

Electromyographic Analysis of Four Techniques for Isometric Trunk Muscle Exercises

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• Posture to avoid hyperextension of the lumbar spine during isometric trunk muscle exercises has been widely recommended. However, there are no common standards for cervical and pelvic alignment during exercises. To investigate the effects of four different techniques regarding cervical and pelvic alignment, electromyographic (EMG) and radiological studies were performed on 30 healthy subjects. The four different postures were: (1) maximally extended neck, (2) neutral neck, (3) maximally flexed neck, and (4) maximally flexed neck with pelvic stabilization through muscle contraction. During flexion exercises, the largest increase in EMG activity in the abdominal muscles was observed with the flexed neck with pelvic stabilization ($p < .01$). During extensor exercises, the largest increase in EMG activity in the erector spinae was also obtained in the same position ($p < .01$). An increase of EMG activity in antagonist muscles (eg, erector spinae on flexion, and rectus and oblique muscles on extension) was also greatest with the flexed neck and pelvic stabilization. From the radiographic study, degrees of lumbar lordosis were least with the flexed neck and pelvic stabilization ($p < .01$). This study showed that neck and pelvic alignment can influence the EMG activity of trunk flexors and extensors during isometric trunk exercises. For isometric trunk muscle exercises, a maximum flexed neck with pelvic stabilization through muscle contraction seems to be the most optimal posture for decreasing the lumbar lordosis and for activating trunk flexors and extensors most effectively.

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Chronic low-back pain (CLBP) is a major socioeconomic problem in industrialized societies.¹⁻⁷ Inadequate strength of trunk muscles seems to be related to the development of CLBP.^{1-3,5,6,8,9} Thus, trunk muscle-strengthening exercises are frequently prescribed for many patients with CLBP.^{1,3,4,5,7} Trunk muscles are usually divided into two major groups—trunk flexors (abdominal muscles) and trunk extensors (back muscles). There is controversy over whether it is more important to exercise the flexors, the extensors, or whether it is more effective to exercise both muscle groups.^{1-4,8,9}

Isotonic, isometric, and isokinetic exercises have been advocated for strengthening trunk muscles.⁷ Two of the most popular are isometric flexion exercise for abdominal muscles and hyperextension exercise for back muscles.^{1-4,10} The former, called "sit-up exercise," is the most popular exercise program and is based on Williams' theory that by reducing the lumbar lordosis, low-back pain is decreased.^{1-3,8,10} Hyperextension exercise strengthens the paravertebral back muscles, which act as an internal support for the lumbar spine. To strengthen abdominal muscles, subjects raise the trunk off the floor while lying in the supine position.¹⁻⁴ To exercise

back muscles, subjects raise the sternum off the floor while they are in a prone position.^{3,4}

Many authors suggest avoiding hyperextension of the lumbar spine during both exercises.¹⁻⁴ A hyperextended lumbar spine can produce bulging of the intervertebral disc and buckling of the ligamentum flavum, followed by the narrowing of the intervertebral foramen.^{1,3,4} As a result, low-back pain can occur or be aggravated by hyperextending the lumbar spine.¹⁻³ Therefore, hip and knee joints are flexed in the supine position for abdominal muscle exercises, and a pillow is placed under the lower abdomen in the prone position during back muscle exercises. Postures that foster iliopsoas muscle and hamstrings relaxation and tilt the pelvis posteriorly, result in reduction of the lumbar lordosis.^{1-3,10}

However, there are no recommended standards for cervical alignment while maintaining posterior pelvic tilt during isometric trunk muscle exercises. Abdominal muscles such as the rectus abdominis, external oblique, and internal oblique muscles, originate from the anterolateral part of the pelvis and insert into the anterolateral part of the various ribs.² Similarly, back muscles such as the erector spinae originate from the posterior part of the pelvis and sacrum, and insert into the posterior part of the various ribs.² To obtain the maximum effect of muscle contraction during isometric exercises, the origin and insertion of each muscle should be fixed tightly.^{2,7} This implies that movement of the thoracic cage and pelvis should be fixed during isometric trunk muscle exercises. Many muscles around the cervical spine and skull contribute to fixation of the thoracic cage. These include the longus colli, scalenus, platysma, sternocleidomastoid, longissimus, spinalis, and multifidus muscles.² The contraction of these muscles is significantly related to the cervical alignment. In contrast, the maintenance of the pelvic tilting is produced mainly by contracting the gluteus

