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FASCIA & PREGNANCY: INTEGRATED CLINICAL MANAGEMENT

Stability, continence and breathing: The role of fascia following pregnancy and delivery

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Summary Pregnancy-related pelvic girdle pain (PRPGP) has a prevalence of approximately 45% during pregnancy and 20–25% in the early postpartum period. Most women become pain free in the first 12 weeks after delivery, however, 5–7% do not. In a large postpartum study of prevalence for urinary incontinence (UI) [Wilson, P.D., Herbison, P., Glazener, C., McGee, M., MacArthur, C., 2002. Obstetric practice and urinary incontinence 5–7 years after delivery. ICS Proceedings of the Neurourology and Urodynamics, vol. 21(4), pp. 284–300] found that 45% of women experienced UI at 7 years postpartum and that 27% who were initially incontinent in the early postpartum period regained continence, while 31% who were continent became incontinent. It is apparent that for some women, something happens during pregnancy and delivery that impacts the function of the abdominal canister either immediately, or over time.

Current evidence suggests that the muscles and fascia of the lumbopelvic region play a significant role in musculoskeletal function as well as continence and respiration. The combined prevalence of lumbopelvic pain, incontinence and breathing disorders is slowly being understood. It is also clear that synergistic function of all trunk muscles is required for loads to be transferred effectively through the lumbopelvic region during multiple tasks of varying load, predictability and perceived threat. Optimal strategies for transferring loads will balance control of movement while maintaining optimal joint axes, maintain sufficient intra-abdominal pressure without compromising the organs (preserve continence, prevent prolapse or herniation) and support efficient respiration. Non-optimal strategies for posture, movement and/or breathing create failed load transfer which can lead to pain, incontinence and/or breathing disorders.

Individual or combined impairments in multiple systems including the articular, neural, myofascial and/or visceral can lead to non-optimal strategies during single or multiple tasks. Biomechanical aspects of the myofascial piece of the clinical puzzle

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as it pertains to the abdominal canister during pregnancy and delivery, in particular trauma to the linea alba and endopelvic fascia and/or the consequence of postpartum non-optimal strategies for load transfer, is the focus of the first two parts of this paper. A possible physiological explanation for fascial changes secondary to altered breathing behaviour during pregnancy is presented in the third part. A case study will be presented at the end of this paper to illustrate the clinical reasoning necessary to discern whether conservative treatment or surgery is necessary for restoration of function of the abdominal canister in a woman with postpartum diastasis rectus abdominis (DRA).

Introduction

Pregnancy-related pelvic girdle pain (PRPGP) has a prevalence of approximately 45% during pregnancy (Wu et al., 2004) and 20–25% in the early postpartum period (Ostgaard et al., 1991; Albert et al., 2002; Wu et al., 2004). Most women become pain free in the first 12 weeks after delivery, however, 5–7% do not (Ostgaard and Andersson, 1992). In a large postpartum study of prevalence for urinary incontinence (UI), Wilson et al. (2002) found that 45% of women experienced UI at 7 years postpartum and that 27% who were initially incontinent in the early postpartum period regained their continence while 31% who were continent became incontinent. It is apparent for some women, something happens during pregnancy and delivery that impacts the function of the abdominal canister (Figure 1) either immediately, or over time.

Current evidence suggests that the muscles and fascia of the lumbopelvic region play a significant role in musculoskeletal function as well as continence and respiration. The combined prevalence of lumbopelvic pain, incontinence and breathing disorders is slowly being understood (Pool-Goudzwaard et al., 2005; Smith et al., 2007a). It is also clear that synergistic function of all trunk muscles is required for loads to be transferred effectively through the lumbopelvic region during multiple tasks of varying load, predictability and perceived threat (Hodges and Cholewicki, 2007). Optimal strategies for transferring loads will balance control of movement while maintaining optimal joint axes, maintain sufficient intra-abdominal pressure without compromising the organs (preserve continence, prevent prolapse or herniation) and support efficient respiration. Non-optimal strategies for posture, movement and/or breathing create failed load transfer which can lead to pain, incontinence and/or breathing disorders (Thompson et al., 2006; Smith et al., 2006a; Pool-Goudzwaard et al., 2005).

