

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*

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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 following³: spine and hip flexion, spine flexion, trunk rotation, position with supported segments, arm and hand position, knee and hip position,

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 | <ul style="list-style-type: none"> • Conventional long lying sit-up • Long lying sit • Sit |
| Spine and hip flexion with bent knees and hips | <ul style="list-style-type: none"> • Conventional hook lying sit-up • Hook lying sit • Sit |
| Spine flexion with stretched knees and hips | <ul style="list-style-type: none"> • Long lying trunk curl-up • Curl-up • Crunch |
| Spine flexion with bent knees and hips | <ul style="list-style-type: none"> • Hook lying curl-up • Partial curl-up • Bench trunk curl • Curl-up • Crunch |
| Spine and hip flexion with trunk rotation | <ul style="list-style-type: none"> • Crossed long lying sit-up |
| Spine flexion with trunk rotation | <ul style="list-style-type: none"> • Crossed trunk curl-up |
| Spine and hip flexion with flexed knees on inclined board | <ul style="list-style-type: none"> • Inclined Sit-up |
| Spine and hip flexion lifting stretched or bent legs | <ul style="list-style-type: none"> • V sit |
| Posterior pelvic tilt with spine and hip flexion (legs stretched or bent) | <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • Crook lying pelvic rotation • Hip roll |
| Posterior pelvic tilt and spine flexion with bended knees and hips hanging from a chin-up bar | <ul style="list-style-type: none"> • Basquet Hang |
| Quadruped exercise in a 2-point stance, with a contralateral arm and leg raise | <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • Abdominal bracing |
| Isometric side support exercises | <ul style="list-style-type: none"> • 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 studies⁴⁻⁶; (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 age⁸; (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 position¹⁵ or using the maximum EMG amplitude value of each muscle during the experimental tasks as a MVC EMG, with no specific MVC maneuvers⁴; 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

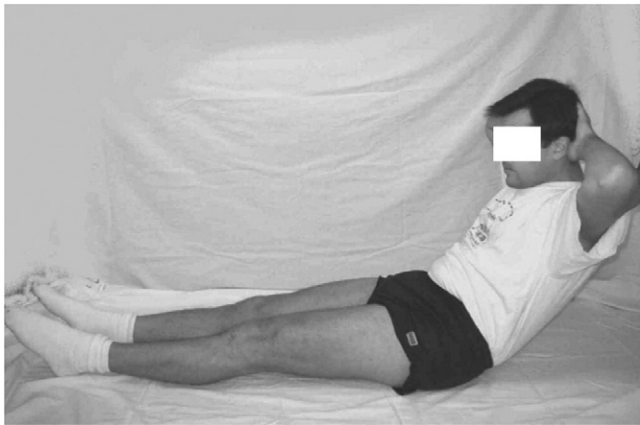


Fig 1. Spine and hip flexion with stretched knees and hips.



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

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 Elfström³⁰ 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, McGill³¹ 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).

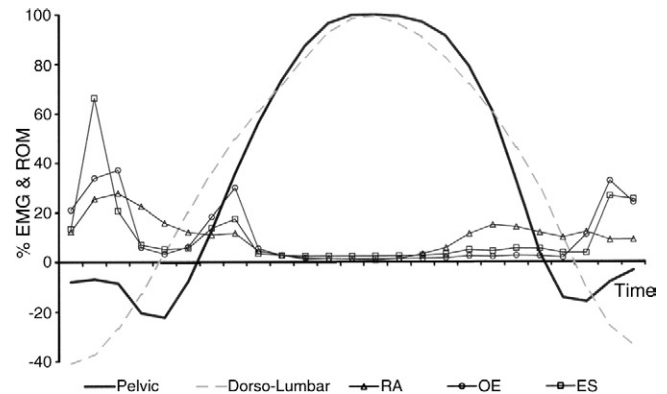


Fig 3. Percentages of the EMG values and range of movement (% EMG and ROM) during the performance of spine and hip flexion with bended knees and hips exercise. Muscles: rectus abdominis (RA), obliquus externus (OE), and erector spinae (ES). Pelvic and dorsolumbar displacement.

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, Monfort³ 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 McGill¹ 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

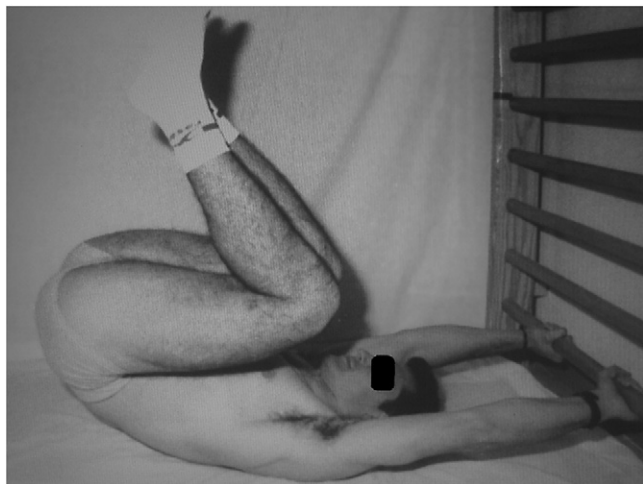


Fig 8. Posterior pelvic tilt and rotation with spine and hip flexion with bent legs and fixed arms.

