Floor muscles contract at the same time as the abdominal muscles, the displacement of the abdominal contents is resisted and the tension in the muscles and fascia is increased as the muscles contract around the abdominal cavity (Fig. 1.49). Thus, pelvic floor muscle contraction is essential both to tense the thoracolumbar fascia and to increase intra-abdominal pressure.

When considering the range of strategies available to control stability, it is important to recognize that intervertebral stability can be achieved if the spine is compressed by co-contraction of the larger superficial muscles, the guy wires, or by contraction of the deeper muscles of the abdominal canister. A key advantage of using the deep muscles, fascial tension, and intra-abdominal pressure is that they control intervertebral motion without restricting the overall movement of the spine. That is, these muscles can control the spine in a dynamic sense by providing underlying control of intervertebral motion, while the larger, more superficial muscles can move the spine and oppose applied forces [Hodges 2004].

**Intra-Abdominal Pressure and the Pelvic Floor**

It has been argued for many years that intra-abdominal pressure contributes to control of the spine. Originally, intra-abdominal pressure was thought to act as a balloon in front of the spine that pushed down on the pelvic floor and up on the diaphragm to cause the spine to extend and thus prevent it from being flexed during lifting [Bartelink 1957, Morris and Lucas 1961]. However, this was questioned, as the pressures that would need to be generated to produce this effect are greater than those recorded during functional tasks [Davis and Troup 1964]. Recent in-vivo human experiments that involved measuring the effect of an artificial increase in intra-abdominal pressure from electrical stimulation of the diaphragm indicate that the extension moment produced by intra-abdominal pressure is small [Hodges et al. 2001a]. Alternatively, it has been argued that intra-abdominal pressure controls shear forces. This has been confirmed in vivo. Resistance of the spine to a posteroanterior shear force is increased when intra-abdominal pressure is increased by stimulation of the diaphragm in humans [Hodges and Shirley, in press] and stimulation of the diaphragm and/or transversus abdominis in pigs [Hodges et al. 2004]. Thus, via a contribution to intra-abdominal pressure, the pelvic floor muscles may contribute to intervertebral control of the lumbar spine (Fig. 1.49). An important consideration is that there are many muscles that can modulate intra-abdominal pressure, and the effect of the pressure on the spine may differ between strategies. For instance, if pressure is generated by bracing of the superficial oblique abdominal muscles, the flexor moment from contraction of these muscle must be matched by contraction of the extensor muscles. This strategy could make the spine rigid, which may compromise dynamic control, and although this strategy may be...
appropriate when high loads are imposed on the spine (e.g., during lifting), this may not be ideal for low-load functional situations. In addition, the pressure generated from this contraction may overcome that of the pelvic floor muscles and lead to descent of the pelvic floor. Alternatively, if pressure is generated by contraction of the pelvic floor muscles, transversus abdominis, and the diaphragm, these muscles do not generate torque and can control intervertebral motion without making the spine rigid.

Thoracolumbar Fascial Tension and the Pelvic Floor

It has been also argued that tension of the thoracolumbar fascia produces an extension moment and controls intervertebral shear force [Farfan 1975, Tesh et al. 1987]. Although the contribution to extension has been shown to be small [Bogduk and Macintosh 1984, McGill and Norman 1988], recent porcine studies provide evidence that fascial tension contributes to the control of intervertebral motion [Hodges et al. 2003a], and in-vitro human cadaver studies indicate that tension of the fascia controls intervertebral translation/shear [Barker and Guggenheimer 2004]. Thus, via an indirect contribution to fascial tensioning by resisting displacement of the abdominal contents (Fig. 1.49), the pelvic floor muscles provide an additional effect on the control of intervertebral motion.