Individual or combined impairments in multiple systems including the articular, neural, myofascial and/or visceral (see Figure 2 The "Puzzle" Lee and Lee, 2007) can lead to non-optimal strategies during single or multiple tasks. Biomechanical aspects of the myofascial piece of the clinical puzzle as it pertains to the abdominal canister during pregnancy and delivery is the focus of the first two parts of this paper. A possible physiological explanation for fascial changes during pregnancy is presented in the third part. A case study will be presented at the end of this paper to illustrate the clinical reasoning necessary to discern whether conservative treatment or surgery is necessary for restoration of function of the abdominal canister in a woman with postpartum diastasis rectus abdominis (DRA).

The anterior abdominal fascia and pregnancy

It is well established that transversus abdominis (TrA) plays a crucial role in optimal function of the lumbopelvis and that one mechanism by which this muscle contributes to intersegmental (Hodges et al., 2003) and intrapelvic (Richardson et al., 2002) stiffness is through fascial tension. DRA has the potential to disrupt this mechanism and is a common postpartum occurrence (Boissonnault and Blaschak, 1988; Spitznagle et al., 2007). Universally, the most obvious visible change during pregnancy is the expansion of the abdominal wall and while most abdomens accommodate this stretch very well, others are damaged extensively (Figure 3).

One structure particularly affected by the expansion of the abdomen is the linea alba, the complex connective tissue (Axer et al., 2001), which connects the left and right abdominal muscles. The width of the linea alba is known as the inter-recti distance and normally varies along its length from the xyphoid to the pubic symphysis.

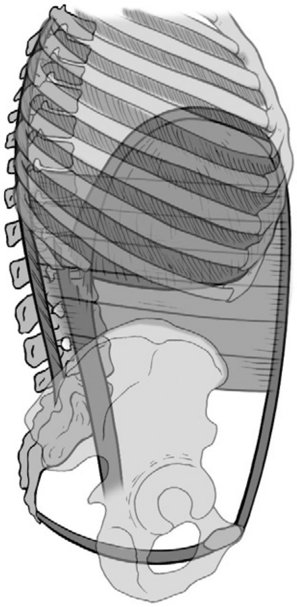


Figure 1 The abdominal canister is a functional and anatomical construct based on the components of the abdominal cavity that synergistically work together. It contains the abdominal and pelvic viscera and is bounded by many structures including: the diaphragm including its crura and by extension the psoas muscle whose fascia intimately blends with that of the pelvic floor and the obturator internus muscle, the deep abdominal wall including transversus abdominis and its associated fascial connections anteriorly and posteriorly, the deep fibres of multifidus, the intercostals, the thoracolumbar vertebral column (T6-12 and associated ribs, L1–L5) and osseus components of the pelvic girdle (innominates, sacrum and femora). The lumbopelvic canister contains 85 joints all of which require stabilization during functional tasks. Optimal strategies for function and performance will ensure controlled mobility, preservation of continence and organ support and respiration. Reproduced with permission from Lee & Lee ©.

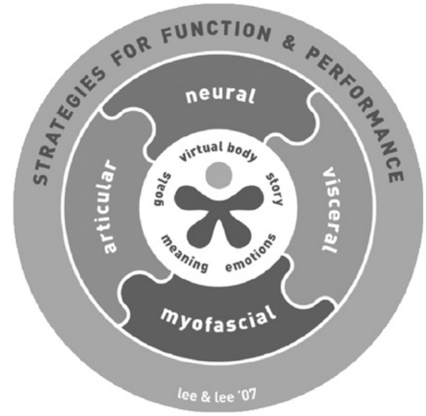


Figure 2 The Clinical "Puzzle". This graphic represents a system-based classification for failed load transfer (Lee and Lee, 2007). Optimal strategies for function and performance depend on the integrity of all pieces within the circle. This patient-centered classification considers the role of and interplay between psychosocial and systemic physiological factors (the person in the middle of the puzzle), the articular system, the neural system, the myofascial system, and the visceral system. Reproduced with permission from Lee & Lee ©.