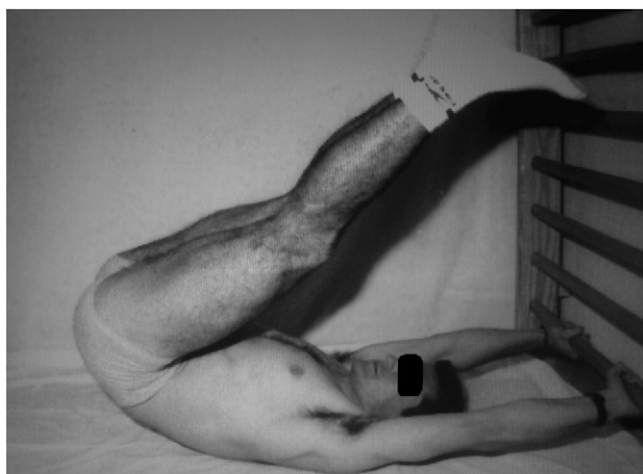


Fig 9. Posterior pelvic tilt and rotation with spine and hip flexion with stretched legs and fixed arms.

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 McGill¹ 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.*

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 abdominis⁶³ 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 al⁷ 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 al⁷ and Willet et al¹⁷ confirmed that the pelvic tilt elicited greater activity of the lower portion of the rectus abdominis than spine flexion. However, neither Piering et al⁶⁴ nor Lehman and McGill⁸ found differences in the EMG activity recorded of the upper

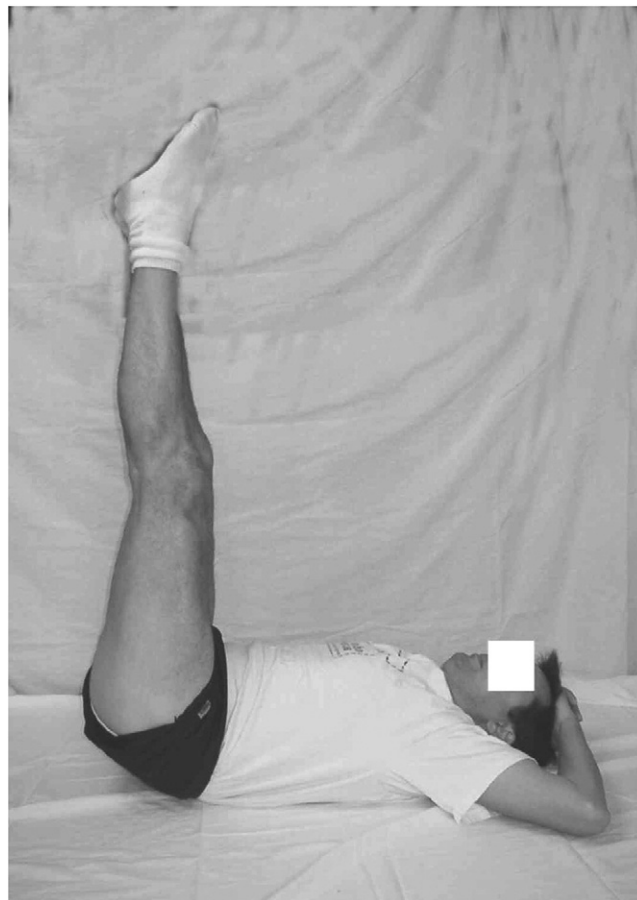


Fig 12. *Posterior pelvic tilt with stretched knees and 90° flexed hips.*

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.

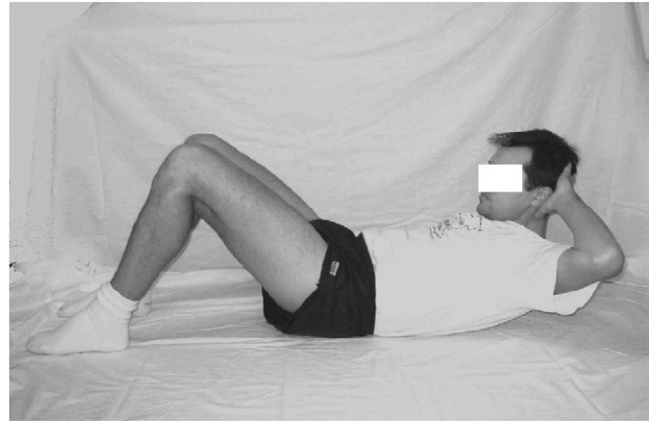


Fig 15. Spine flexion and pelvic tilt with bent knees.