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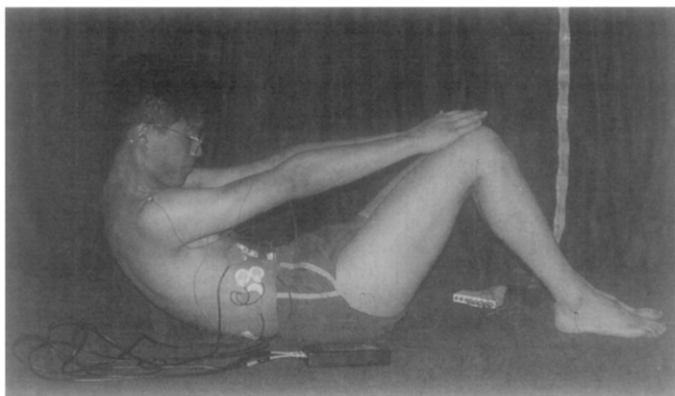


Fig 1—Isometric abdominal muscle exercise and experimental set-up. Subjects were asked to lie in a supine position keeping the trunk in 45° of flexion for 5 seconds with the hip and knee joints flexed. This figure shows the maximum flexed neck position. Five small LED markers placed just behind the ear, at the acromion, hip, knee, and ankle, were connected through the interface (seen below the knees) to a computer. A small black box in front of the subject is a microcomputer for data acquisition.

maximus muscle.^{1,2} In that sense, it is hypothesized that cervical alignment and maintenance of the pelvic tilting might influence the isometric trunk muscle exercises.

The goals of this study were twofold: to investigate the effects of four different techniques of neck and pelvic alignment during isometric trunk muscle strengthening exercises, and to determine which is the optimal exercise posture.

MATERIALS AND METHODS

Thirty male volunteers participated in this study. Criteria for selection included no history of low-back pain and motivation for this project. All subjects were physical therapists and graduate students in a physical therapy department. Ages ranged from 21 to 28 years, with a mean age of 26.4 yrs. Height ranged from 167 to 180 cm ($x = 172$ cm), weight ranged from 58 to 72 kg ($x = 65$ kg). Physical examination showed no pathological findings. Informed consent was obtained from all of the subjects and the procedure for this project was reviewed by an Institutional Review Board.

Isometric Trunk Muscle Exercise Procedures

For isometric flexor exercise, subjects were asked to lie in a supine position while keeping the trunk in 45° of flexion for 5 seconds with the hip and knee joints flexed (fig 1). For extensor exercise, subjects were asked to lie in a prone position while holding the trunk in 15° of extension for 5 seconds (fig 2).

Four different postures were assumed by the subjects: (1) maximally extended neck (neck extension); (2) neutral neck; (3) maximally flexed neck (neck flexion), and (4) maximally flexed neck with pelvic stabilization. Pelvic stabilization can be obtained by asking the subjects to keep a maximum contraction of the gluteal maximus muscles during the exercises.^{1,2}

Isometric abdominal muscle exercise was repeated three times at each posture, followed by isometric back muscle

exercise in the same way. Sufficient rest was allowed for subjects to recover from muscle fatigue between each trial.

Myoelectric Measurements and Evaluations

Electrical activity of abdominal and back muscles was monitored during the isometric exercises. Before attaching electrodes the skin was cleaned with ether. A pair of silver-silver chloride surface electrodes was attached with glue and tape over the right-side erector spinae at the L3 level, 3cm lateral from the midline.¹¹ The size of electrodes was 2.5cm in diameter and each electrode was approximately 3cm apart. A pair of surface electrodes was also attached over the right-side rectus abdominis muscles at the level of the umbilicus, and over the right-side external oblique muscles 3cm above and anterior to the anterior superior iliac spine. Electrical data from each muscle was amplified, and stored digitally on memory cards with 4 channels and 1 MB in an ME 3000P^a (Figs 1, 2). The ME 3000P is a portable microcomputer with dimensions of 7.5 × 16 × 2.8 cm and weight of 0.4kg. This microcomputer makes it possible to store the data as raw and integrated EMG. The data stored in the ME 3000P was transferred through an interface (ME 3001P^a) to a computer^b and analyzed with software (ME 3000P Professional version 1.2^a). The sensitivity of the EMG preamplifier was 1μV, and the sampling rate was 1,000Hz with a frequency band of 20 to 500 Hz. Using the microcomputer, the raw EMG signals were converted to digital signals which were subsequently calculated into absolute values (full wave rectification). The absolute EMG values were integrated every 0.1 second. The average integrated EMG of 0.1 second was calculated with the following formula;

$$\frac{\int_0^{99} \text{raw data}^*}{100^{**}}$$

(*digital data in 0.1 second; **number of data (data points) in 0.1 second)

