Functional load abdominal training: part 1

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Abstract This article reviews the principles of muscle imbalance relevant to abdominal training. Mobilisor and stabilisor muscle categories are described and muscle length adaptation is discussed. Examples of individual muscle tests to determine muscle lengthening and muscle shortening are given. Concepts of trunk stability are considered and integrated into abdominal training.

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Introduction

Abdominal training is a popular aspect of any fitness programme. Recreational fitness activities tend to emphasize the cosmetic aspects of training, seeking a ‘flat stomach’ or ‘slim waist’. Sport-based programmes on the other hand often stress the importance of a strong mid-section to enhance sports performance and reduce the risk of back injury. Both of these approaches hold merit for different target populations. The aim of this article is to review abdominal training with respect to both *training effectiveness* and *injury prevention*, opening abdominal training to subjects from a wider range of fitness levels.

Muscle imbalance

New concepts of muscle training

Popular training programmes for the abdominal muscles tend to emphasize strength by using the muscles as prime movers. Sit up actions with or without rotation, and leg raise exercises often form the bases of many programmes. However, one of the most important functions of the abdominal muscles is to stabilize the spine (Norris 1995) a feature often neglected, especially in sport.

Owing to anatomical, biomechanical and physiological features muscles may be categorized into two groups, stabilisors and mobilisors (Richardson 1992). The main differences between these two muscle categories are shown in Box 1. The structural and functional characteristics of the two muscle categories makes the stabilisors better equipped for postural holding with an ‘anti gravity’ function. The mobilisors are better set up for rapid ballistic movements and are often referred to as ‘task muscles’. In the case of the abdominal muscles (Box 2), the rectus abdominis and lateral fibres of external oblique may be considered as the prime movers (mobilisors) of trunk flexion, while the internal oblique and transversus abdominis are the major stabilizers of trunk movement in general. These muscles are the only two which pass from the anterior trunk to the lumbar spine (Miller & Medeiros 1987), and are critically involved in stabilization (Cresswell et al. 1994, Hodges & Richardson 1996).

Further categorization may be made into *primary* and *secondary* stabilisors. The primary stabilisors are those muscles which cannot create significant joint movements, such as the multifidus and transversus abdominis. These muscles act only to stabilize. The secondary stabilisors, such as the internal oblique, have excellent stabilizing capacity, but may also move joints. Taking this categorization further, mobilisors could be termed ‘tertiary stabilisors’ in that they primarily move the joint, but can stabilize in times of extreme need, an example being muscle spasm in the presence of pain. In this situation, however, stability has moved on to become rigidity and does not allow normal movement patterns.

Box 1 Muscle categories

Stabilisors	Mobilisors
• Deeply placed	• Superficial
• Aponeurotic	• Fusiform
• Slow twitch nature	• Fast twitch nature
• Active in endurance activities	• Active in power activities
• Selectively weaken	• Preferential recruitment
• Poor recruitment, may be inhibited	• Shorten and tighten
• Activated at low resistance levels (30–40% MVC)	• Activated at higher resistance levels (above 40% MVC)
• Lengthen	

Box 2 Trunk muscle categorization

Stabilisors		Mobilisors
Primary	*Secondary*	
• Transversus abdominis • Multifidus	• Internal oblique • Medial fibres of external oblique • Quadratus lumborum	• Rectus abdominis • Lateral fibres of external oblique • Erector spinae

Muscle length adaptation

Muscle adaptation to reduced usage has been extensively studied using immobilized limbs (Appell 1990). The greatest tissue changes are seen to occur within the first few days of disuse. Strength loss has been shown to be as much as 6% per day for the first 8 days, with minimal loss after this period (Muller 1970). The reaction of type (I) and (II) muscle fibres differs considerably, an important factor in the muscle imbalance process. Type (I) fibres show a greater reduction in size and loss of total fibre numbers within the muscle than type (II). In fact, the number of type (II) fibres actually increases demonstrating a process of selective atrophy of the type (I) fibres (Templeton et al. 1984). However, not all muscles show an equal amount of type (I) fibre atrophy. Atrophy is largely related to change in use relative to normal function, with the initial percentage of type (I) fibres that a muscle contains being a good indicator of likely atrophy pattern.

