Literature Review

Electromyographic Studies in Abdominal Exercises: A Literature Synthesis

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Abstract

Objective: The purpose of this article is to synthesize the literature on studies that investigate electromyographic activity of abdominal muscles during abdominal exercises performance.

Methods: MEDLINE and Sportdiscus databases were searched, as well as the Web pages of electronic journals access, ScienceDirect, and Swetswise, from 1950 to 2008. The terms used to search the literature were *abdominal muscle* and the specific names for the abdominal muscles and their combination with *electromyography*, and/or *strengthening*, and/or *exercise*, and/or *spine stability*, and/or *low back pain*. The related topics included the influence of the different exercises, modification of exercise positions, involvement of different joints, the position with supported or unsupported segments, plane variation to modify loads, and the use of equipment. Studies related to abdominal conditioning exercises and core stabilization were also reviewed.

Results: Eighty-seven studies were identified as relevant for this literature synthesis. Overall, the studies retrieved lacked consistency, which made it impossible to extract aggregate estimates and did not allow for a rigorous meta-analysis. The most important factors for the selection of abdominal strengthening exercises are (*a*) spine flexion and rotation without hip flexion, (*b*) arm support, (*c*) lower body segments involvement controlling the correct performance, (*d*) inclined planes or additional loads to increase the contraction intensity significantly, and (*e*) when the goal is to challenge spine stability, exercises such as abdominal bracing or abdominal hollowing are preferable depending on the participants' objectives and characteristics. Pertaining to safety criteria, the most important factors are (*a*) avoid active hip flexion and fixed feet, (*b*) do not pull with the hands behind the head, and (*c*) a position of knees and hips flexion during upper body exercises.

Conclusions: Further replicable studies are needed to address and clarify the methodological doubts expressed in this article and to provide more consistent and reliable results that might help us build a body of knowledge on this topic. Future electromyographic studies should consider addressing the limitations described in this review. (J Manipulative Physiol Ther 2009;32:232-244)

Key Indexing Terms: *Electromyography; Abdominal Muscles; Spine; Hip Joint*

Abdominal strengthening exercises are widely used for training both in athletic programs (competitive sports and fitness) and rehabilitation. The importance of the abdominal musculature in trunk movement and spine stability, as well as its role in the prevention and treatment of low back pain, has promoted the development of a variety of studies from the 1950s to present. Surface electromyographic (EMG) has been the most widely used instrument for the study of muscle activation during the exercises. The object of study of the different articles has varied considerably. Primarily, the intensity of muscle contraction and the loads on the spine in different movements and postures have been investigated.[1,2] The performance factors analyzed are the following[3]: spine and hip flexion, spine flexion, trunk rotation, position with supported segments, arm and hand position, knee and hip position,

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Table 1. *Methodological diversity across 13 recent abdominal EMG studies in healthy subjects*

Author	Subjects	EMG recording	EMG processing	Control of tests performance
Andersson (1997)	6 men, age 22-29, physical activity level described only as "habitually active"	Surface, left side, RA + OE with no description of electrode placement	No MVC; % of the highest EMG of each muscle during the exercises	Not described in the text
Drysdale (2004)	26 women, age 19.9 ± 1.9, physical activity level described as "all subjects participated in recreational or intercollegiate athletic activity," with no mention of the kind of activity or its frequency	Surface, bilateral, RA (at the level of the umbilicus) + OE (above the ASIS, halfway between the iliac crest and the ribs at a slightly oblique angle); no distances from any reference points; "because of a hardware error, 11 subjects did not have usable recordings from their right RA, and 1 subject did not have usable recordings from the right and left OE"	MVC: RA (with subjects in crook lying, arms placed across the chest) sit-up against resistance; OE (with subjects on their side, knees bent, thighs secured to a table, trunk rotated so shoulders were facing upward, arms across the chest) shoulder rotation to the opposite side against resistance	Tasks rehearsed previously, performance supervised by one of the authors
Hildenbrand (2004)	23 (10 men, age 23.4 ± 3.9; 13 women, age 20.8 ± 2.6), physical activity level described only as "moderately active"	Surface, right side, upper and lower RA (upper, second or inferior to the ribs and lower, lowest segment of the 4 segments of the RA) + OE ("over the center of that muscle in a diagonal direction, coinciding with the muscle fibers"); no further specifications about electrode placement	No MVC; no normalization; mean integrated EMG (area under the curve)	Previous orientation meeting, tasks rehearsed previously, supervision of the performance not described in the text
Juker (1998)	8 (5 men, age 25.8 ± 1.3; 3 women, age 23.3 ± 2.3), no description of physical activity level	Left side, intramuscular (OE, OI, TA midway between the linea semilunaris and the midline laterally and at the transverse level of the umbilicus) and surface (RA: 3 cm lateral to the umbilicus, OE: 15 cm lateral to the umbilicus, OI: below the external oblique electrodes and just superior to the inguinal ligament)	MVC: with the same maneuver for all abdominal muscles, sit-up against resistance trying to exert "simultaneous slow isometric twisting efforts"; some MVC values for abdominal muscles were obtained during other muscles maximal exertions, such as the psoas routines	Previous pilot work, tasks rehearsed previously, feedback in the form of EMG displayed in real time on the computer monitor, supervision of the performance not described in the text
Konrad (2001)	10 (7 men, 3 women), age 27.8 ± 2.4, physical activity level described as "none (of the subjects) were specifically training at that time"	Surface, right side, RA (3 cm lateral to the umbilicus) + OE (at the level of the umbilicus, approximately 15 cm apart, 3 cm above the iliac crest)	MVC: 5 different tasks against resistance for both abdominal muscles, variations of sit-up and rotation/twisting maneuvers	Not described in the text
Lehman (2001)	11, no information about sex or age. 8 varsity athletes in basketball and volleyball, the remaining 3 performed abdominal muscle training exercises more than 3 times/wk	Surface, right side, upper and lower RA (upper, 3 cm lateral to midline on the second to topmost RA segment, and lower, 3 cm lateral and 2 cm inferior to the umbilicus) + OE (15 cm lateral to the umbilicus, 45° to the midline)	MVC: RA, sit-up against resistance; OE, sit-up twisting to the left against resistance	Not described in the text
Sarti (1996)	33 (20 men, age 21.4; 13 women, age 22.5). The level of physical activity was assessed by a questionnaire, and the subjects were split in low and high activity groups	Surface, bilateral, upper and lower RA (3 cm lateral to midline, RA segments localized by echography, upper on the geometric midpoint of the first and second segments, lower on the midpoint of the third and fourth segments)	No MVC; no normalization; mean integrated EMG (area under the curve)	Performance supervised by 2 experienced observers, both during EMG data collection and afterwards with the recorded video; subjects subdivided into correct or incorrect performers

(*continued on next page*)

Table 1. (*continued*)