Mean values of the average integrated EMG over a 5-second interval was calculated for each of the three muscle groups. Based on the mean values of the average integrated EMG at the neutral neck position, changes (%) of EMG activity at the other three postures were calculated and compared for each subject.

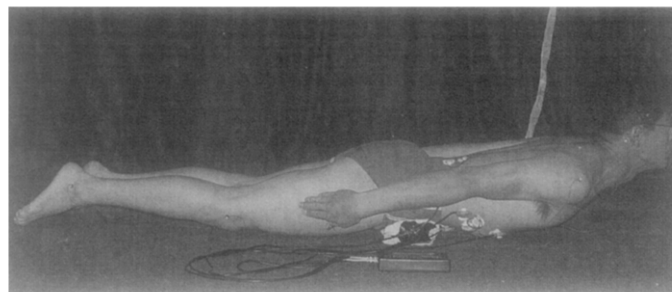


Fig 2—Isometric back muscle exercise and experimental set-up. Subjects were asked to lie in a prone position while holding their trunk in 15° of extension for 5 seconds. This figure shows the maximum extended neck position. Also noted on this figure was the same experimental set-up as figure 1.

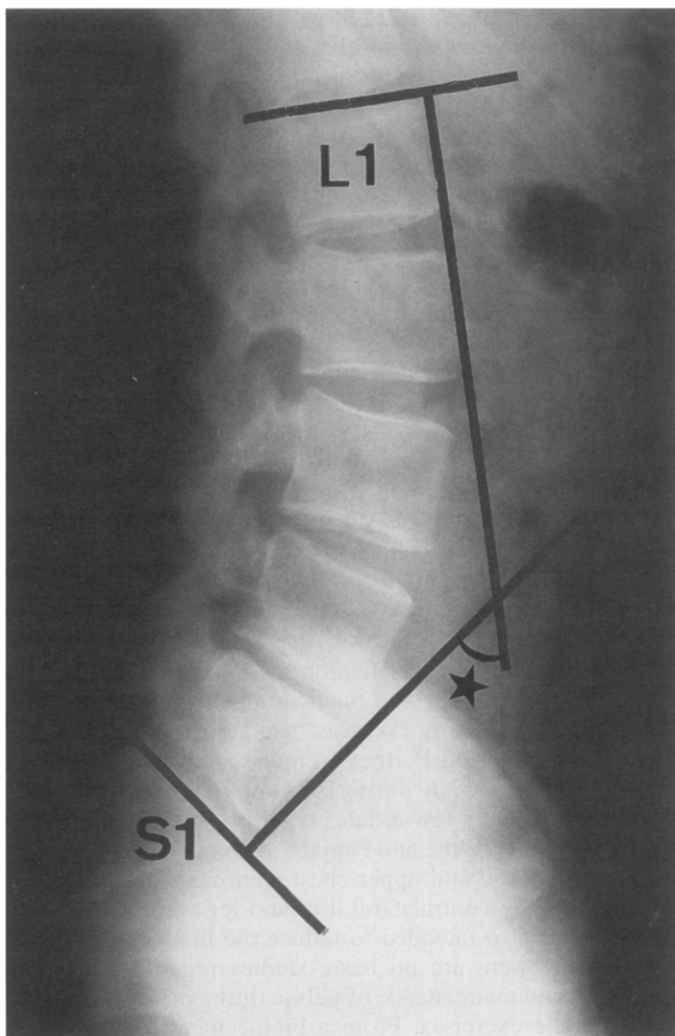


Fig 3—Radiological measurement of lumbar lordosis during isometric abdominal muscle strengthening exercise. Lumbar lordosis is defined as an angle(*) between the end-plates of L1 and S1 vertebrae.