Selective changes in muscle may also occur as a result of training (Richardson & Bullock 1986). In the knee, rapid flexion-extension actions have been shown to selectively increase activity in the rectus femoris and hamstrings (biarticular) but not in the vasti (monoarticular). In this particular study, comparing

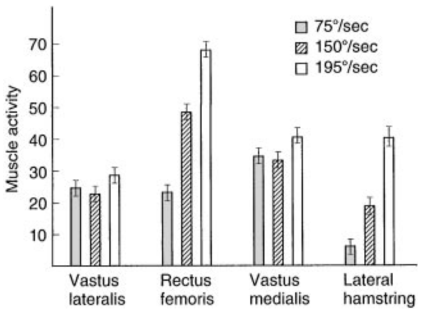


Fig. 1 Changes in muscle activity with increases in speed. Reproduced from Norris 1994, with kind permission from Butterworth Heinemann.

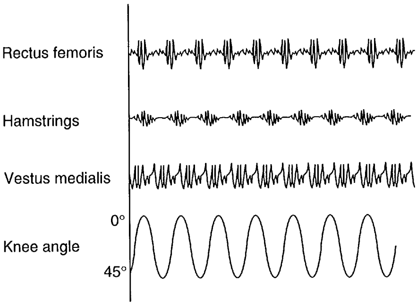


Fig. 2 Pattern of muscle activity during rapid alternating knee flexion–extension. Biarticular muscles are phasic, monoarticular muscles are tonic. Reproduced from Norris 1994, with kind permission from Butterworth Heinemann.

speeds of 75°/s and 195°/s, mean muscle activity for the rectus femoris increased from 23.0uV to 69.9uV. In contract, muscle activity for the Vastus medialis increased from 35.5uV to only 42.3uV (Fig. 1). The pattern of muscle activity was also noticeably different in this study after training. At the fastest speeds the rectus femoris and hamstrings displayed phasic (on and off) activity while the vastus medialis showed a tonic (continuous) pattern (Fig. 2).

Even in the more functional closed kinetic chain position similar changes have been found (Ng & Richardson 1990). A 4-week training period of rapid plantar flexion in standing gave significant increases in jump height reflecting gastrocnemius activity (mobilisor) but also significant loses of static function of the soleus (stabilisor).

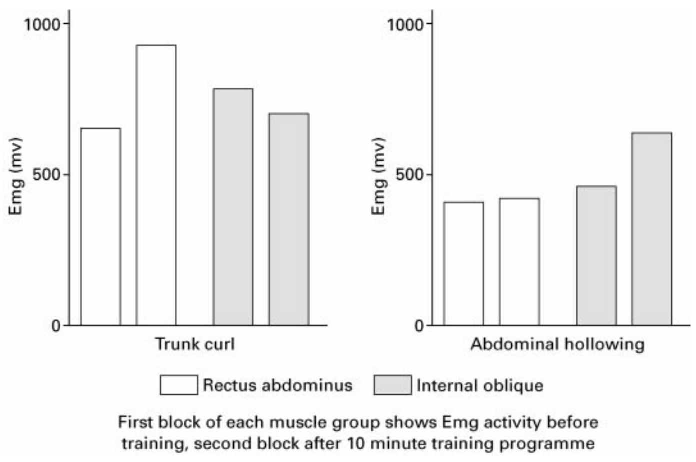
In the trunk, recruitment patterns of the abdominal muscles have also been shown to change depending on the type of training used (O'Sullivan et al. 1998). Subjects followed a 10-week training programme involving either abdominal hollowing or gym exercise including sit-up type activities. In the hollowing group EMG activity for the internal oblique increased, while that of rectus abdominis remained relatively unchanged. Those subjects incorporating sit-up type actions (but not hollowing) showed an increase in rectus abdominis activity and a reduction in that of the internal oblique (Fig. 3).

Stabilisor muscles tend to 'weaken' (sag) whereas mobilisors tend to 'shorten' (tighten). The length tension relationship of a muscle dictates that a stretched muscle, where the actin and myosin filaments are pulled apart, can exert less force than a muscle at normal resting length. Where the stretch is maintained, however, this *short term response* (reduced force output) changes to a *long-term adaptation*. The muscle tries to move its actin and myosin filaments closer together, and to do this, it must add more sarcomeres to the ends of the muscle (Fig. 4). This adaptation, known as an increase in serial sarcomere number (SSN), changes the nature of the length tension curve itself.