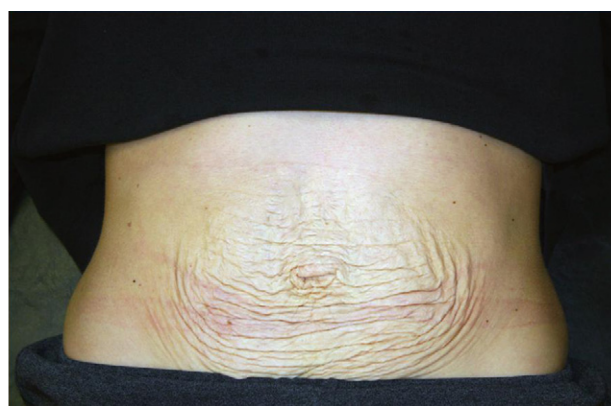


Figure 3 This patient has sustained obvious damage to her skin and superficial fascia. Further assessment is required to determine the functional status of the linea alba and abdominal canister. Reproduced with permission from Lee & Lee ©.

Rath et al. (1996) have established the normal, average inter-recti distance to be 0.9 cm half-way between the pubic symphysis and umbilicus, 2.7 cm just above the umbilicus and 1.0 cm half-way between the umbilicus and the xyphoid which can be reliably measured with ultrasound imaging (Coldron et al., 2007). A DRA is diagnosed when the width exceeds these amounts.

There is little scientific literature on this condition; Boissonnault and Blaschak (1988) found 27% of women have a DRA in the second trimester and 66% in the third trimester of pregnancy. 53% of these women continued to have a DRA immediately postpartum and 36% remained abnormally wide at 5–7 weeks postpartum. Coldron et al. (2007) measured the inter-recti distance from day 1 to 1 year postpartum and noted that the distance decreased markedly from day 1 to 8 weeks, and that without any intervention (e.g. core training) there was no further closure at the end of the first year. In the urogynecological population, 52% of patients were found to have a DRA (Spitznagle et al., 2007). Sixty-six percent of these women had at least one support-related pelvic floor dysfunction (stress urinary incontinence (SUI), faecal incontinence and/or pelvic organ prolapse). There are no studies to guide clinicians on what is the best treatment for postpartum women with DRA.

Clinically, it appears that there are two subgroups of postpartum women with DRA:

1. those who through a multi-modal treatment programme are able to restore optimal strategies for transferring loads through the abdominal canister (i.e. resolve the clinical "Puzzle") with or without achieving closure of the DRA and
2. those who in spite of apparently being able to restore optimal function of the deep muscles (optimal neural system) and who do not have loss of articular integrity of the SIJs or pubic symphysis (optimal articular system) and in whom the inter-recti distance remains greater than normal (non-optimal myofascial system) fail to achieve optimal strategies for transferring loads through the abdominal canister. In multiple vertical loading tasks (single leg standing, squatting, walking, moving from sit to stand, and climbing stairs) failed load transfer through the pelvic girdle and/or hip joint is consistently found.

The second subgroup of postpartum women have sustained significant damage to the midline fascial structures and sufficient tension can no longer be generated through the abdominal wall for resolution of function. For this subgroup, a surgical abdominoplasty to repair the midline abdominal fascia (the linea alba) should be considered (Toranto, 1988). The clinical findings which warrant a surgical consultation are listed in Table 1. More research is needed to substantiate or refute these clinical hypotheses and studies are being developed at this time to investigate this very significant postpartum complication.