Author	Subjects	EMG recording	EMG processing	Control of tests performance
Shirado (1995)	30 men, age 21-28, no description of physical activity level	Surface, right side, RA ("at the level of the umbilicus") + OE (3 cm above and anterior to the ASIS); no further specifications about electrode placement	No MVC; % of the EMG of each muscle at the neutral neck position	Performance supervised through 2 video cameras
Sternlicht (2003)	33 (20 male, 13 female), age 27.3 ± 10.7, no description of physical activity level	Surface, right side, upper and lower RA + OE with no description of electrode placement	No MVC; no normalization; "mean EMG," with no further specifications about EMG processing	Previous explanation of the experimental protocol, with tasks rehearsed previously, supervision of the performance not described in the text
Vera-García (2000)	8 men, age 23.3 ± 4.3, "their history of abdominal muscle exercising was neither investigated or controlled"	Surface, bilateral, upper and lower RA (3 cm lateral and 5 cm superior and inferior to the umbilicus) + OE (15 cm lateral to the umbilicus) + OI (halfway between ASIS and midline, above inguinal ligament)	MVC: RA, isometric sit-up against resistance; OE, same maneuver, but subjects also attempted isometric twisting efforts	Correct positioning supervised through slide film recording
Warden (1999)	22 (10 men, 12 women), age 19.8 ± 1.5, no description of physical activity level	Surface, right side, upper and lower RA (10 cm above and 3 cm below the umbilicus, 3 cm from the midline) + OE (in the coronal plane, middistance between the iliac crest and the costal margin)	No MVC; EMG during the exercise with abdominal equipment was expressed as % of the EMG during the conventional exercises	Previous explanation of the experimental protocol, with tasks rehearsed previously; exercises were video recorded
Whiting (1999)	19 (9 male, age 23.4 ± 6.7; 10 female, age 21.0 ± 2.5), no description of physical activity level	Surface, right side, upper and lower RA + OE with no description of electrode placement	No MVC; no normalization; "mean EMG," with no further specifications about EMG processing	Previous explanation of the experimental protocol, with tasks rehearsed previously, supervision of the performance not described in the text
Willett (2001)	25 (10 men, 15 women), age 26.7 ± 5.8, no description of physical activity level	Surface, right side, upper and lower RA (halfway between the umbilicus, xiphoid process and pubic symphysis, 3 cm to the right of midline) + OE (halfway between the ASIS and the lowest rib, 45° to the midline superolaterally to inferomedially)	MVC: 5 different maximum-effort, isometric tasks for both abdominal muscles, variations of sit-up and rotation/twisting maneuvers	Previous explanation of the experimental protocol, with tasks rehearsed previously, supervision of the performance not described in the text

RA indicates rectus abdominis muscle; OE, obliquus externus abdominis muscle; OI, obliquus internus abdominis muscle; TA, transversus abdominis muscle; ASIS, anterior superior iliac spine.

movement of the upper and/or lower body segments, use of equipment, and spine stabilization effect. The contributions made by EMG and mechanical studies are important for the design and prescription of safe and effective exercises for abdominal strengthening. The purpose of this review is to show the actual state of affairs.

Methods

We searched MEDLINE and Sportdiscus databases as well as the Web pages of electronic journals accessed, ScienceDirect and Swetswise, from 1950 to 2008. The terms used to search in specific literature were *abdominal muscle* and the specific names for the abdominal muscles, *rectus abdominis*, *transversus abdominis*, *internal oblique*, or *obliquus internus abdominis* and *external oblique* or *obliquus externus abdominis*, and their combination with *electromyography*, and/or *strengthening*, and/or *exercise*, and/or *spine stability*, and/or *low back pain*.

Studies that applied electromyography techniques to the abdominal muscles during strengthening or stabilization exercises were included and reviewed for content. Those studies with patients undergoing abdominal surgery were

Table 2. *Anatomic terminology vs traditional terminology*[21-87]

Anatomic terminology	Used terminology
Spine and hip flexion with stretched knees and hips	• Conventional long lying sit-up • Long lying sit • Sit
Spine and hip flexion with bent knees and hips	• Conventional hook lying sit-up • Hook lying sit • Sit
Spine flexion with stretched knees and hips	• Long lying trunk curl-up • Curl-up • Crunch
Spine flexion with bent knees and hips	• Hook lying curl-up • Partial curl-up • Bench trunk curl • Curl-up • Crunch
Spine and hip flexion with trunk rotation	• Crossed long lying sit-up
Spine flexion with trunk rotation	• Crossed trunk curl-up
Spine and hip flexion with flexed knees on inclined board	• Inclined Sit-up
Spine and hip flexion lifting stretched or bent legs	• V sit
Posterior pelvic tilt with spine and hip flexion (legs stretched or bent)	• Posterior pelvic tilt (crook lying or long lying position) • Posterior pelvic tilt • Reverse curl-up
Posterior pelvic tilt and rotation with spine and hip flexion	• Crook lying pelvic rotation • Hip roll
Posterior pelvic tilt and spine flexion with bended knees and hips hanging from a chin-up bar	• Basquet Hang
Quadruped exercise in a 2-point stance, with a contralateral arm and leg raise	• Bird dog
Hollowing the lower abdomen by drawing the navel up and in toward the spine and maintaining the lumbar spine in a neutral position	• Abdominal hollowing
Contracting the entire abdominal wall without any change in the position of the muscles and maintaining the lumbar spine in a neutral position	• Abdominal bracing
Isometric side support exercises	• Side bridges

excluded from this review, as well as studies about training methods, because this is a different and specific topic in the literature.

Results

Eighty-seven studies were identified as relevant for this literature synthesis. There was considerable difficulty in the pooling of the results recovered from the studies we analyzed. Some of the studies dealt with subjects with low back pain with different sampling population and different exercises. In the studies focused on healthy subjects, there were several technical issues exemplified in Table 1: (1) samples with a nonsignificant number of subjects, less than 10 in several studies[4-6]; (2) insufficient or no description of the physical activity level of the subjects is a generalized flaw of these kind of studies, with just a few exceptions using questionnaires to split the sample into groups of low and high physical activity level,[7] and there were samples with no description of sex or age[8]; (3) lack of explanation of EMG recording techniques, with insufficient or no description of electrode placement landmarks[4,9-11]; (4) deficient techniques for EMG signal processing.

Normalization of the surface EMG signals to maximum voluntary contraction (MVC) amplitudes is the recommended normalization method to facilitate physiologic interpretation and for comparison between different subjects, different muscles, different electrodes sites on the same muscle, and different days.[12,13] The MVC maneuvers require preliminary training and must be carefully described in EMG studies, which was not done in most of the studies about abdominal EMG. Even more, several studies did not perform any normalization of the EMG signal,[7,9-11,14,15] whereas others used unorthodox normalization methods, such as expressing EMG as a percentage of the EMG amplitude at a neutral neck position[15] or using the maximum EMG amplitude value of each muscle during the experimental tasks as a MVC EMG, with no specific MVC maneuvers[4]; no description of either previous rehearsals of the tasks performed[4,6-8,15,16] or control strategies for the correct exercise performance during the studies.[4,5,8,9,11,12,17]

The most concerning problem was the methodological diversity across studies, including various authors using different names for to the same exercises.[3,4] Some researchers made efforts to standardize the surface EMG recording and signal processing techniques.[18,19] The many inconsistencies in the literature made it impossible for us to extract aggregate estimates and did not allow for a rigorous meta-analysis.[20] We therefore chose to provide a synthesis of the information. To avoid confusing factors such as names, in this review, we use an anatomic terminology that refers to the action performed and the joint/s involved in the main movement under study (Table 2).

Discussion

Spine and Hip Flexion Vs Spine Flexion

In the past, the most widely used abdominal exercises were spine and hip flexion in supine decubitus position, with

Fig 1. *Spine and hip flexion with stretched knees and hips.*

Fig 2. *Spine and hip flexion with bended knees and hips.*

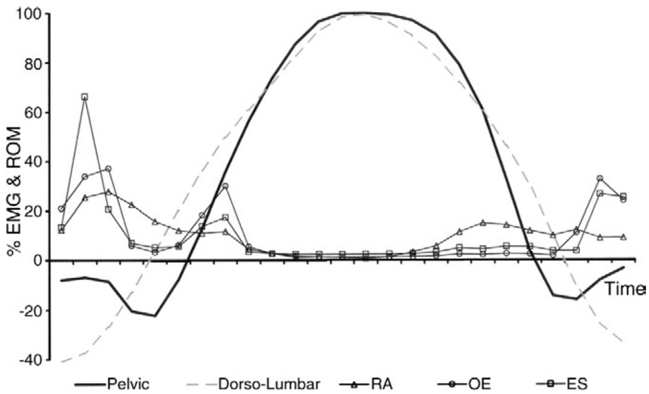

Fig 3. *Percentages of the EMG values and range of movement (% EMG and ROM) during the performance of spine and hip flexion with bended knees and hips exercise. Muscles: rectus abdominis (RA), obliquus externus (OE), and erector spinae (ES). Pelvic and dorsolumbar displacement.*

the knees and hips outstretched first (Fig 1), and after with the knees and hips bent (Fig 2).[21-24] The first EMG studies that analyzed the engagement of abdominal muscles in these types of exercises appeared in the 1950s and 1960s.[25-29] Since then, numerous biomechanical and EMG studies have shown the limitations of these exercises to strength development of the abdominal musculature.