Long-term elongation of this type causes a muscle to lengthen by the addition of up to 20% more sarcomeres (Gossman et al. 1982). The length–tension curve of an adaptively lengthened muscle moves to the right (Fig. 5). The peak tension such a muscle can produce in the laboratory situation is up to 35% greater than that of a normal length muscle (Williams & Goldspink 1978). However, this peak tension occurs at approximately the position where the muscle has been immobilized (point A, Fig. 5). If the strength of the lengthened muscle is tested with the joint in mid-range or inner-range (point B, Fig. 5), as is common clinical practice, the muscle cannot produce its peak tension, and so the muscle appears 'weak'.

In the laboratory situation the lengthened muscle will return to its optimal length within approximately 1 week if placed in a shortened position once more (Goldspink 1992). Clinically, restoration of optimal length may be achieved by either immobilizing the muscle in its physiological rest position (Kendall et al. 1993), and/or exercising it in its shortened (inner range) position (Sahrmann 1990). Enhancement of strength is not the priority in this situation, indeed the load on the muscle may need to be reduced to ensure correct alignment of the various body segments and correct performance of the relevant movement pattern.

Serial sarcomere number (SSN) may be responsible partly for changes in muscle strength without parallel changes in hypertrophy (Koh 1995). SSN exhibits marked



First block of each muscle group shows Emg activity before training, second block after 10 minute training programme

Fig. 3

Fig. 4 Muscle length adaptation. (a) Normal muscle length. (b) Stretched muscle–filaments move apart and muscle loses tension. (c) Adaptation by increase in serial sarcomere number (SSN), normal filament alignment restored, muscle length permanently increased. Reproduced from Norris 1994, with kind permission from Butterworth Heinemann.

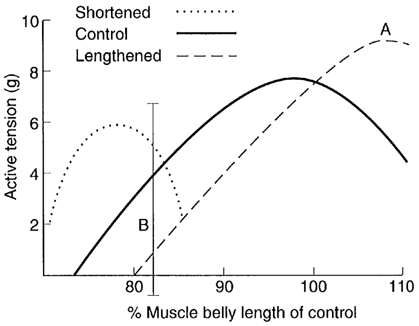


Fig. 5 Effects of immobilizing a muscle in shortened and lengthened positions. The normal length–tension curve (control) moves to the right for a lengthened muscle, giving it a peak tension some 35% greater than the control (point A). When tested in an inner range position however (point B), the muscle tests weaker than normal. Reproduced from Norris 1994, with kind permission from Butterworth Heinemann.

plasticity and may be influenced by a number of factors. For example, immobilization of rabbit plantarflexors in a lengthened position showed an 8% increase in SSN in only 4 days, while applying electrical simulation to increase muscle force showed an even greater increase (Williams et al. 1986). Stretching a muscle appears to have a greater effect on SSN than does immobilization in a shortened position. Following immobilization in a shortened position for 2 weeks, the mouse Soleus has been shown to decrease SSN by almost 20% (Williams 1990). However, stretching for just 1 h per day in this study not only eliminated the SSN reduction, but actually produced nearly a 10% increase in SSN. An *eccentric stimulus* appears to cause a greater adaptation of SSN than a concentric stimulus. Morgan and Lynn 1994 subjected rats to uphill or downhill running, and showed SSN in the vastus intermedius to be 12% greater in the eccentric trained rats after 1 week. It has been suggested that if SSN adaptation occurs in humans, strength training may produce such a change if it were performed at a joint angle different from that at which the maximal force is produced during normal activity (Koh 1995).

Rather than being weak, the lengthened muscle lacks the ability to maintain a full contraction within inner range. This shows up clinically as a difference between the active and passive inner ranges. If the joint is passively placed in full anatomical inner range, the subject is unable to hold the position. Sometimes the position cannot be held at all, but more usually the contraction cannot be sustained, indicating a lack in slow twitch *endurance capacity*.