Motor Control of the Pelvic Floor Muscles for Control of the Lumbar Spine

Coordinated activity of the muscles that surround the abdominal cavity (sometimes described as an “abdominal canister,” Fig. 1.48) is required to meet the demands of control of the lumbar spine. Coordinated activity of the pelvic floor muscles, diaphragm, and transversus abdominis has been investigated in a number of studies, and a variety of control strategies have been identified. When the spine is challenged in a predictable manner, such as when a limb is moved rapidly, the pelvic floor muscles [Hodges and Sapsford 2002] (Fig. 1.50), transversus abdominis [Hodges and Richardson 1997], and diaphragm [Hodges et al. 1997] contract in advance of the initiation of the movement. Notably, this response occurs irrespective of the direction of force at the spine, and is accompanied by contraction of the deep fibers of the lumbar multifidus [Moseley et al. 2002]. Another example of a predictable challenge to spinal control is lifting a mass from the floor. Pelvic floor muscle activity has been recorded during this task [Hemborg et al. 1985]. It is argued that the activity of these muscles is responsible for the control of intervertebral motion (Fig. 1.46). Contraction of the more superficial muscle also occurs in this situation. However, the activity of these muscles is responsible for controlling the orientation of the spine.

Fig. 1.50 The response of the pelvic floor muscles to perturbation to the spine. When a limb is moved rapidly, activity of the pelvic floor muscles (arrows) is initiated before the muscle that moves the arm (deltoid). EMG: electromyography.
and control of buckling forces (Fig. 1.46) and is dependent on the direction of forces acting on the spine [Aruin and Latash 1995, Hodges and Richardson 1997]. As expected, in conjunction with the activity of the muscles of the abdominal canister, intra-abdominal pressure is increased in advance of predictable challenges to the spine [Hodges et al. 1997]. Thus, the response of the pelvic floor muscles in this context is similar to the activity of the pelvic floor muscles in advance of other tasks that involve an increase in intra-abdominal pressure, such as a cough or sneeze [Thind et al. 1990]. An important issue to consider is that the majority of these studies have investigated the general activity of the pelvic floor muscles. Further studies are required to determine whether specific muscles in the pelvic floor are differentially active in these tasks.

When the spine is challenged unpredictably, activity of the trunk muscles is initiated with short latency after the disturbance, in response to afferent (sensory) input from the perturbation, such as muscle stretch or joint movement. Recent studies with recordings of pelvic floor muscle activity have confirmed the contribution of these muscles to this task [Sommerville and Hodges, unpublished data]. When stability of the spine is challenged in an ongoing manner, such as during repetitive arm movements or walking, activity of the diaphragm [Hodges and Gandevia 2000a] and transversus abdominis [Hodges and Gandevia 2000b] occurs tonically. Studies of repetitive arm movement confirm that activity of the pelvic floor muscles occurs tonically, with increased activity with each arm movement [Hodges and Sapsford 2002].

Coordination of the Muscles of the Abdominal Canister

Studies of the postural function of the pelvic floor muscles suggest a coordinated strategy in which all of the muscles of the abdominal canister are co-activated in order to control the intra-abdominal pressure and fascia tension. Ideally, this would be simplified by neural strategies that coordinate their activity. Early animal studies provide support for this hypothesis. Stimulation of the pelvic afferents was associated with reflex co-activation of the diaphragm, pelvic floor and abdominal muscles [Yamamoto et al. 1961]. This provides an initial indication that coordinative strategies do exist, even at the reflex level. More recent studies have investigated similar phenomena in human subjects. These studies have evaluated whether co-activation of the transversus abdominis, diaphragm, and pelvic floor muscles is initiated by contraction of one muscle of the group. Initial studies showed that although activity of all of the abdominal muscles was initiated by maximal contraction of the pelvic floor muscles, the activity was more selective to the transversus abdominis when the pelvic floor muscle contraction was performed in a slow, controlled manner [Sapsford et al. 2001] (Fig. 1.51). The converse was also tested, with the subjects performing a transversus abdominis contraction, and pelvic floor muscle activity was initiated [Sapsford and Hodges 2001].