Some biomechanical studies have shown that spine and hip flexion result in high compressive forces on the lumbar vertebrae. Nachemson and Elfström[30] observed that full trunk flexion results in compressive loads at the third lumbar intervertebral disk that are similar to compressive loads with a 10-kg load in each hand at 20° trunk flexion. In 1995, McGill[31] used a mathematical model to assess the distribution of lumbar spine load when performing dynamic and static abdominal exercises involving spine and hip flexion and stated that these exercises were not recommended because of high compressive forces on the lumbar spine (more than 3000 N).

Some studies on the EMG profile have described an irregular activation pattern of the trunk musculature during hip flexion when performing a spine and hip flexion exercise. In the initial phase of the exercise, during the dorsolumbar spine flexion, the rectus abdominis muscle was activated. Subsequently, its activation fell sharply when the lumbar region was lifted from the floor (from 30° to 45° of trunk flexion) and with the activation of the hip flexors (Fig 3).[4,5,25,26,32-37] In a study carried out on 21 abdominal exercises, Monfort[3] showed the existence of this pattern of EMG activation in the rectus abdominis and obliquus externus muscles when performing exercises in which the hip flexor musculature was actively involved. Recent studies that analyzed pelvis and spine displacement stated that the fall in abdominal EMG occurred with the start of pelvic displacement (Fig 3).[38]

This EMG response of the abdominal musculature to the involvement of the hip flexor musculature during abdominal strengthening exercises and its relation to increased compressive forces exerted on the lumbar spine have been used as a criterion for not selecting these exercises due to the high loads they place on the spine.[1,30] As a result, abdominal strengthening exercises performed with ‘spine flexion and/or pelvic tilt without active hip flexion’ are preferred over those performed with active hip flexion.[3] The risks of using spine and hip flexion exercises to strengthen the muscles of the abdominal wall motivated researchers to look for alternatives. Efforts have been primarily centered on limiting the movement of the trunk to the most useful range, thus eliminating hip flexor activation. Consequently, exercises with spine flexion (Fig 4) began to be recommended as the most specific and safest exercises for strengthening abdominal muscles.[1,3,23]

Studies investigating EMG amplitude have shown that the mean amplitude of the rectus abdominis activation during exercises of spine flexion was similar or higher than the

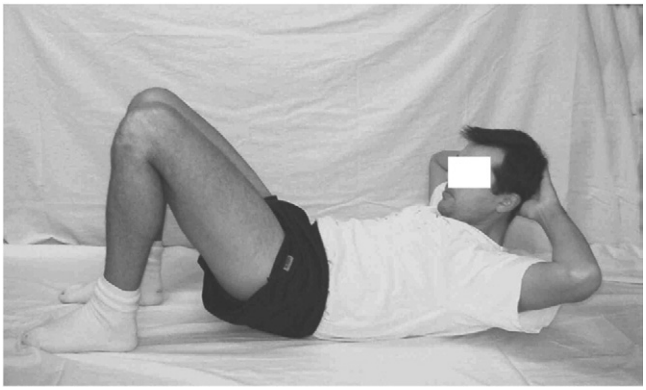

Fig 4. *Spine flexion with bended knees and hips.*

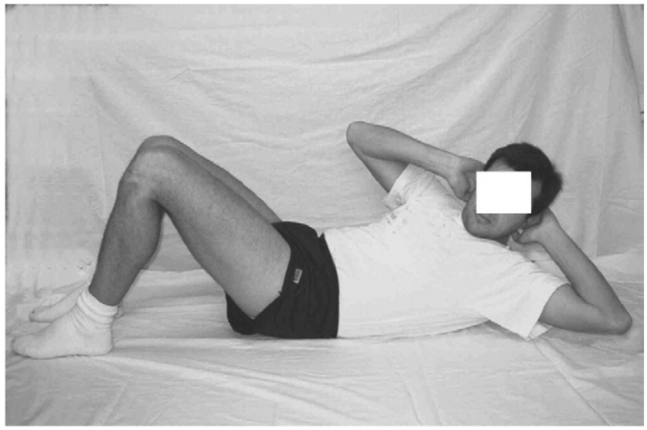

Fig 6. *Spine flexion with trunk rotation.*

Fig 5. *Spine and hip flexion with trunk rotation.*

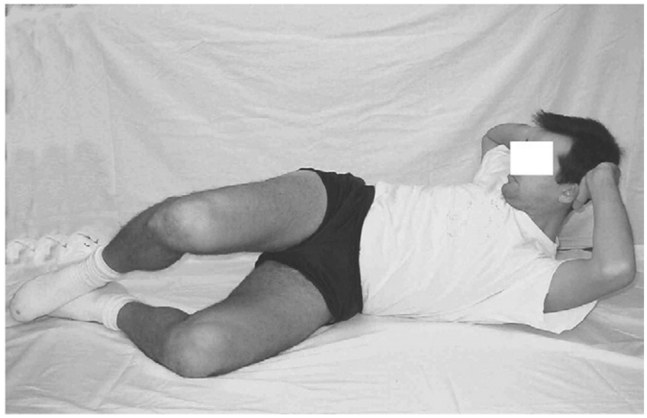

Fig 7. *Spine flexion with trunk rotation in lateral decubitus position.*

activation produced in most exercises involving spine and hip flexion.[1,3,5,15,16,33,34,36,37,39,40] In 1997, Axler and McGill[1] conducted a study in which a large number of abdominal exercises were analyzed. The exercises with spine flexion were found to cause the highest ratio of abdominal muscle recruitment/disk compression.[1] Therefore, these exercises are widely used in therapeutic, sport, recreational, and educational settings since they are safer and more effective because they isolate the abdominal musculature.[41-47] Thus, there is reliable evidence to recommend that abdominal strengthening exercises are performed with spine flexion and without hip flexion.

Trunk Rotation

The reviews and the outcomes of the studies on EMG amplitude to date are consistent. Trunk flexion exercises performed with trunk rotation (Figs 5 and 6) resulted in higher activation of the anterolateral muscles of the abdomen than single-plane exercises.[1,3,23,25,28,40,48-50] It should be noted that the direction of movement and initial body position will result in variations in abdominal activation patterns, whether ipsilateral or contralateral to trunk rotation. Thus, it was found that the exercises performed in lateral decubitus position (Fig 7) evoked greater rectus and obliquus externus abdominis activation ipsilateral to the direction of rotation.[3,25] Performing trunk rotation exercises in the supine decubitus position (Figs 5 and 6), although not significant, elicits greater activity in the contralateral rectus and obliquus externus abdominis muscles.[3]

Position with Supported Segments

Most studies confirm the fact that leg support during a pelvic tilt[3,51] and fixed feet during spine and hip flexion exercises may decrease the intensity of rectus abdominis EMG.[1,3,26,33,40,52] In the latter case, having the feet fixed facilitates activation of the hip flexors.[4,5,34,40,52,53] Positions with fixed arms (Figs 8 and 9) facilitate activation of the abdominal musculature.[3,54] A possible reason for these outcomes is based on the Proprioceptive Neuromuscular Facilitation Theory by Voss et al,[55] which explains that the