Clinically, reduction of muscle length is seen as the enhanced ability to hold an inner range contraction. This may or may not represent a reduction in SSN, but is a required functional improvement in postural control. Muscle shortening has been shown in the dorsiflexors of horseriders. Clearly this position is not held permanently as with splinting, but rather shows a training response. Following pregnancy, SSN increases in the rectus abdominis in combination with diastasis. Again, length of the muscle gradually reduces in the months following childbirth. Inner range training then is likely to shorten a lengthened muscle (Goldspink 1996).

Assessment and correction of muscle imbalance

Structural and functional alterations of muscles which occur as part of the imbalance process show as three important signs (Fig. 6). Firstly, *tightening* of the mobilisor (two joint) muscles and secondly, loss of endurance (*holding*) within inner range for the stabilisor (single joint) muscles. These two changes are used as tests for the degree of muscle imbalance present.

The combination of length and tension changes alters muscle pull around a joint and so may draw the joint out of alignment. Changes in body segment *alignment* and the ability to perform movements which dissociate one body segment from another forms the bases of the third type of test used when assessing muscle imbalance.

The mixture of tightness and weakness seen in the muscle imbalance process alters body segment alignment and changes the equilibrium point of a joint. Normally, the equal resting tone of agonist and antagonist muscles allows the joint to take up a balanced resting position where the joint surfaces are evenly loaded and the inert tissues of the joint are not

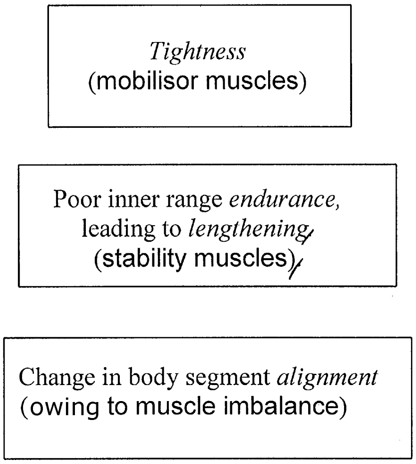


Fig. 6 Muscle alteration as part of the imbalance process.

excessively stressed. However, if the muscles on one side of a joint are tight and the opposing muscles are lax, the joint will be pulled out of alignment towards the tight muscle (Fig. 7). This alteration in alignment throws weight bearing stress onto a smaller region of the joint surface increasing pressure per unit area (focal loading). Further, the inert tissues on the shortened (closed) side of the joint will contract over time. These alignment changes are highlighted during the assessment of static posture in standing and sitting especially. Taking pelvic alignment during standing as an example which is highly relevant to abdominal training, the lordotic posture is one which combines muscles lengthening and shortening. In an optimal posture (Kendal et al. 1993) the pelvis should be level such that the anterior superior iliac spine is horizontally aligned to the posterior superior iliac spine and vertically aligned to the pubis (Fig. 8). In the lordotic posture, the pelvis tilts forwards, an alignment which is associated with lengthening of the abdominal muscles (especially rectus abdominis) and gluteals combined with shortening of the hip flexors, the so called 'pelvic crossed syndrome' (Janda & Schmid 1980). Individual muscle tests are used to assess the degree of muscle length change. The Thomas test may be used to measure hip flexor tightness (Fig. 9) while inner range holding of the gluteals in this case is used to assess sarcomere adaptation of these muscles (Fig. 10).

Imbalance also leads to a lack of accurate segmental control. The combination of stiffness (hypoflexibility) in one body segment and laxity (hyperflexibility) in an adjacent body segment leads to the establishment of relative flexibility (White & Sahrmann 1994). In a chain of movement, the body seems to take the path of least resistance, with the more flexible segment always contributing more to the total movement range.

Figure 11 shows a toe touching movement. The two areas of interest with relation to relative flexibility are the hamstrings and lumbar spine tissues. As we flex forwards, movement should occur through a combination of anterior pelvic tilt and lumbar spine flexion. Subjects often have tight hamstrings and far more lax lumbar tissues due to excessive bending (lumbar flexion) as part of everyday activities. During this flexion action, greater movement and, therefore, greater tissue strain will always occur at the lumber spine. Relative flexibility in this case makes the toe touching exercise ineffective as a hamstring stretch unless the trunk muscles are tightened to stabilize the lumbar spine at the same time.