Motion Analysis

During the task, flexion angles of the trunk, hip, and knee, were measured simultaneously in real time by using a three-dimensional motion analyzer; LOCUS III-D.^c In this system, five small infrared LED (Light Emitted Diode) markers were attached to the skin surface of the following areas; just behind the ear, acromion, hip, knee, and ankle (figs 1 and 2). During the performance, the subject's posture was monitored through two video cameras which were placed approximately 4m from the subject and tracked the five LEDs.¹² This special stereo camera system was used to obtain the absolute coordinates of the markers with an accuracy of 0.5%, at a sampling rate of 200Hz. The alignment of the spinal column and pelvis in each subject and performance was confirmed with this system.

Radiographic Analysis

Lateral roentgenograms of the spine were taken on five randomly-selected subjects to assess the degree of lumbar

lordosis associated with each posture during isometric abdominal muscle exercises. The distance between the X-ray tube and the film was kept constant at 2m to minimize errors in radiographic measurements.⁴ The degree of lumbar lordosis was measured as an angle between the upper end-plates of the L1 and S1 vertebrae (fig 3).

Statistical analysis was performed using paired *t*-test.

RESULTS

All 30 subjects completed this study without any problems. There were no significant differences among trials in any subject for any measurements in the reference exercise positions. A total of 360 data-sets was evaluated for this study.

Isometric Trunk-Flexor Strengthening Exercises

Compared with EMG activity in the neutral neck position (fig 4), an increase in the EMG activity of the abdominal muscles was observed with neck extension, neck flexion, and neck flexion with pelvic stabilization ($p < .05$). The largest increase of EMG activity in the abdominal muscles was obtained in the flexed neck position with pelvic stabilization ($p < .01$). There were $21.5 \pm 5.4\%$ and $42.6 \pm 8.5\%$ increases in rectus abdominis and external oblique muscle activity, respectively. The EMG activity of the external oblique muscle was greater than that of the rectus abdominis muscle ($p < .01$). The largest percentage of increase of EMG activity in the erector spinae was also obtained in neck flexion with pelvic stabilization ($p < .05$).

Isometric Trunk-Extensor Strengthening Exercises

The findings during isometric extensor exercise were similar to those obtained during isometric flexor exercises (fig

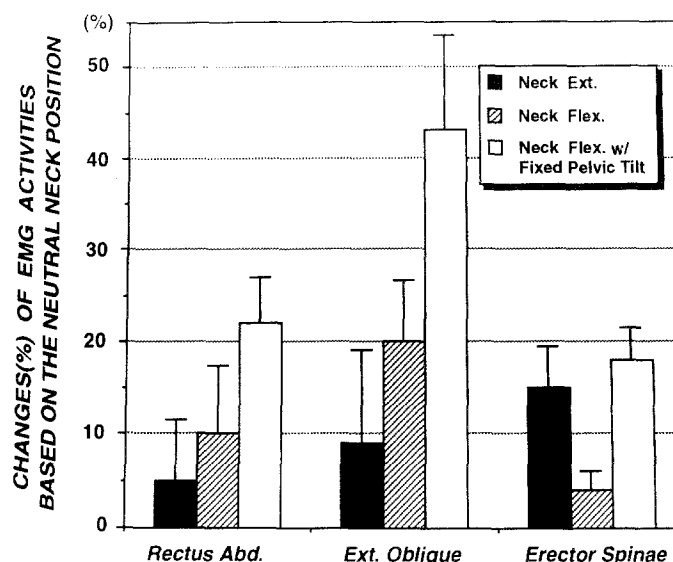


Fig 4—EMG activity at each posture during isometric abdominal muscle exercises. Abbreviations: Neck Ext, maximum neck extension; Neck Flex, maximum neck flexion; Neck Flexion w/ Pelvic Stabilization, maximum neck flexion with pelvic stabilization through muscle contraction. Increase of EMG activity at each posture is shown, based on the EMG activity at the neutral neck position.