Table 1 When should consideration be given for a surgical repair of a diastasis rectus abdominis? The current clinical hypothesis is that:

1. The woman should be at least 1 year postpartum (Coldron et al., 2007) and a proper multi-modal program for restoration of effective load transfer through the lumbopelvis (Lee, 2004; Lee and Lee, 2004a) has failed to restore optimal strategies for function, resolve lumbopelvic pain and/or UI.
2. The inter-recti distance is greater than normal (Rath et al., 1996) and the abdominal contents are easily palpated through the midline fascia.
3. Multiple vertical loading tasks reveal failed load transfer through the pelvic girdle
   (a) Unlocking of the SIJ or PS during single leg loading (stork or one leg standing test) (Hungerford et al., 2004, 2007).
   (b) Unlocking of the SIJ or PS during a squat or sit to stand task (Lee and Lee, 2004a).
4. The active straight leg raise test is positive (Mens et al., 1999) and the effort to lift the leg improves with both approximation of the pelvis anteriorly as well as approximation of the lateral fascial edges of rectus abdominis (Lee, 2007).
5. The articular system tests for the SIJs and the pubic symphysis (mobility and stability) are normal.
6. The neural system tests are normal. The individual is able to perform a co-contraction of transversus abdominis, multifidus and the pelvic floor yet this co-contraction does not control neutral zone motion of either the sacroiliac joint(s) or the pubic symphysis (Lee, 2004; Lee and Lee, 2004a).

The pelvic floor complex

Abdominal wall function is but one component that contributes to optimal lumbopelvic load transfer. The pelvic floor and its associated fascia form the bottom of the abdominal canister (Figure 1) and play a role not only in urogynecological function (Peschers et al., 2001; Baessler et al., 2005; DeLancey, 1994; Ashton-Miller et al., 2001; Barbic et al., 2003), but also trunk stability (Hodges et al., 2000, 2007; Pool-Goudzwaard et al., 2004; Richardson et al., 2002; Sapsford and Hodges, 2001; Sapsford, 2004; Smith et al., 2007b) and respiration (Neumann and Gill, 2002; Hodges et al., 2007).

The ability of the pelvic floor complex to perform these multiple roles depends on the integrity of all systems in "The Puzzle" (Table 2) as impairments in any of these components can alter pelvic floor function (Ashton-Miller and DeLancey, 2007; DeLancey, 1994; Lee and Lee, 2004b).

For a detailed review of the anatomy of this region, anatomical texts and reviews are recommended. Careful review of the anatomy reveals the extensive role that fascia plays.

- The levator ani muscles attach from the dense connective tissue of the arcus tendineus fasciae pelvis (ATFP) that runs from the pubic symphysis to the ischial spine bilaterally.
- The endopelvic fascia surrounds the vagina and forms a sling between both ATFPs laterally.
- These connections also continue superiorly with the fascia surrounding the pelvic organs and ligaments of the pelvic joints (Leffler et al., 2001).

Table 2 "The Puzzle" and its pieces as they pertain to the pelvic floor (Lee and Lee, 2007)

The Puzzle considers the systemic physiological and psychosocial status of the patient as well as the functional integrity of the
Myofascial system

- levator ani muscles
- endopelvic fascia
- arcus tendineus fasciae pelvis
- rectovaginal septum

Neural system

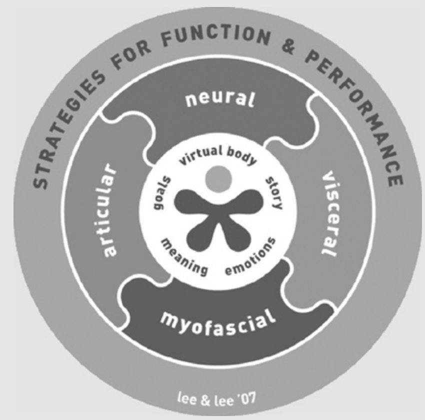
- central and peripheral innervation of the PFM
- control of timing and recruitment of PFM

Articular system

- sacroiliac joints and associated ligaments
- pubic symphysis and associated ligaments

Visceral system

- all pelvic organs



- The myofascial pelvic floor complex is also closely linked to the hip via connections of the ATFP to the obturator internus muscle, and thus it is proposed that the functional pelvic floor extends from greater trochanter to greater trochanter (Lee and Lee, 2007) (Figure 4).
- Indeed, recent evidence has shown that pelvic floor muscle contraction can alter femoral head position (Bendova et al., 2007).