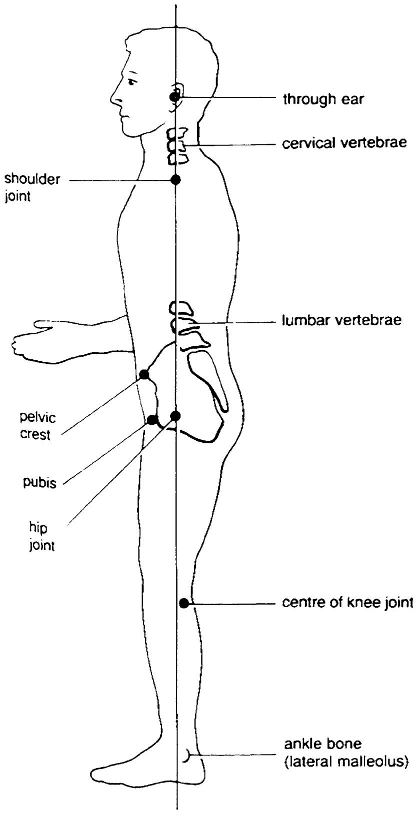


Fig. 8 Optical postural alignment. Reproduced with kind permission from Norris (1999), The Complete Guide to Stretching, published by A & C Black Ltd. © A & C Black Ltd.

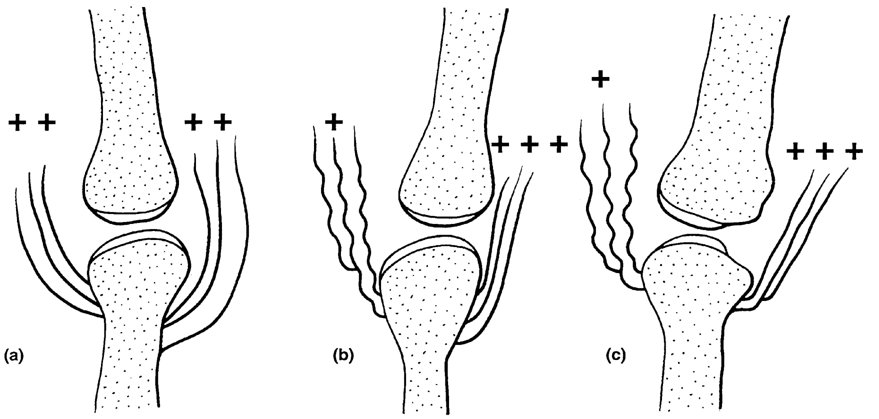


Fig.7 Muscle imbalance altering joint mechanics: (a) symmetrical muscle tone – normal joint; (b) unequal muscle pull (imbalance) – joint alignment poor; (c) joint surface degeneration. Reproduced with kind permission from Norris (1999), The Complete Guide to Stretching, published by A & C Black Ltd. © A & C Black Ltd.

Trunk stability

Lack of stability (*instability*) of the lumbar spine must be contrasted with *hypermobility*. In both conditions the range of motion is greater than normal. However, instability is present when there is 'an excessive range of abnormal movement for which there is no protective muscular control'. With hypermobility, stability is provided

