in the lying position.

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