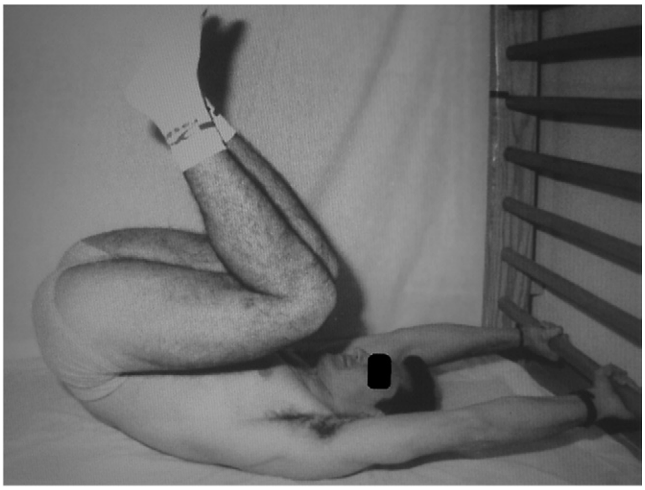

Fig 8. *Posterior pelvic tilt and rotation with spine and hip flexion with bent legs and fixed arms.*

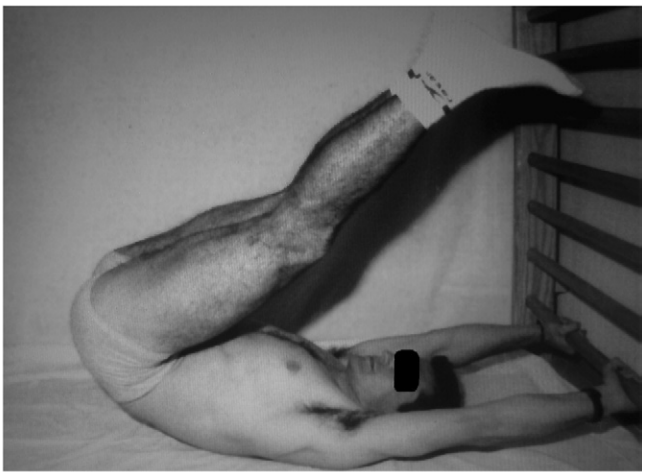

Fig 9. *Posterior pelvic tilt and rotation with spine and hip flexion with stretched legs and fixed arms.*

involvement of the hip flexors is related to the activation of the trunk muscle extension chain. Meanwhile, the involvement of the shoulder flexors is related to the activation of the trunk muscle flexion chain. Consequently, according to the available literature, to maximally challenge the abdominal muscles, exercises with fixed arms and free feet are preferable.

Arm and Hand Position

During spine flexion exercises, the load can be increased by changing the arm position. The load will be reduced if the arms are resting at the side or are crossed over the chest, and the load will increase if they are stretched backward.[21,45,56,57] Nevertheless, to do repetitions to exhaustion, it is recommended that the hands are used to

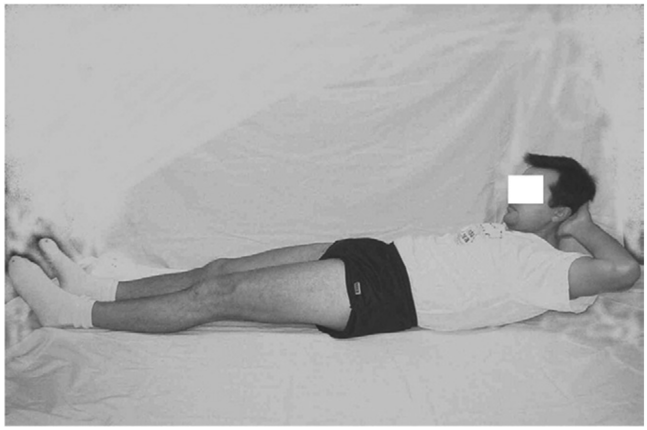

Fig 10. *Spine flexion with stretched knees and hips.*

help support the head and neck to avoid neck pain and fatigue, as observed in some experimental studies.[41,58,59] To avoid excessive or violent flexion of the cervical spine, the hands should not pull the head up (Fig 4).[7] Therefore, previous studies show that if a prolonged abdominal exercise session is to be executed, spine flexion should be performed supporting the head and neck with the hands, although avoiding excessive cervical flexion.

Knee and Hip Position

The results are not consistent with regard to hip and knee position. Although some studies found no differences in abdominal muscle activation when modifying hip and knee flexion during spine flexion exercises[1,4,48] (Figs 4 and 10) or spine and hip flexion exercises[26,34,37,52] (Figs 1 and 2), others found greater activation in spine flexion exercises performed with the knees and hips bent.[33,40] Nevertheless, many studies support the recommendation to perform spine flexion exercises with knees and hips bent to neutralize lumbar lordosis[35,60] and reduce tension in the psoas muscle,[60] the involvement of the hip flexor musculature,[40,52] and the torque it produces.[61] According to the estimates made by Johnson and Reid,[60] there was a decrease in the compressive force (men: 5% and 17%; women: 4% and 18%) and in shear stress (men: 46% and 87%; women: 29% and 97%) during spine flexion in exercises with the hips flexed to 45° and 90°, as compared to the forces produced when the hips are not flexed. On the other hand, Axler and McGill[1] showed that bending the hips and knees during spine and hip flexion exercises with fixed feet did not significantly reduce large spinal compressive loads that are common in this type of exercise. Moreover, they showed that the involvement of the psoas iliacus muscle was not reduced by pressing the feet on the floor during spine and hip flexion exercises: in fact, it was increased due to shortened length and more activation required independent of hamstring activation.

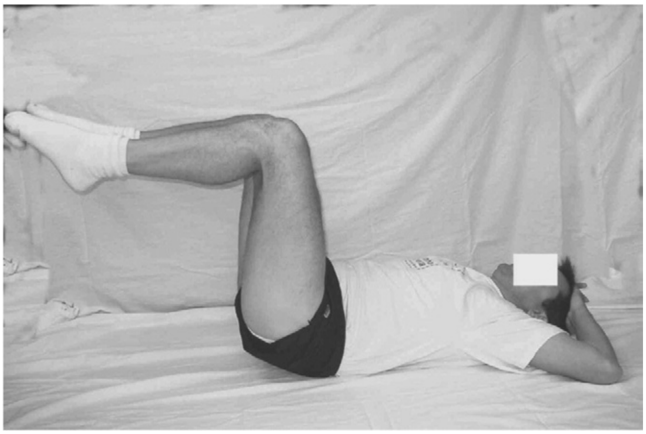

Fig 11. *Posterior pelvic tilt with 90° flexed knees and hips.*

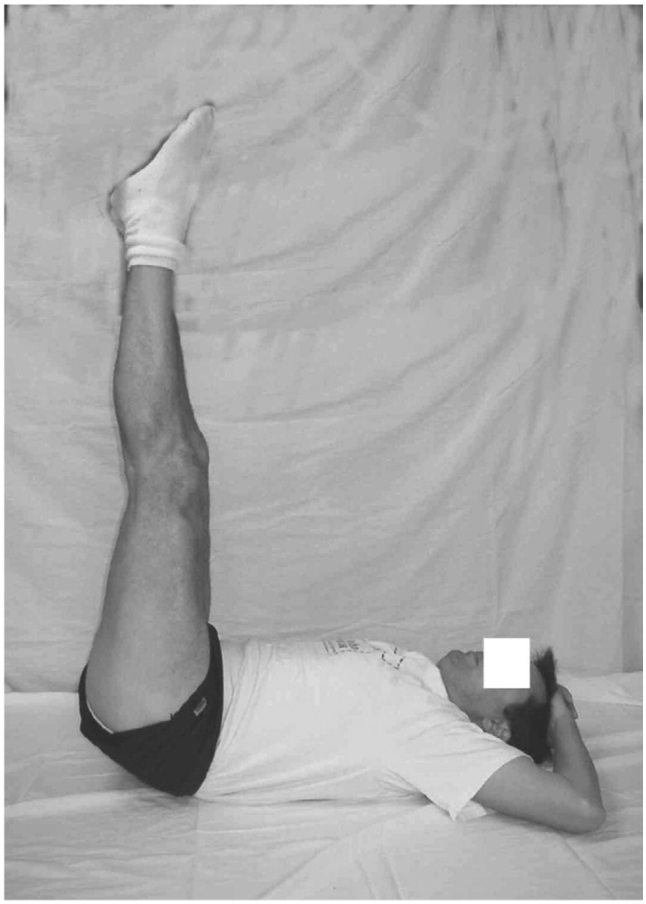

Fig 12. *Posterior pelvic tilt with stretched knees and 90° flexed hips.*

Movement of Upper and/or Lower Body Segments

In general, it could be said that the movement of the lower body segments (Figs 8, 9, 11, and 12) elicits greater activity of the rectus and the obliquus externus abdominis muscles than the movement of the upper body segments (Figs 1, 2, 4, and 10).[17,40,52,62] Nevertheless, this statement should be taken with caution because it results from the comparison of the involvement of different body segments exercises with or without hip flexion, which could be acting as a confounding factor.