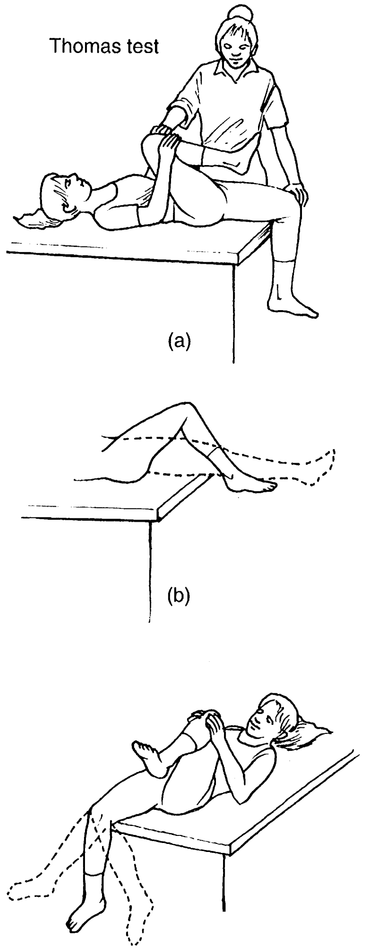


Fig. 9 The Thomas test. The subject is positioned at the end of the treatment couch. His/her spine is passively flexed by bringing the knees to the chest. One knee is held to the chest to maintain the pelvic position while the other leg is lowered. Optimal alignment occurs when the femur is horizontal and tibia vertical (a). If the femur is held above the horizontal, hip flexor tightness is indicated. Extending the knee will take the stretch off rectus femoris (b), if the knee then drops down, tightness in the iliopsoas in present. The position of the tibia in the frontal plane indicates the presence of hip rotation requiring further examinatiion (c). Reproduced from Norris 1994, with kind permission from Butterworth Heinemann.

because the 'excessive range of movement... has complete muscular control' (Maitland 1986). The essential feature of stability is, therefore, the ability of the body to control the whole range of motion of a joint, in this case the lumbar spine.

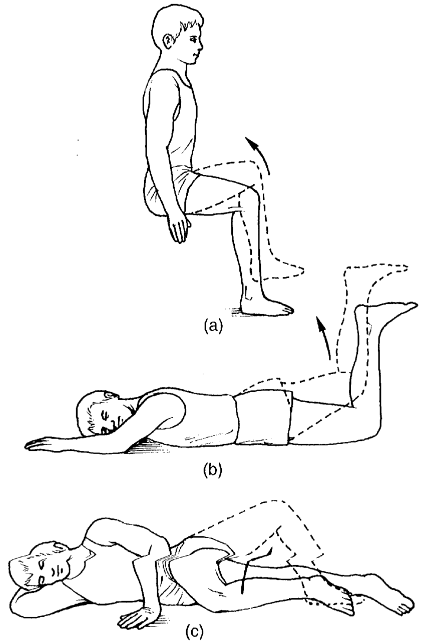


Fig. 10 Inner range holding tests. The limb is taken to full passive inner range and the subject is instructed to hold this position. Optimal endurance is indicated when the full inner range position can be held for 10–20 seconds. Muscle lengthening is present if the limb drops away from the inner range position immediately. Endurance is poor if the inner range position is maintained for less than 10 seconds. Tests for possible lengthened muscles around the hip include the illopsoas (a), gluteus maximus (b), and posterior fibres of gluteus medius (c). Reproduced from Norris 1994 with kind permission from Butterworth Heinemann.

When the lumbar spine demonstrates instability, there is a failure to maintain correct vertebral alignment. The unstable segment shows decreased stiffness (resistance to bending) and as a consequence movement is increased even under minor loads. Both the quality and quantity of motion is therefore altered. Clinically, with reference to the lumbar spine, this description of instability means that there is no damage to the spinal cord or nerve roots, and no incapacitating deformity. However, because movement is excessive, pain sensitive structures may be either stretched or compressed and inflammation may occur (Kirkaldy-Willis 1990, Panjabi 1992).

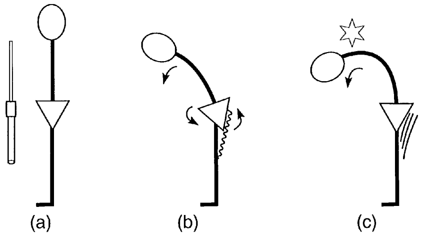


Fig. 11 Relative flexibility in the body. (a) Tighter hamstrings, more lax spinal tissues. (b) Forward flexion should combine pelvis tilt and spinal flexion equally. (c) Tight hamstrings limit pelvic tilt, throwing stress on the more lax spinal tissues. Reproduced from Norris (1994), with kind permission from Butterworth Heinemann.

To maintain spinal stability, three interrelated systems have been proposed (Fig. 12). Passive support is provided by inert tissues, while active support is from the contractile tissues. Sensory feedback from both systems provides coordination via the neural control centres (Panjabi 1992). Importantly, where the stability provided by one system reduces, the other systems may compensate. Thus, the proportion of load taken by the active system may increase to minimize stress on the passive system through load sharing (Tropp et al. 1993). This gives the individual the opportunity to reduce pain and improve function by restoring back stability through exercise. Such improvement may be accomplished by augmenting both the active and neural control systems. Simply developing muscle strength is insufficient. Moreover, many popular strength exercises for the trunk actually increase mobility in this region to dangerously high levels (Norris 1993, 1994a). Rather than improving stability, exercises of this type may reduce it and could therefore increase symptoms, especially those associated with inflammation.