More recently, authors have argued that in some individuals, contraction of the transversus abdominis may lead to descent of the pelvic floor muscles [Bø et al. 2003]. However, it is not possible to infer activity of pelvic floor muscles from this measure. In addition, it is difficult to interpret these data as the strategy used by the subjects, as no attempt was made to confirm that the contraction of transversus abdominis was isolated from a bracing maneuver of the oblique abdominal muscles, pelvic floor motion was measured via a transabdominal technique (bracing of the abdominal wall would have displaced the ultrasound transducer, giving the appearance of pelvic floor descent), and women with mild incontinence were included in the study. In a final study, activity of the diaphragm was identified in conjunction with voluntary contraction of the transversus abdominis [Allison et al. 1998]. Although this could not be convincingly confirmed due to the use of surface electrodes to record from the diaphragm, the findings were confirmed in a more recent study using intramuscular electrodes to record the activity of the diaphragm [Hodges and Gandevia 1998].

In summary, the muscles of the pelvic floor provide a critical contribution to the control of the spine, particularly for control of intervertebral motion via intra-abdominal pressure increases and tension of the thoracolumbar fascia. Notably, the activity of these muscles is coordinated as a component of the neural strategy to meet the challenges to control of the spine.
Contribution of the Pelvic Floor Muscles to Control of the Pelvis

Muscular Control of the Pelvic Girdle

Control of the joints of the pelvic girdle (sacroiliac joints and pubic symphysis) is dependent on muscle activity. Contraction of the transversus abdominis, which attaches to the iliac crests, generates a compressive force at the sacroiliac joint and reduces joint laxity [Snijders and Vleeming 1995] (Fig. 1.52). Due to the lever created by the ilia, the force of contraction of this muscle is amplified, creating an efficient mechanism for control [Snijders and Vleeming 1995]. The effect of this contraction on the sacroiliac joints has been confirmed in vivo in humans with measurement of sacroiliac joint laxity with ultrasound imaging [Richardson et al. 2002]. This mechanism can also be assisted by contraction of the obliquus internus abdominis due to the horizontal orientation of the lower fibers of this muscle. Furthermore, posterior muscles such as the gluteal muscles and latissimus dorsi (together called the posterior sling, Fig. 1.52) and some fibers of the lumbar multifidus, which also cross the joints, may assist the force closure mechanism [Snijders and Vleeming 1995] (Fig. 1.52).

Control of the pubic symphysis has been less well investigated. Contraction of the transversely oriented abdominal muscles, with attachments to the iliac crests and inguinal ligaments, will compress the joint, at least superiorly [Cowan and Schache, in press]. It has also been argued that some fibers of the abdominal muscles may cross the joint, leading to direct compression (Fig. 1.52). Whether the pelvic floor muscles contribute to the control of the pubic symphysis is unclear.

Finally, in addition to the control of the joints of the pelvis it is also necessary to control the orientation of the pelvis in space (Fig. 1.46). Orientation of the pelvis may be controlled by co-contraction of the larger superficial abdominal muscles or by carefully sequenced activity of these muscles [Saunders et al. 2004]. As for the lumbar spine,
the balance between movement and stability must be matched to the demands of each task.