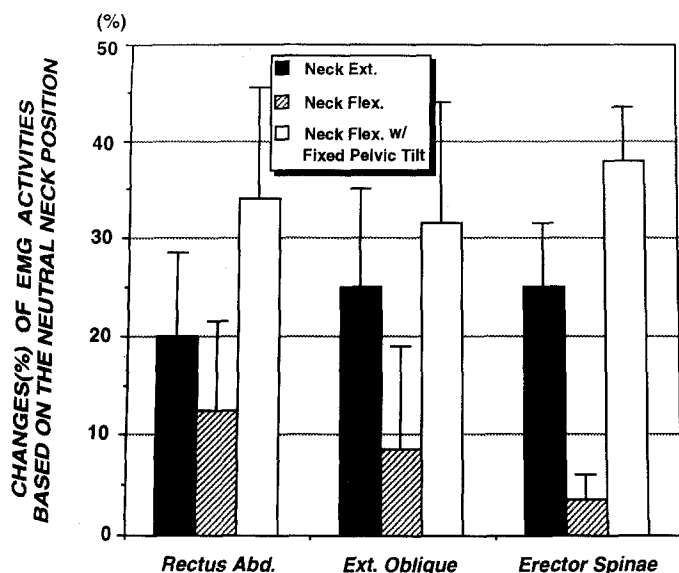


Fig 5—EMG activity at each posture during isometric back muscle exercises. Increase of EMG activity at each posture is shown, based on the EMG activity at the neutral neck position. Abbreviations: Neck Ext, maximum neck extension; Neck Flex, maximum neck flexion; Neck Flexion w/ Pelvic Stabilization, maximum neck flexion with pelvic stabilization through muscle contraction.

5). Compared with EMG activity in the neutral neck position, the increase in the EMG activity of the erector spinae was observed with the other three techniques: neck extension, neck flexion, and neck flexion with pelvic stabilization ($p < .05$). The largest increase of EMG activity ($38.0 \pm 5.5\%$) in the erector spinae was also obtained in the flexed neck position with pelvic stabilization ($p < .01$).

The largest percentage of increase in EMG activity in abdominal muscles was also obtained with neck flexion and pelvic stabilization ($p < .05$).

Lumbar Lordosis During Isometric Trunk Flexors Exercise

Degrees of lumbar lordosis (table 1) were largest in the maximum extended neck position ($21.5 \pm 11.1^\circ$) and were least in the maximum flexed neck one with pelvic stabilization ($-20.4 \pm 10.3^\circ$).

DISCUSSION

The major goal of this study was to find the most effective position in which to exercise to strengthen trunk flexors and extensors. For this project, we chose isometric exercises in the supine and prone positions, because these are the exercises used in most conventional programs for strengthening trunk muscles. From the clinical standpoint, therapeutic exercise, especially of trunk muscles, should include the following criteria: maximum contraction; and safety for anatomical components such as spinal cord, cauda equina, and spinal nerve roots. Isometric exercises have the advantage of being easy to perform for most muscles, requiring little time, set-up, and equipment, and rarely resulting in muscle soreness.⁷ It is also reported that isometric exercises do not improve activities requiring rapid movement and they may

hamper the ability to exert force rapidly.¹³ Other methods for strengthening trunk muscles are isotonic and isokinetic exercises. Isotonic exercises also have the advantage of being easy to perform, although a theoretical disadvantage of this program is that all the motor units are recruited only with the 100% effort.⁷ Isokinetic exercises have forces exerted against an object at a constant velocity. Currently, a variety of isokinetic dynamometers are commercially available to increase trunk-muscle strength.¹⁴ These machines strengthen trunk muscles, however, one of the major disadvantages is the cost of the equipment.^{7,14}

A number of articles have been published regarding the appropriate posture during isometric abdominal muscle exercises.^{1,2,8,10} Williams first developed his exercise program in 1937 for patients with CLBP.¹ In his article, he noted that the posterior pelvic tilt position reduced lumbar lordosis and was essential for optimum results. Thus, he recommended the supine position with hips and knees flexed. Using EMG, Halpern and Beck investigated five different types of "sit-up" exercise to strengthen abdominal muscles.⁸ They noted that the greatest amount of abdominal muscle activity was obtained by doing a sit-up with the knees and hips flexed. They also found that full flexion of the lumbar spine was not necessary to strengthen the abdominal muscles. In their study on the Williams exercises using surface EMG electrode, Blackburn and Portney¹⁶ emphasized the importance of posterior pelvic tilt during abdominal muscle exercise. There are relatively few articles regarding postures for back muscle exercise. White and Panjabi⁴ recommended a posture in which the head and upper chest were raised in the prone position and the contralateral arm and leg were lifted. This position was also intended to reduce the lumbar lordosis.