In terms of spinal stabilization, rather than the strength of the abdominal muscles, it is the speed with which they contract in reaction

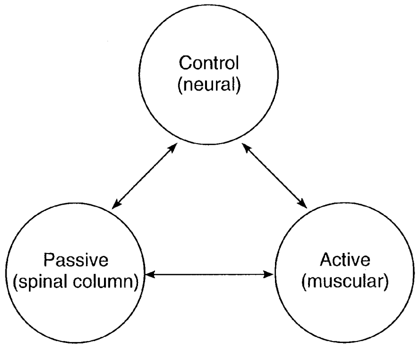


Fig. 12 The spinal stabilizing system consists of three interrelating sub-systems. Reproduced from Norris (1994), with kind permission from Butterworth Heinemann.

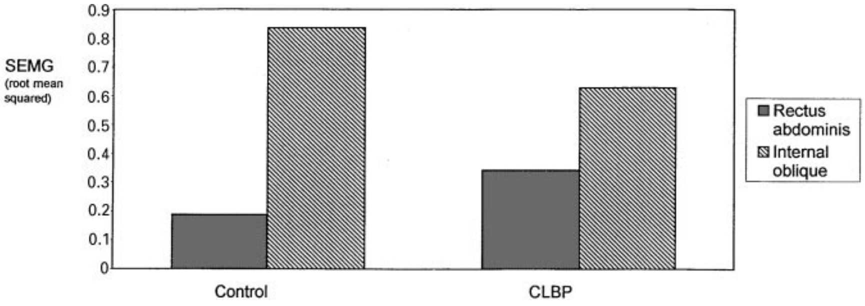


Fig. 13 Abdominal muscle activation is chronic low back pain. (Data adapted from O'Sullivan et al. 1997).

to a force tending to displace the lumbar spine which is important (Saal & Saal 1989). Additionally, the ability of a patient to dissociate deep abdominal function from that of the superficial abdominals is also vital, as it is the deep abdominals which have the more significant stabilizing function. An abdominal hollowing action rather than a sit-up movement has been shown to work the transversus abdominis and the internal oblique (stabilisors) rather than the rectus abdominis and the external oblique (Richardson et al. 1992). Patients with chronic low back pain (CLBP) have been shown to be poorer at using the internal oblique than the rectus abdominis and external oblique, reflecting a shift in the pattern of motor activity (O'Sullivan et al. 1997). As an abdominal hollowing action is attempted, there is a substitution of the superficial muscles which override the deep abdominals (Fig. 13). When expressed as a ratio of internal oblique over rectus abdominis (IO/RA) the value from the control group (non-LBP) was 8.74, while the CLBP group had a ratio of only 2.41 indicating a much larger proportional contribution to hollowing by the internal oblique in the normal group. It seems that pain inhibition in these subjects may have lead to altered muscle recruitment and compensatory strategies when performing motor tasks (O'Sullivan et al. 1997). The ratio of muscle activity rather than the intensity of muscle activity is therefore relevant.

The rectus abdominis will flex the trunk by approximating the pelvis and ribcage. EMG investigation has shown the supraumbilical portion to be emphasized by trunk flexion, while activity in the infraumbilical portion is greater in positions where a posterior pelvic tilt is held (Lipetz & Gutin 1970, Guimaraes et al. 1991).

By assessing EMG activity of the trunk muscles it has been shown that the muscles do not simply work as prime movers of the spine, but show antagonistic activity during various movements. The oblique abdominals are more active than predicted, to help to stabilize the trunk (Zetterberg et al. 1987). During maximum trunk extension, activity of the abdominal muscles varied from 32% to 68% of the activity in longissimus. In resisted lateral flexion, as would be expected, the ipsilateral muscles showed maximum activity, but the contralateral muscles were also active at about 10%–20% of these maximum values (Zetterberg et al. 1987).