One of the critical issues concerning the use of abdominal exercises is the widespread belief that trunk flexion exercises mainly activate the supraumbilical region, whereas the lifting of the lower limbs and posterior pelvic tilt mainly activate the infraumbilical region. This belief has been justified by the metameric innervation of the portions of the rectus abdominis[63] and by the perception of the subjects performing the exercise who claim to "localize" the stress mainly on one or several muscle portions. Nevertheless, research has shown a weak relationship between stress perception and muscle contraction intensity.[3,42] In the same way, the results of the studies that have analyzed the possibility to selectively activate one of the portions of the rectus abdominis more intensely than others are controversial. These results do not provide clarifying information because the methodological differences hamper comparisons across the studies.[7,8,17,64] Sarti et al[7] observed that the spine flexion exercise elicited greater EMG activity of the upper portions of the rectus abdominis than of the lower portions. Only the most skilled participants were able to contract the lower portion of the rectus abdominis muscle more intensely than the upper portion when performing the exercise with posterior pelvic tilt and hips and knees flexed to 90°. Sarti et al[7] and Willet et al[17] confirmed that the pelvic tilt elicited greater activity of the lower portion of the rectus abdominis than spine flexion. However, neither Piering et al[64] nor Lehman and McGill[8] found differences in the EMG activity recorded of the upper and lower portions of the rectus abdominis muscles, although neither of these authors stated controlling the individual's skill. Interestingly, recent studies have shown that it may be possible to train subjects in separating the voluntary activation of individual abdominal muscle segments, with such activities as middle-eastern–style dancing.[65]

It could be expected that when moving the upper and lower body segments simultaneously, there would be a greater activity of the trunk musculature. This has been observed during hip and spine flexion exercises lifting stretched or bent legs (Figs 13 and 14).[3,25,34] The studies carried out with spine flexion and pelvic tilt exercises (Fig 15) did not find the expected results.[3] This was likely due to the fact that spine flexion and pelvic tilt exercises were performed with the feet flat on the floor. This allowed a decrease in the load and more lumbar spine stability. Although hip and spine flexion exercise with the lifting of stretched legs (Fig 14) elicited considerable activation of the abdominal muscles, it is not recommended for people with back pain because of high compressive force on the lumbar vertebrae.[1,30] The correct technique involves keeping the lumbar spine in a "neutral" position[50,57] and requires both

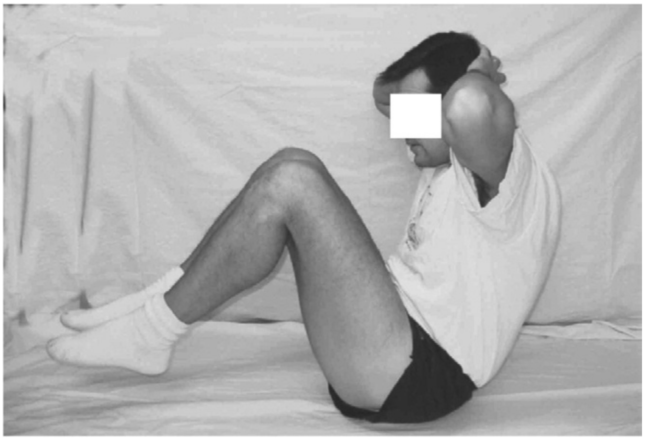

Fig 13. *Spine and hip flexion with flexed legs lifting.*

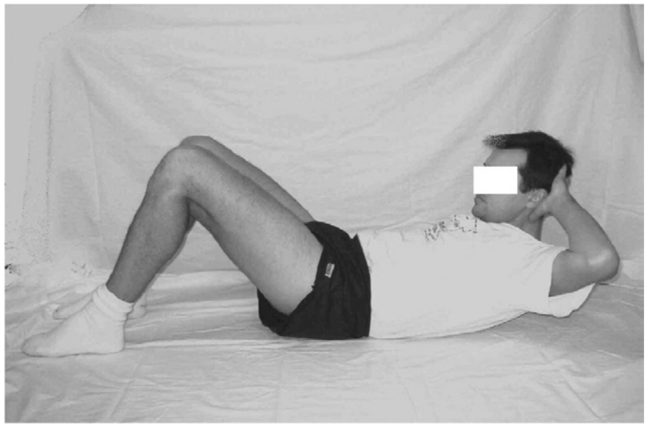

Fig 15. *Spine flexion and pelvic tilt with bent knees.*

Fig 14. *Spine and hip flexion with stretched legs lifting.*

Fig 16. *Spine flexion with flexed knees on inclined board.*

good conditioning of the abdominal muscles and control of lumbopelvic position.

Use of Equipment

Free-weights, resistance machines, inclined, boards and other equipment have been used to increase the intensity of the trunk muscle activation when doing abdominal exercises.

Research confirms that the use of inclined boards (Figs 16 and 17) as compared to flat boards (Figs 2 and 4) elicits greater activity of the abdominal muscles.[3,50] The most demanding exercise is pelvic tilting with the knees and hips bent while hanging from a chin-up bar (Fig 18).[3] Nevertheless, some authors carried out descriptive studies and did not confirm these results.[14,43,45,66-68] It has also been shown that the use of free weights and resistance machines increases the intensity of training and facilitates abdominal strengthening. However, some authors find that performing exercises with resistance machines and abdominal exercise devices does not ensure greater activity of the muscles.[9-11,14,39,44,69] Instead, the use of the ABslide and FitBall resulted in greater involvement of the hip flexors.[9] Nevertheless, the use of devices such as the AbVice, which incorporate contraction of the hamstring and gluteal musculature in conjunction with the abdominals, is claimed to allow greater activity levels of the abdominal musculature with a decreased activation of the hip flexors via the theory of reflex inhibition.[70]

When the exercises are performed for aesthetic reasons, a number of devices advertised in the media are commonly used. Although not proven useful by experimental studies,[44,71] the current trend is to use commercial abdominal exercise stations and electrical muscle stimulation devices to burn subcutaneous fat in the anterolateral region of the abdomen.

