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Abdominal Strengthening Exercises: A Comparative EMG Study

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The purpose of this study was to compare electromyographic (EMG) activity of the abdominal muscles between the crunch exercise and five other popular abdominal exercises. Surface EMG recordings of four muscles (upper rectus, lower rectus, external oblique, and internal oblique) of the anterior abdominal wall were collected and analyzed on 20 healthy, male volunteers. EMG activity was recorded during execution of the abdominal crunch, the sit-up, and exercises performed with the Abflex machine, the AbRoller, the Nordic Track Ab Works, and the Nautilus crunch machine. The results indicate that the crunch exercise is comparable to the five other abdominal exercises with respect to muscle activation of the internal and external abdominal oblique muscles. Activation of the upper rectus abdominal muscles appears to be best achieved with the Abflex machine, whereas the crunch exercise is superior to the sit-up for activation of the upper and lower rectus abdominal muscles.

The average athlete often trains the abdominal muscles inadequately as compared to other muscle groups. Although adequate muscle tone in the abdominal region is important, abdominal exercises can be harmful to the spine if performed incorrectly (23). Chronic low back pain is a major health care problem in industrialized societies, and inadequate strength of trunk muscles appears to be related to the development of chronic low back pain. Several authors have described the important role of strong abdominal muscles in both postural control and prevention of low back injury (7, 9, 11, 14, 18, 23, 24). A wealth of evidence points to the need for adequate levels of muscular strength in the treatment and prevention of low back pain, with several sources advocating the use of abdominal exercises

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(11–13, 27). Patients with chronic low back pain demonstrate decreased levels of strength for trunk flexion when compared to normal subjects (7). Medical evidence suggests that more than 80% of all low back pain cases are caused by weak trunk muscles (20). Many studies have supported the use of endurance exercises that incorporate the abdominal muscles to prevent low back pain (7). Several authors have found that sedentary individuals possess trunk muscle imbalances that favor strength of the postural-antagonist muscles, such as the iliopsoas, as compared with weakness of the more phasically acting abdominal muscles. In addition, the iliopsoas muscle, with its extensive lumbar attachment, contributes potentially hazardous compressive and lordotic forces on the lumbar spine and intervertebral disks, if not balanced by the stabilization forces of the abdominal muscles (20).

The curled trunk sit-up with the hips and knees flexed has been a popular abdominal exercise. Nachemson demonstrated, in vivo, that intradiscal pressure at L3 was higher in sit-up exercises than standing posture (21). White and Panjabi stated that the sit-up exercise should be avoided for patients with acute or subacute low back pain (28). Norris (23) suggested that subjects in poor physical condition may not achieve adequate pelvic fixation during the sit-up as a result of abdominal muscle weakness. Due to concern about the safety of executing a sit-up, the abdominal crunch came into favor (7, 9, 11, 12, 23, 25, 26). Currently, numerous equipment manufacturers are marketing improved, sophisticated abdominal machines. Therefore, the purpose of this study was to compare activation of the abdominal muscles between the abdominal crunch exercise and five other popular abdominal exercises.

Methods

Twenty athletically active males with a mean age of 21 years (range 18–23 years) with no previous history of abdominal trauma volunteered to participate in this study. Subjects were examined visually to determine suitability for this study. A single investigator evaluated each volunteer's abdominal musculature to determine if sufficient definition existed to allow electrode placement. This method facilitated accurate electrode placement. Each subject provided written informed consent as approved through the Biomedical Institutional Review Board at the University of Pittsburgh.