In maximum voluntary isometric trunk extension, transversus abdominis is the only one of the abdominal muscles to show marked activity. The coordinated patterns seen between the abdominal muscles have been shown to be task specific, with transversus abdominis being the muscle most consistently related to changes in IAP (Cresswell et al. 1992). The transversus abdominis not only contracts with multi-directional trunk activities, its activity also precedes the contraction of the other trunk muscles (Cresswell et al. 1994).

Where repeated movements are concerned the onset of the load is predictable, and so the body *anticipates* the load and braces the muscles accordingly. This action is commonly seen in stance, but has also been found to occur with the transversus abdominis during rapid shoulder movements. Using fine wire electrodes, Hodges and Richardson (1996) assessed abdominal muscle action during shoulder movements. They found that transversus abdominis and internal oblique contracted before the shoulder muscles by as much as 38.9 msec. The reaction time for the deltoid was on average 188 msec, with the abdominal muscles, except transversus, following the deltoid contraction by 9.84 msec. With subjects who had a history of lower back pain, however, none of the abdominal muscles preceded contraction of the deltoid, indicating that they had lost the anticipatory nature of stability (Fig. 14).

Contraction of the abdominal muscles before the initiation of limb movement has been highlighted by a number of authors, as an example of a feed forward postural reaction

(Friedli et al. 1984, Aruin & Latash 1995). In these cases, as would be expected, the erector spinae and the external oblique are seen to contract before arm flexion while the rectus abdominis contracts before arm extension. In each case, the trunk muscles act to limit the reactive body movement towards the moving limb. Contraction of the transversus before the other abdominal muscle has been described by Cresswell et al. (1994) in response to trunk movements, but anticipatory contraction during limb movements is a newer finding. The transversus abdominis seems to be contracting during posture, not simply to bring the body back closer to the posture line, but to increase the stiffness of the lumbar region and enhance stability (Hodges et al. 1996).

Importance of imbalance for functional abdominal training

A number of important points concerning imbalance and muscle adaptation have direct relevance to improving the standard of abdominal training. Firstly, rapid movement speeds and higher resistance's have been shown to selectively recruit mobilisor muslces, and, in the case of the abdomen, the rectus abdominis especially. To reduce the recruitment of this muscle and increase the work on transversus abdominis and internal oblique, *low resistances and slow movements should be used.*

Secondly, *eccentric actions* have been shown to be better suited for reversal of serial sarcomere adaptation. In the lordotic posture, the pelvis is anteriorly tilted, and the rectus abdominis lengthened. A significant realstionship exists between angle of pelvis tilt and abdominal muscle length, but not between pelvic tilt and abdominal muscle strength (Toppenberg & Bullock 1990). To modify the abdominal muscles in a lordotic posture, therefore, *inner range movements* should be used (full lumbar flexion combined with posterior pelvic tilt) with an emphasis on eccentric training initially. This should be combined with hip flexor muscle stretching to allow full posterior pelvic tilt. Clearly to determine whether muscle shortening or muscle lengthening is required, a *muscle imbalance assessment* should be made to assess static posture and then individual muscles tests used to determine muscle shortening (range of motion) or lengthening (inner range holding). Full details of tests of this type are described elsewhere (Norris 1998, Norris 2000).

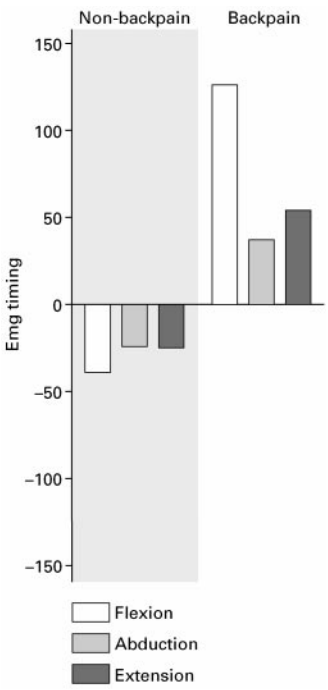


Fig. 14 Activity of transversus abdominis muscle during shoulder movements. Note that subjects with backpain had a longer transversus reaction time. 0 emg timing represents the onset of shoulder movement. (Data from Hodges and Richardson 1996.)

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