However, there are no basic studies regarding cervical alignment and maintenance of pelvic tilting during isometric trunk muscle exercises. From a biomechanical standpoint, the spinal column can be regarded as part of a "biomechanical chain," by which loads are transmitted from hands or skull through entire spines to a stable foot and floor contact.⁵ In this sense, the flexion-extension movement of the trunk and the ability for trunk muscles to contribute to the generation of torque is related to the interaction of skull, thoracic cage, and pelvis which are connected to each other by the vertebral column and muscles. Therefore, we hypothesized that cervical alignment and maintenance of the pelvic tilting might influence isometric trunk muscle strengthening exercises. As a result, four different techniques were selected for investigation; maximum flexed neck, neutral neck, maximum extended neck, and maximum flexed neck with pelvic stabilization. Before initiating this project, it was decided that the maximum extended neck would be an inappropriate position, especially for aged patients who may have spondylosis changes of the cervical spine. This posture could lead

Table 1: Lumbar Lordosis (degrees) at Each Posture During Isometric Abdominal Muscle Exercise (n = 5)

Neutral neck	-8.2 ± 5.5
Extended neck	21.5 ± 11.1
Flexed neck	-12.7 ± 8.2
Flexed neck with pelvic stabilization	$-20.4 \pm 10.3^*$

* $p < .01$

to a narrowing of neural foramina, accompanied by bulging discs and buckling of the ligamentum flavum.¹⁵ We believe that such a posture should be avoided even for the short time period involved in trunk muscle exercises. Therefore, only the maximum extended neck without pelvic stabilization was chosen in this project.

This study noted that the neck and pelvic alignment can influence the electromyographic (EMG) activity of trunk flexors and extensors during isometric trunk muscle exercises. During isometric flexor exercises, maximum EMG activity in abdominal muscles, such as the rectus abdominis and external oblique muscles, were obtained in the posture with maximum cervical flexion and pelvic stabilization. Similarly, during isometric extensor exercises, maximum EMG activity in back muscles, such as the erector spinae, was observed in the same posture. The mechanism of this phenomenon can be explained as follows: first, the thoracic cage is fixed firmly when the cervical spine is maximally flexed. Contraction of cervical flexor muscles inserting into thoracic cage provides the fixation of the thoracic cage.² Second, contraction of the gluteus maximus muscles keeps the pelvis tilting posteriorly.^{1,2} Thus, maximum cervical flexion with pelvic stabilization could provide the best circumstance for trunk muscles to produce maximum EMG activity. More interestingly, the increase of EMG activity in antagonist muscles (eg, erector spinae on flexion versus rectus and oblique muscles on extension) was greatest in the maximum flexed neck with pelvic stabilization. This posture showed the maximum EMG activity of antagonist muscles, caused by simultaneous cocontraction, during both flexor and extensor exercises.

The radiological study showed that maximum cervical flexion with pelvic stabilization provided the least lumbar lordosis during isometric abdominal muscle exercise. The literature supports the recommendation that hyperextended posture should be avoided for patients with CLBP.^{1-3,8} Nachemson, however, showed in his *in vivo* study that intradiscal pressure at the L3 disc was higher in sit-up exercise than in standing posture.¹⁶ We believe, based on the Williams' study,¹ that it is more important for patients with CLBP to reduce the lumbar lordosis as much as possible while doing isometric trunk muscle exercises. White and Panjabi⁴ stated that sit-up exercise should be avoided for patients with acute or subacute low-back pain.

Therapeutic exercise for patients with CLBP should also include other modalities such as ROM, stretching, endurance, and work simulation exercises.^{5,7} Isometric trunk muscle exercise, however, remains one of the most effective treatment methods for patients with CLBP. Strengthening the gluteal maximus muscles is also advantageous in supporting the trunk.^{1,2}

In conclusion, the maximum flexed neck position with pelvic stabilization was seen to be the optimum posture not

only for strengthening trunk flexors and extensors most effectively, but also for decreasing the lumbar lordosis. During abdominal muscle exercise, increase of EMG activity was greater in the external oblique muscle than in the rectus abdominis muscle. Further investigation is needed to clarify the importance of the external oblique muscles for lumbar spine movement.

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