Procedures

Subjects lay in a supine position and were instructed to perform an isometric contraction of their abdominal muscles. Landmarks were easily identifiable on these lean subjects and were labeled with a marking pen. Surface electrode (Ag–Ag/Cl) placement was carried out as described by Floyd and Silver (6) (Figure 1). Electrode placement for the upper rectus abdominis muscle was measured as 25% of

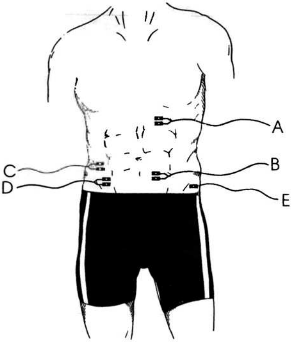

Figure 1 — Surface electrode placement on the anterior abdominal wall musculature: (a) upper rectus abdominis, (b) lower rectus abdominis, (c) external oblique, (d) internal oblique, (e) reference electrode at the anterior superior iliac spine.

the proximal distance between the xyphoid process and the pubic symphysis, halfway between the lateral border of the rectus abdominis and the linea alba. Electrode placement for the lower rectus abdominis was 25% of the distal distance between the xyphoid process and the pubic symphysis, halfway between the lateral border of the rectus abdominis and the linea alba. Electrodes were placed over the external abdominal oblique muscles as measured by two finger-widths above the anterior half of the iliac crest. Electrode placement for the internal abdominal oblique muscles was the center of the triangle bounded by the inguinal ligament, the lateral edge of the rectus sheath, and the line joining the anterior superior iliac spine to the umbilicus.

Once the appropriate locations for the different muscle groups were identified, conduction resistance was reduced by shaving, abrading, and cleaning the skin surface with isopropyl alcohol. To ensure minimal impedance, a value of <2.0 kΩ was accepted as the criterion. Excessive movement of the electrode cables was minimized by securing them with tape, underwrap, and an elastic wrap. Electromyographic (EMG) activity was assessed with the Noraxon Telemyo system (Noraxon

USA, Scottsdale, AZ). EMG signals were sampled at a rate of 1000 Hz and recorded by an FM transmitter and amplifier worn by the subject in a beltpack. Recorded signals were broadcast to an FM receiver that was interfaced to an IBM microprocessor. The recorded signals underwent analog to digital (A/D) conversion by a 16-bit A/D board. Raw EMG signals were then integrated over the duration of the contraction for each exercise.

Exercise Performance

The exercises in this study included a standard abdominal crunch, a sit-up, and four other exercises utilizing four commercially available exercise devices: the Abflex machine, the AbRoller, the Nordic Track Ab Works, and the Nautilus crunch machine.

Abdominal Crunch. The subject performed the standard abdominal crunch in a supine position with the hips and knees flexed, the feet planted unsupported on the floor, and the hands held behind the head. The subjects were then instructed to curl the thorax by contracting the abdominal muscles in an isometric fashion until the scapulae were just off the floor. This contraction was maintained for 3 s.

Sit-Up. The sit-up was performed with the subject in a supine position with the hips and knees flexed and feet planted supported on the floor. The subject's hands were placed behind the head, and the subject was instructed to flex the abdominal muscles in a concentric fashion until the trunk contacted the thighs. Subjects were instructed to maintain this position for 3 s.

Nautilus Crunch Machine. The subject sat in the device with his hands placed on the handles on either side of his head. Abdominal flexion was performed in an isotonic concentric fashion by bringing the chest toward the knees; a resistance of 100 lb was placed on the weight stack attached to the upper portion of the machine. Subjects were instructed to flex forward and to maintain this position for 3 s.

Nordic Track Ab Works. The subject lay supine with both hips and knees supported by the device at 90° of flexion. The hands were placed on the handles on either side of the head, and the subject moved his chest toward his knees, maintaining this position for 3 s.

Abflex Machine. For this exercise, the subject was in the same position as for the standard abdominal crunch. Subjects were instructed to grasp the handles of the device with the forearms supinated. Both the hips and knees were flexed 90° with the feet elevated. The subjects were then instructed to pull the handles toward the umbilicus, where the abdominal pad of the device is placed, and to maintain this contraction for 3 s.

AbRoller. The subject lay supine with hips and knees flexed and feet planted unsupported on floor. The head was placed in a support and the elbows were placed on rests with the shoulders in slight flexion and neutral rotation. The hands were placed gently on a bar with the elbows flexed to 90°. Subjects were instructed to roll into a crunch position by contracting their abdominal muscles for 3 s.