When abdominal exercises are performed on a labile surface (Fig 19), the trunk is subject to continuous imbalances, which increases abdominal coactivation[6,72] and stimulates propioception[50]; these exercises are becoming

Fig 17. *Spine and hip flexion with flexed knees on inclined board.*

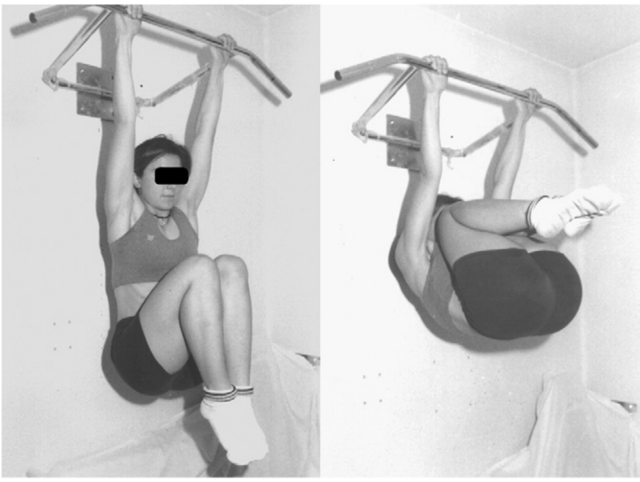

Fig 18. *Pelvic tilt and spine flexion with bended knees and hips hanging from a chin-up bar.*

increasingly popular for these reasons. However, this type of exercise is recommended for advanced training because the lumbar spine is subject to high loads, which are not advisable for inexperienced individuals or patients with spine instability or spine lesions.[73] Some devices, such as the Bodyblade, in spite of being effective for recruiting the entire abdominal wall when used properly, can also cause an increase of lumbar compressive forces, which may make them inappropriate for some people with lumbar spine pathology affected by compression.[74]

Core Stabilization Exercises: A New Trend

Abdominal coactivation increases the stiffness of the spine, promoting stability in the vertebral segments.[75-77] Instability of the lumbopelvic region can result in pain and disablement.[78] Thus, increasing trunk stability is considered one of the most important functions of the abdominal muscles.[3,50] Promotion of this stabilizing role should be a

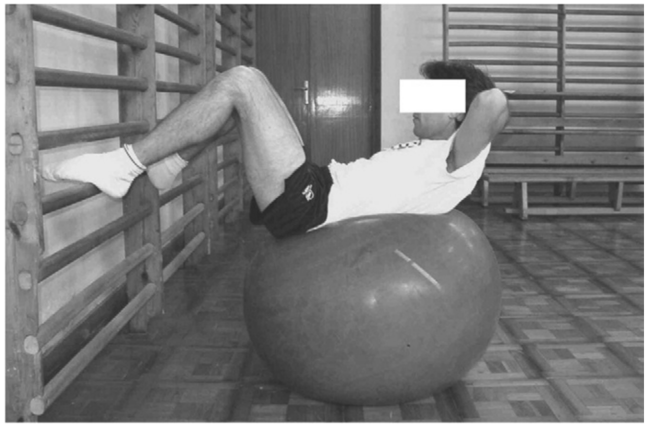

Fig 19. *Spine flexion with flexed knees and hips on an unstable surface.*

prime consideration when designing abdominal exercise programs. There has been much interest lately in evaluating different core stabilization exercises. Many of these studies are relatively recent and methodologically correct according to the criteria discussed previously. Most of the studied exercises challenge spine stability by applying perturbation forces to the trunk in 2 different ways, that is, using some devices such as unstable surfaces or Bodyblade or through the movement of the limbs. One example of this last approach would be the contralateral arm and leg raise from a quadruped position in a 2-point stance, also known as "bird dog"[79] (Fig 20).

Despite the large number of studies that has been carried out, controversy remains over which are the best stabilization exercises. The abdominal hollowing exercise consists of hollowing the lower abdomen by drawing the navel up and in toward the spine and maintaining the lumbar spine in a neutral position, which isolates the coactivation of transversus abdominis and internal oblique muscles.[77,80,81] This maneuver has been widely used in rehabilitation for patients with segmental spinal instability, since it seems effective as a way to retrain perturbed motor patterns in deep abdominal muscles and consequently to increase spine stability and reduce disability and pain.[80,81] On the basis of these and other findings,[82,83] some clinical groups advocate that exercises which coactivate transversus abdominis, internal oblique, and multifidus and minimize rectus abdominis activity are critical for spine stabilization programs.[84,85]

On the other hand, the results of biomechanical studies where spine stability has been quantified suggest that all trunk muscles play an important role in achieving spinal stability and must work harmoniously to reach this goal.[2,77,86,87] Under this approach, 1 or 2 muscles should not be the specific targets when training the abdominals; on the contrary, stabilization exercises should produce a more global coactivation such as that produced during abdominal bracing, which implies contracting the entire abdominal wall

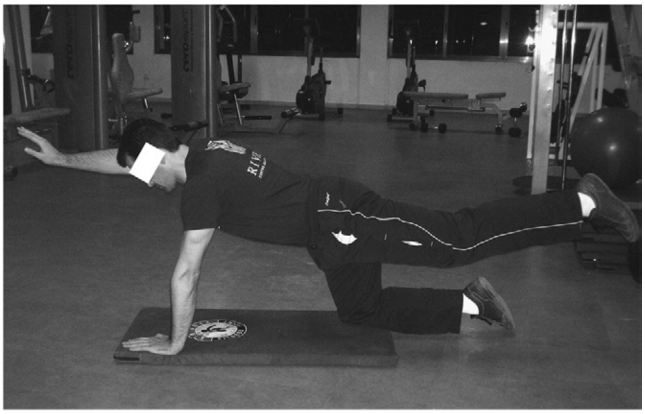

Fig 20. *Quadruped exercise in a 2-point stance, with a contralateral arm and leg raise.*

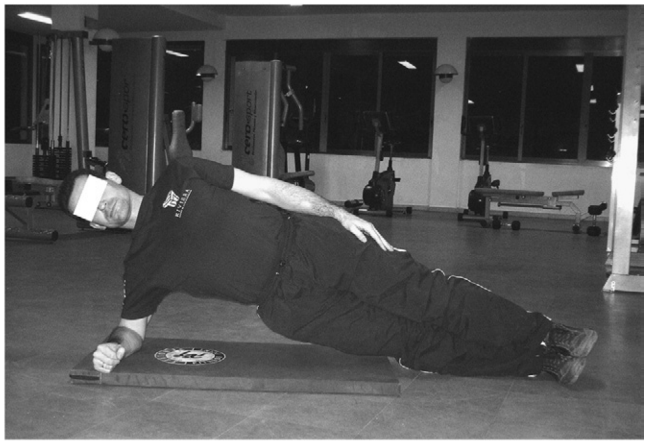

Fig 21. *Isometric side support exercise.*

without any change in the position of the muscles and maintaining the lumbar spine in a neutral position.[76,77,86] Vera-Garcia et al[77] compared the effects of abdominal bracing and abdominal hollowing maneuvers on the control of spine motion and stability against sudden trunk perturbations in healthy males, and they found that abdominal bracing was more effective than abdominal hollowing for stabilizing the spine against posterior and rapid loading.

Both approaches (clinical and mechanical) do not necessarily exclude each other. The use of abdominal bracing or hollowing may depend on the characteristics of the user: Abdominal hollowing may be useful for patients with spinal instability and an altered abdominal motor pattern, whereas abdominal bracing techniques could be better for stabilization training in healthy subjects. Finally, in both approaches, researchers have paid much attention to find core exercises without risk of spinal injury during the performance. For example, biomechanical studies have shown that right isometric side support exercises, also known as "side bridges" (Fig 21), elicit considerable activity of the oblique and transverse muscles without generating large compressive forces on the lumbar spine.[1,5,79]

Conclusions

In regard to efficacy criteria, the most important factors for the selection of abdominal conditioning exercises are (*a*) spine flexion and rotation without hip flexion, (*b*) arm support, (*c*) lower body segments involvement controlling the correct performance, (*d*) inclined planes or additional loads to increase the contraction intensity significantly, and (*e*) when the goal is to challenge spine stability, exercises such as abdominal bracing or abdominal hollowing are preferable depending on the participants' objectives and characteristics. Attending to safety criteria, the most important factors are (*a*) avoid active hip flexion and fixed feet, (*b*) do not pull with the hands behind the head, (*c*) a position of knees and hips flexion during upper body exercises. Finally, it could be said that further replicable studies are needed to address and clarify the methodological doubts expressed in this article and to provide more consistent and reliable results that might help us build a body of knowledge on this topic.