Pelvic Floor Muscles and Pelvic Girdle Control

The effect of pelvic floor muscles on the joints of the pelvis is complex. The iliococcygeus and ischiococcygeus muscles cross the sacroiliac joints and may generate a compressive force [Pool-Goudzwaard et al. 2004] (Fig. 1.52). Data from an in-vitro model suggest that simulated contraction of these muscles may increase sacroiliac stability in women, but not men [Pool-Goudzwaard et al. 2004]. However, contraction of the pelvic floor muscles – particularly the pubococcygeus and puborectalis – would also have the effect of counternutation of the sacrum (i.e., rotation of the sacrum backward relative to the ilia) (Fig. 1.52). This would place the sacroiliac joints in an open packed position, thus reducing the inherent stability of the joint. This motion may be counteracted by co-contraction with the lumbar multifidus, which acts to nutate the sacrum [Snijders and Vleeming 1993a] (Fig. 1.52). This requirement for coordinated activity of multiple muscles to ensure control highlights the importance of the integrated function of the muscles of the abdominal canister. For instance, pelvic floor muscle activity is required when intra-abdominal pressure is increased, but as this is accompanied by counternutation of the sacrum, activity of the transversus abdominis is required to increase force closure of the sacroiliac joint, and activity of the lumbar multifidus is required to nutate the sacrum and assist force closure. Any factor that compromises the function of any component of the system (for example, altered function of the pelvic floor muscles with incontinence, altered function of multifidus with

![Fig. 1.52](image-url)
low back pain, or altered function of the transversus abdominis with respiratory disease or low back pain) is likely to lead to compromised control of lumbopelvic stability.

**Coordination of the Multiple Functions of the Trunk Muscles**

A factor that complicates the normal control of the lumbopelvic muscles is that these muscles not only control stability of the lumbar spine and pelvis, but also provide an essential contribution to continence and respiration. Conveniently, the demands for stability and continence are generally consistent. That is, sustained activity of the pelvic floor muscles to maintain continence is consistent with the requirement for activity to control the lumbar spine and pelvis. One exception would be a situation in which increased demand for spinal control leads to increased pelvic floor muscle activity and compromised micturition or defecation. This has been proposed in specific subgroups of patients with lumbopelvic pain [Pool-Goudzwaard 2003]. In contrast, the coordination of activity of these muscles for respiration and stability can be challenging, as respiration requires phasic modulation of activity to move air in and out of the lungs. This may compete with the demand to maintain tonic activity of the pelvic floor, abdominal, and diaphragm muscles, particularly if respiratory demand is increased and the depth of breathing is increased.

The diaphragm is the principal muscle of inspiration [Agostoni and Sant’Ambrogio 1970]. Although expiration is produced by passive recoil of the chest wall during quiet breathing, the transversus abdominis is the first muscle recruited when expiratory flow or volume is increased [DeTroyer et al. 1990]. Activity of the pelvic floor muscles is also modulated with respiration (Fig. 1.53). In general, this activity is associated with periods of increased intra-abdominal pressure [Hodges and Sapsford 2002]. During quiet breathing, intra-abdominal pressure is increased during inspiration in association with activity of the diaphragm [Campbell and Green 1953]. Thus, in quiet breathing, pelvic floor muscle activity is inspiratory [Hodges and Sapsford 2002]. Importantly, this is not identified in all individuals [Hodges and Sapsford 2002], and tonic activity or passive tension on the pelvic floor muscles may be sufficient to meet the demands of the small increase in intra-abdominal pressure. When respiration is increased – for example, during exercise – intra-abdominal pressure increases biphasingly, with a rise in pressure during inspiration in association with diaphragm contraction and a second increase in pressure during expiration in association with contraction of the abdominal muscles (particularly the transversus abdominis) [Hodges and Sapsford 2002]. In summary, during inspiration, contraction of the pelvic floor muscles is required to maintain the integrity of the continence mechanism. However, during expiration, intra-abdominal pressure is increased to elevate and lengthen the diaphragm. Thus, pelvic floor muscle activity contributes to

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![Fig. 1.53](image-url) Respiratory activity of the pelvic floor muscles. Inspiration is indicated by the gray boxes. During quiet breathing, intra-abdominal pressure (IAP) increases during inspiration. When breathing is increased by hypercapnia, intra-abdominal pressure increases during inspiration and expiration, and there are small changes in pelvic floor activity as measured by anal electromyography (EMG) either during inspiration or expiration, or both phases. During expiration against resistance, intra-abdominal pressure is increased during expiration, associated with a large increase in pelvic floor muscle activity.