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 proprioception⁵⁰; these exercises are becoming



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

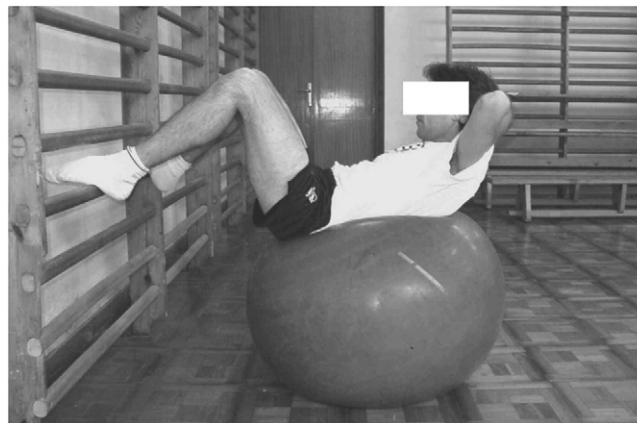


Fig 19. Spine flexion with flexed knees and hips on an unstable surface.

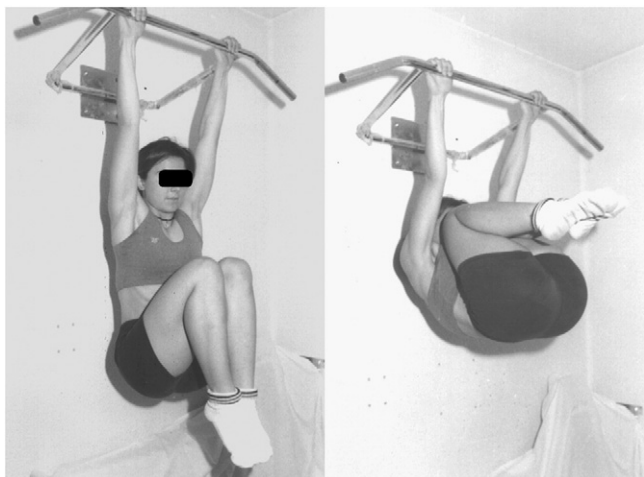


Fig 18. Pelvic tilt and spine flexion with bended knees and hips hanging from a chin-up bar.

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

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

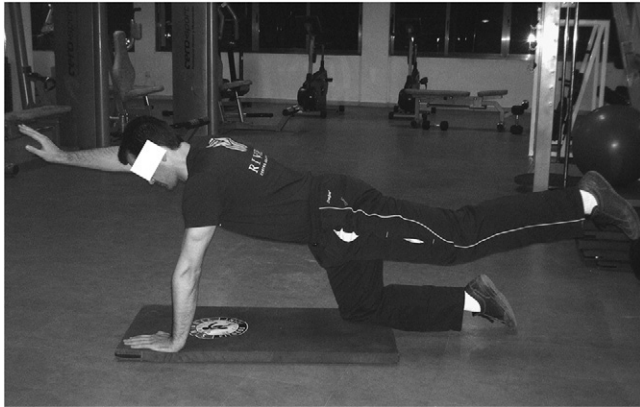


Fig 20. *Quadruped exercise in a 2-point stance, with a contralateral arm and leg raise.*

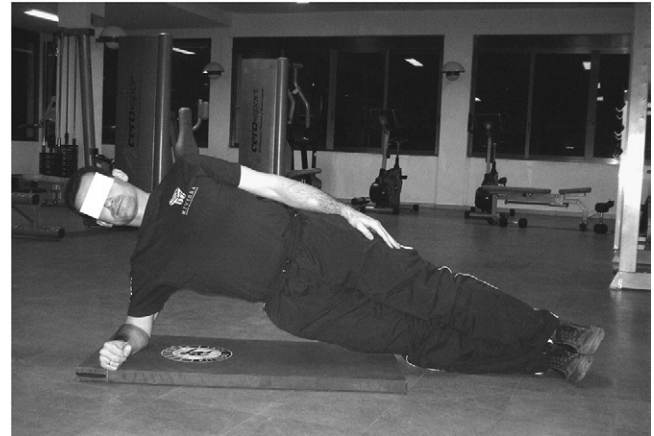


Fig 21. *Isometric side support exercise.*

without any change in the position of the muscles and maintaining the lumbar spine in a neutral position.^{76,77,86} Vera-Garcia et al⁷⁷ 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.

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