Practical Applications

- The efficacy of abdominal exercises increases with (*a*) spine flexion and rotation without hip flexion, (*b*) arm support, (*c*) lower body segments involvement controlling the correct performance, and (*d*) inclined planes or additional loads.
- Attending to safety criteria, the most important factors are (*a*) avoid active hip flexion and fixed feet, (*b*) do not pull with the hands behind the head, and (*c*) a position of knees and hips flexion during upper body exercises.

References

1. Axler CT, McGill SM. Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. Med Sci Sports Exerc 1997;29:804-11.
2. Kavcic N, Grenier S, McGill S. Determining the stabilizing role of individual torso muscles during rehabilitation exercises. Spine 2004;29:1254-65.
3. Monfort M. Master's thesis: trunk muscles in abdominal strengthening exercises. 1st ed. València, Spain: Servei de Publicacions de la Universitat de València; 1998 [Spanish].
4. Andersson EA, Nilsson J, Ma Z, Thorstensson A. Abdominal and hip flexor muscle activation during various training exercises. Eur J Appl Physiol 1997;75:115-23.
5. Juker D, McGill S, Kropf P, Steffen T. Quantitative intramuscular myoelectric activity of lumbar portions of

psoas and the abdominal wall during a wide variety of tasks. Med Sci Sports Exerc 1998;30:301-10.
6. Vera-García FJ, Grenier SG, McGill S. Abdominal response during curl-ups on both stable and labile surfaces. Phys Ther 2000;80:564-9.
7. Sarti MA, Monfort M, Fuster MA, Villaplana LA. Muscle activity in upper and lower rectus abdominus during abdominal exercises. Arch Phys Med Rehabil 1996;77:1293-7.
8. Lehman GJ, McGill S. Quantification of the differences in electromyographic activity magnitude between the upper and lower portions of the rectus abdominis muscle during selected trunk exercises. Phys Ther 2001;81:1096-101.
9. Hildenbrand K, Noble L. Abdominal muscle activity while performing trunk-flexion exercises using the AbRoller, AbSlide, FitBall, and conventionally performed trunk curls. J Athl Train 2004;39:37-43.
10. Sternlicht E, Rugg S. Electromyographic analysis of abdominal muscle activity using portable abdominal exercise devices and a traditional crunch. J Strength Cond Res 2003;17:463-8.
11. Whiting WC, Rugg S, Coleman A, Vincent WJ. Muscle activity during sit-ups using abdominal exercise devices. J Strength Cond Res 1999;13:339-45.
12. Lehman GJ, McGill SM. The importance of normalization in the interpretation of surface electromyography: a proof of principle. J Manipulative Physiol Ther 1999;22:444-6.
13. Ng JK, Kippers V, Parnianpour M, Richardson CA. EMG activity normalization for trunk muscles in subjects with and without back pain. Med Sci Sports Exerc 2002;34:1082-6.
14. Warden SJ, Wajswelner H, Bennell KL. Comparison of Abshaper and conventionally performed abdominal exercises using surface electromyography. Med Sci Sports Exerc 1999;31:1656-64.
15. Shirado O, Ito S. Electromyographic analysis of four techniques for isometric trunk muscle exercises. Arch Phys Med Rehabil 1995;76:225-9.
16. Konrad P, Schmitz K, Denner A. Neuromuscular evaluation of trunk-training exercises. J Athl Train 2001;36:109-18.
17. Willet GM, Hyde JE, Uhrlaub MB, Wendel CL, Karst GM. Relative activity of abdominal muscle during prescribed strengthening exercises. J Strength Cond Res 2001;15:480-5.
18. Merletti R. Standards for reporting EMG data. J Electromyogr Kinesiol 1996;6:iii-iv.
19. Yang JF, Winter DA. Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. Arch Phys Med Rehabil 1984;65:517-21.
20. Davies HO, Crombie IK. What is a systematic review? What is …? Series. Evidence-based Medicine, Hayward Medical Communications. 2004; volume 1, number 5. Available from: http://www.whatisseries.co.uk/whatis/index.asp [accessed 12 March 2008].
21. Alexander MJL. Biomechanics of sit-up exercises. Can Assoc Health Phys Educ Recreation J 1985;51:36-8.
22. Clarke HH. Exercise and the abdominal muscles. Phys Fit Res Dig 1976;6:1-21.
23. Knudson D. A review of exercise and fitness tests for abdominal muscle. Sports Med Update. 1996;11:4-5, 25-30.
24. Vincent W, Britten S. Evaluation of the curl up: a substitute for the bent knee sit up. J Phys Educ Rec Dance 1980;51:74-5.
25. Flint MM. An electromyographic comparison of the function of the iliacus and the rectus abdominis muscles. J Am Phys Ther Assoc 1965;45:248-53.
26. Flint MM, Gudgell J. Electromyographic study of abdominal muscular activity during exercise. Res Q 1965;36:29-37.
27. Floyd WF, Silver PH. Electromyographic study of patterns of activity of the anterior abdominal wall muscles in man. J Anat 1950;84:132-45.
28. Ono K. Electromyographic studies of the abdominal wall muscles in visceroptosis. I. Analysis of the abdominal wall muscles in normal adults. Tohoku J Exper Med 1958;68:347-54.
29. Partridge MJ, Walters CE. Participation of the abdominal muscles in various movements of the trunk in man: an electromyographic study. Phys Ther Rev 1959;39:791-800.
30. Nachemson A, Elfstrom G. Intravital dynamic pressure measurements in lumbar discs. A study of common movements, maneuvers and exercises. Scand J Rehab Med Suppl 1970;1:1-40.
31. McGill S. The mechanics of torso flexion: sit-ups and standing dynamic flexion manoeuvres. Clin Biomech 1995;10:184-92.
32. Andersson EA, Ma Z, Thorstensson A. Relative EMG levels in training exercises for abdominal and hip flexor muscles. Scand J Rehabil Med 1998;30:175-83.
33. Godfrey K, Kindig L. Electromyographic study of duration of muscle activity in sit-up variations. Arch Phys Med Rehabil 1977;58:132-5.
34. Guimaraes AC, Vaz MA. The contribution of the rectus abdominis and rectus femoris in twelve selected abdominal exercises. J Sports Med Phys Fitness 1991;31:222-30.
35. Halpern A, Bleck E. Sit-up exercises: an electromyographic study. Clin Orthop Relat Res 1979;145:172-8.
36. Monfort M, Lisón JF, López E, Sarti MA. Trunk muscles and spine stability. Eur J Anat 1997;1(Suppl 1):52.
37. Ricci B, Marchetti M, Figura F. Biomechanics of sit-up exercises. Med Sci Sports Exerc 1981;13:54-9.
38. Monfort M, Sarti MA, Pamblanco MA, Sánchez D, Vera-Garcia FJ, Lisón JF. Effect of spine-hip interaction in the electromyographic activity of the trunk muscles during an abdominal strengthening exercise. In: Oña A, Bilbao A, editors. Proceedings of the 2nd World Congress of Physical Activity and Sport Sciences: Sport and Quality of Life; 2003 Nov 12-15; Granada, Spain. Granada, Spain: Universidad de Granada; 2003. p. 242-7 [Spanish].
39. Beim GM, Giraldo JL, Pincivero DM, Borror MJ, Fu FH. Abdominal strengthening exercises: a comparative EMG study. J Sport Rehabil 1997;6:11-22.
40. Gutin B, Lipetz S. An electromyographic investigation of the rectus abdominis in exercises. Res Q 1971;42:256-63.
41. Alon G, McCombe SA, Koutsantonis S, Stumphauzer LJ, Burgwin KC, Parent MM, Bosworth RA. Comparison of the effects of electrical stimulation and exercise on abdominal musculature. J Orthop Sports Phys Ther 1987;8:567-73.
42. Bell R, Laskin J. The use of curl-up variations in the development of abdominal musculature strength and endurance by post 50 year old volunteers. J Hum Mov Stud 1985;11:319-24.
43. Cerny K. Do curl-up exercises improve abdominal muscle strength? J Hum Mus Perform 1991;1:37-47.
44. Demont RG, Lephart SM, Giraldo JL, Giannantonio FP, Yuktanandana P, Fu FH. Comparison of two abdominal training devices with an abdominal crunch using strength and EMG measurements. J Sports Med Phys Fitness 1999;39:253-8.
45. Hemborg B, Mortiz U, Hamberg J, Löwing H, Akesson I. Intra-abdominal pressure and trunk muscle activity during lifting. Effect of abdominal muscle training in healthy subjects. Scand J Rehabil Med 1983;15:183-96.
46. Levine D, Walker JR, Tillman LJ. The effect of abdominal muscle strengthening on pelvic tilt and lumbar lordosis. Physiother Theory Pract 1997;13:217-26.
47. Vera-García FJ, Sarti MA, Monfort M, Peris R. Static versus dynamic abdominal training controversy. Eur J Anatomy 2002;6(Suppl 1):21.