Care was taken to eliminate fatigue by offering sufficient rest between the exercises. The duration of the rest period was dictated by each subject's feeling of volitional recovery following the preceding bout. The exercises were randomized for order of execution, and all data collection was conducted without any changes in the position of the electrodes.

Data Analysis

In each exercise, the first 2 s of integrated EMG (IEMG) activity of each contraction was analyzed and the mean areas of the three contractions were obtained. This value was used for statistical analysis. Multiple paired t tests were calculated between the crunch exercise and the five other abdominal exercises for each individual muscle. An alpha level of $p < .05$ was set.

Results

For the upper rectus, the results demonstrated that abdominal exercise with the Abflex resulted in significantly greater muscle activation as compared to the crunch exercise ($t_{19} = 2.93$, $p = .009$) (Figure 2). Muscle activation of the upper rectus

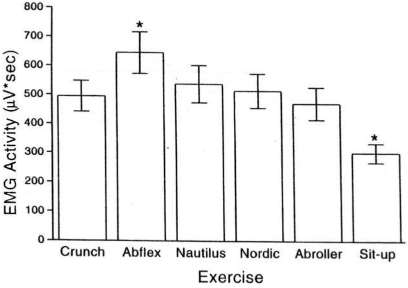

Figure 2 — EMG activity of the upper rectus abdominal muscles during the crunch exercise, Abflex, AbRoller, Nordic Track Ab Works, Nautilus exercises, and sit-up (*significantly different than the crunch exercise).

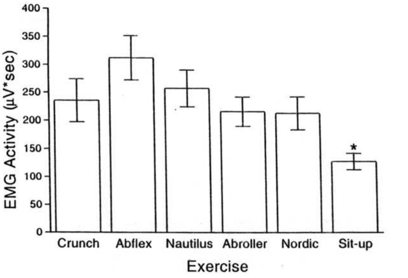

Figure 3 — EMG activity of the lower rectus abdominal muscles during the crunch exercise, Abflex, AbRoller, Nordic Track Ab Works, Nautilus exercises, and sit-up (*significantly different than the crunch exercise).

while performing the crunch exercise, however, was significantly greater than for the sit-up exercise ($t_{19} = 5.79$, $p < .001$). There were no differences in muscle activation between the crunch exercise and exercises performed with the AbRoller, Nordic Track Ab Works, or Nautilus machines.

For the lower rectus, muscle activation was significantly greater during the crunch exercise as compared to the sit-up ($t_{19} = 3.64$, $p = .002$) (Figure 3). The crunch exercise was not statistically different from the other exercises.

For the external and internal oblique muscles, muscle activation during the crunch exercise was not statistically different from the sit-up or the exercises performed with the Abflex, AbRoller, Nordic Track Ab Works, and Nautilus machines (Figures 4 and 5).

Discussion

The major finding of the present study was that the crunch exercise was comparable to most of the other exercises with respect to muscle activation. However, exercise performed with the Abflex appeared superior to the crunch exercise with respect to muscle activation of the upper rectus abdominal muscle. Furthermore, it was found that the crunch exercise was more effective than the sit-up with respect to muscle activation of the upper and lower rectus abdominal muscles.

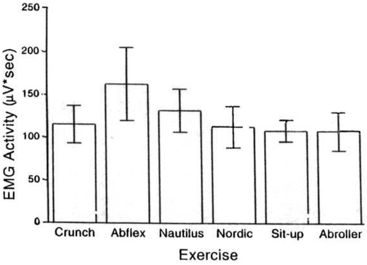

Figure 4 — EMG activity of the external abdominal oblique muscles during the crunch exercise, Abflex, AbRoller, Nordic Track Ab Works, Nautilus exercises, and sit-up (*significantly different than the crunch exercise).

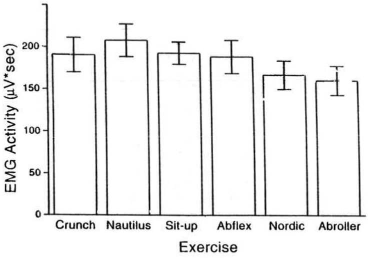

Figure 5 — EMG activity of the internal abdominal oblique muscles during the crunch exercise, Abflex, AbRoller, Nordic Track Ab Works, Nautilus exercises, and sit-up (*significantly different than the crunch exercise).