48. Ekholm J, Arborelius U. Activation of abdominal muscles during some physiotherapeutic exercises. Scand J Rehabil Med 1979;11:75-84.
49. Moraes AC, Bankoff ADP, Pellegrinotti IL, Moreira ZW. Electromyography analysis of the rectus abdominis and external oblique muscles of children 8 to 10 years old. Electromyogr Clin Neurophysiol 1995;35:425-30.
50. Norris CM. Abdominal muscle training in sport. Br J Sports Med 1993;27:19-27.
51. Drysdale CL, Jennifer E, Earl JE, Hertel J. Surface electromyographic activity of the abdominal muscles during pelvic-tilt and abdominal-hollowing exercises. J Athl Train 2004;3:32-6.
52. Lipetz S, Gutin B. An electromyographic study of four abdominal exercises. Med Sci Sports Exerc 1970;2:35-8.
53. Miller M, Medeiros J. Recruitment of internal oblique and transversus adominis muscles during the eccentric phase of the curl-up exercise. Phys Ther 1987;67:1213-7.
54. Bankoff A, Furlina J. Electromyographic study of the rectus abdominis and external oblique muscles during exercises. Electromyogr Clin Neurophysiol 1984;24:501-10.
55. Voss DE, Ionta MK, Myers BJ. Proprioceptive neuromuscular facilitation, patterns and techniques. 3rd ed. Philadelphia: Harper and Row; 1985.
56. Enoka RM. Neuromechanical basis of kinesiology. 2nd ed. Champaign (Ill): Human Kinetics; 1994.
57. Knudson D. Issues in abdominal fitness: testing and technique. J Phys Educat Rec Dance 1999;70:49-55.
58. Faulkner RA, Sprigings EJ, Mcquarrie A, Bell RD. A practical curl-up protocol for adults based on an analysis of two procedures. Can J Sport Sci 1989;14:135-41.
59. Moreland J, Finch E, Stratford P, Balsor B, Gill C. Interrater reliability of six tests of trunk muscle function and endurance. J Orthop Sports Phys Ther 1997;26:200-8.
60. Johnson C, Reid JG. Lumbar compressive and shear forces during various trunk curl-up exercises. Clin Biomech 1991;6: 97-104.
61. Neeves N, Barlow D. Torque work and power differences in bent-knee and straight-leg situps in women. Med Sci Sports Exerc 1975;7:77.
62. Carman DJ, Blanton PL. Electromyographic study of the anterolateral abdominal musculature utilizing indwelling electrodes. Am J Phys Med 1972;51:113-29.
63. Duchateau J, Declety A, Lejour M. Innervation of the rectus abdominis muscle: implications for rectus flaps. Plast Reconstr Surg 1988;82:223-7.
64. Piering AW, Janowski AP, Moore MT, Snyder AC, Wehrenberg WB. Electromyographic analysis of four popular abdominal exercises. J Athl Train 1993;28:120-6.
65. Moreside JM, Vera-Garcia FJ, McGill SM. Neuromuscular independence of abdominal wall muscles as demonstrated by middle-eastern style dancers. J Electromyogr Kinesiol 2008;18: 527-37.
66. Cresswell AG, Thorstensson A. Changes in intra-abdominal pressure, trunk muscle activation and force during isokinetic lifting and lowering. Eur J Appl Physiol 1994;68:315-21.
67. Demichele PL, Pollock ML, Graves JE, et al. Isometric torso rotation strength: effect of training frequency on its development. Arch Phys Med Rehabil 1997;78:64-9.
68. Smidt GL, Blanpied PR, White RW. Exploration of mechanical and electromyographic responses of trunk muscles to high-intensity resistive exercise. Spine 1989;14:815-30.
69. Bird M, Fletcher KM, Koch AJ. Electromyographic comparison of the Ab-slide and crunch exercises. J Strength Cond Res 2006;20:436-40.
70. Avedisian L, Kowalsky DS, Albro RC, Goldner D, Gill RC. Abdominal strengthening using the AbVice machine as measured by surface electromyographic activation levels. J Strength Cond Res 2005;19:709-12.
71. Porcari JP, McLean KP, Foster C, Kernozek T, Crenshaw B, Swenson C. Effects of electrical muscle stimulation on body composition, muscle strength, and physical appearance. J Strength Cond Res 2002;16:165-72.
72. Drake JDM, Fischer SL, Brown SHM, Callaghan JP. Do exercise balls provide a training advantage for trunk extensor exercises? A biomechanical evaluation. J Manipulative Physiol Ther 2006;29:354-62.
73. McGill S. Low back disorders. Evidence-based prevention and rehabilitation. . 1st ed. Champaign (Ill): Human Kinetics; 2002.
74. Moreside JM, Vera-Garcia FJ, McGill SM. Trunk muscle activation patterns, lumbar compressive forces, and spine stability when using the bodyblade. Phys Ther 2007;87:153-63.
75. Gardner-Morse M, Stokes AF. The effects of abdominal muscle coactivation on lumbar spine stability. Spine 1998;23:86-92.
76. Vera-Garcia FJ, Brown SH, Gray JR, McGill SM. Effects of different levels of torso coactivation on trunk muscular and kinematic responses to posteriorly applied sudden loads. Clin Biomech 2006;21:443-55.
77. Vera-Garcia FJ, Elvira JL, Brown SH, McGill SM. Effects of abdominal stabilization maneuvers on the control of spine motion and stability against sudden trunk perturbations. J Electromyogr Kinesiol 2007;17:556-67.
78. Cleland J, Schulte C, Durall C. The role of therapeutic exercise in treating instability-related lumbar spine pain: a systematic review. J Back Musculoskelet 2002;16:105-15.
79. Kavcic N, Grenier S, McGill S. Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises. Spine 2004;29:2319-29.
80. O'Sullivan PB, Phyty GD, Twomey LT, Allison GT. Evaluation of specific exercise in the treatment of chronic low back pain with radiological diagnosis of spondylolysis and spondylolisthesis. Spine 1997;22:2959-67.
81. O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. J Orthop Sports Phys Ther 1998;27:114-24.
82. Hodges PW, Cresswell AG, Thorstensson A. Perturbed upper limb movements cause short-latency postural responses in trunk muscles. Exp Brain Res 2001;138:243-50.
83. Hodges PW, Richardson C. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine 1996;21: 2640-50.
84. Jull GA, Richardson CA. Motor control problems in patients with spinal pain: a new direction for therapeutic exercise. J Manipulative Physiol Ther 2000;23:115-7.
85. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil 2005;86:242-9.
86. Grenier SG, McGill SM. Quantification of lumbar stability by using 2 different abdominal activation strategies. Arch Phys Med Rehabil 2007;88:54-62.
87. McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol 2003;13:353-9.