Johannsen et al. (14) found that back extension training alone is not the best training model for patients with chronic low back pain. Isometric abdominal exercises and stretching exercises have also been found to improve low back pain (2–4, 16, 17). A hyperextended lumbar spine can produce bulging of the intervertebral disc and buckling of the ligamentum flavum, followed by narrowing of the intervertebral foramen. As a result, low back pain can occur or can be aggravated by hyperextending the lumbar spine (26). Several authors have found that postures which relax the iliopsoas and hamstring muscles, which in turn tilts the pelvis posteriorly, reduce lumbar lordosis (1, 9, 15, 29). Shirado et al. (26) found an increase in EMG activity of the abdominal muscles with neck flexion in conjunction with pelvic stabilization. They also found that the degree of lumbar lordosis was least in the maximum flexed neck with pelvic stabilization during an abdominal crunch exercise.

Those are the facts which demonstrate that lumbar spinal flexion is dangerous in people with discal pathology. During lumbar spine flexion, the intervertebral disc is compressed anteriorly, which stretches the posterior annular fibers and thereby places them under tension. The discal nucleus is thought to move posteriorly with flexion (23). Nachemson (22) found that the intradiscal pressure within the lumbar spine varies tremendously with general alterations in posture, and variation is equally marked between the various sit-up techniques. If the pressure at the L3 disc for a 70-kg standing individual is 100%, supine lying reduces this pressure to 25%. The pressure variations increase dramatically as soon as the lumbar spine is flexed, with the sitting posture increasing intradiscal pressure to 140%.

To support this contention, Halpern and Bleck (10) used X-ray analysis during their study on four sit-up variations and a standard abdominal crunch exercise. They found that the L1–L5 resting angle of 44° decreased to between 6 and 15° in the various sit-up exercises and only decreased to 41° during the abdominal crunch exercise. This 3° change in flexion angle was found to be insignificant. As Nachemson (22) demonstrated, maximum flexion of the lumbar spine causes an extraordinary increase in the intradiscal pressure at the L3 level. This may contribute to degenerative changes of the lumbar disk.

Flint (5) found that abdominal muscles are responsible for the initial 45° of flexion; movement beyond 45° and the return to 45° rely on the hip flexors. Movement of the trunk upward from 45° to the perpendicular and back down to 45° requires limited abdominal function. The movement is performed primarily by the hip flexors. Flint also found that concentric contraction elicits greater action potential from the rectus abdominis muscles than eccentric contraction. Godfrey et al. (8) also substantiated the superior abdominal isolation of the crunch portion of a sit-up.

The trunk curl sit-up with the hips and knees flexed requires the highest lumbar spine flexion when performed correctly. Conversely, the standard abdominal crunch as previously described by several authors (10, 25, 26) does not cause flexion of the lumbar spine and has been found to be a superior isometric exercise to strengthen the rectus abdominis. However, upper rectus EMG activity was found to be significantly greater when subjects used the Abflex device than when they performed the standard abdominal crunch. This finding may be due to the fact that abdominal exercise with the Abflex is performed as a regular crunch in addition to external resistance. Since this device utilizes the same anatomic action as the abdominal crunch, it may be considered superior to the other devices in regard to the safety of the exercise.

Activation of the abdominal muscles appears to be comparable between the crunch exercise and the other exercises studied in the present investigation. Strength enhancement of the abdominal muscles depends upon their activation during various exercise maneuvers. The only condition in which muscle activation exceeded that of the crunch exercise was for the upper rectus abdominal muscle using the Abflex machine. The crunch exercise was shown to be superior to the sit-up exercise for muscle activation. Future research should attempt to delineate the role of muscle activation in enhancing abdominal strength over the course of a training period. Furthermore, the contribution of hip flexor muscle activation during execution of these various exercises may prove to be a confounding factor in the development of abdominal muscle strength and correction of muscular imbalances.

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