Pregnancy, delivery and the pelvic floor complex

Pregnancy, labour, and delivery can impact the myofascial structures of the pelvic floor complex in multiple ways. Stretching or tearing of tissues can occur, either slowly over time as the weight of the foetus increases, or traumatically during second stage labour and vaginal delivery. Lien et al. (2004) estimated with MRI-based computer modelling that the most medial parts of the levator ani muscles undergo the greatest stretch, lengthening by a factor of 3.26 during crowning of the foetal head. Studies in populations with SUI and pelvic organ prolapse have identified deficits in the levator ani muscle, the attachments of the muscle, and in various fascial layers and attachments of the pelvic floor complex (DeLancey, 2002; DeLancey et al., 2003, Dietz and Lanzarone, 2005; Richardson et al., 1981; Tunn et al., 1998).

Muscle changes have also been compared between nulliparous and primiparous populations (DeLancey et al., 2003; Tunn et al., 1999) as well as pelvic organ mobility in women pre- and post-childbirth (Dietz and Bennett, 2003; Dietz and Lanzarone, 2005; Dietz and Steensma, 2006; O'Boyle et al., 2005; Peschers et al., 1996). Interestingly, these kinds of deficits have also been identified in nulliparous women (DeLancey, 2002; Dietz et al., 2004; Dietz and Clarke, 2005), as well as in asymptomatic women (Dietz and Clarke, 2005). This has led to the hypothesis that congenital factors may exist previous to childbirth that are then further impacted by childbirth.

We propose that a significant additional factor that contributes to changes in the myofascial structures of the pelvic floor are the neuromuscular strategies used by women for postural and trunk control during everyday function and performance (the outer ring of "The Puzzle").

Non-optimal strategies can develop as a result of habit (Lee and Lee, 2004a; O'Sullivan, 2005), due to pain and injury (Moseley and Hodges, 2004a), or anticipation of pain (Moseley and Hodges, 2004b). We have observed that the postpartum population adopts some common non-optimal strategies, seemingly as a response to the changes over the course

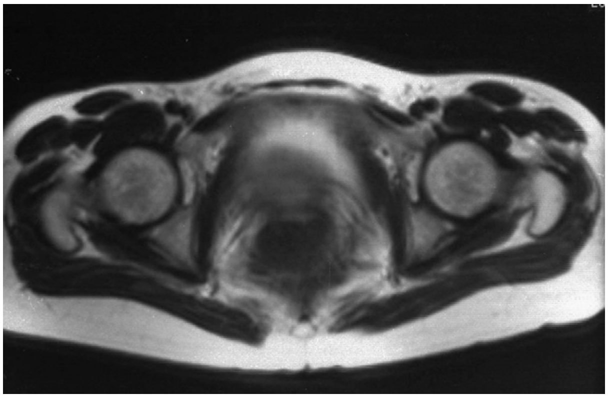


Figure 4 This is a transverse plane MRI of the functional pelvic floor complex. Note the continuity between the obturator internus and the levator ani muscles connecting the left and right greater trochanters. Reproduced with permission from Lee & Lee ©.

Figure 5 This is the classic posture of a 'butt-gripper'. Note the narrowing of the lower part of the pelvis posteriorly and the gathering in of the fabric of her pants. These signs are suggestive of overactivation of the muscles of the posterior pelvic wall and hip. Reproduced with permission from Lee & Lee ©.

of the pregnancy, as well as in response to trauma that can occur during delivery (vaginal or C-section).

One common postpartum strategy is the overuse of the muscles of the posterior buttock (the deep hip external rotators, the coccygeus muscle, and/or gluteal muscles) referred to as the "butt-gripping" strategy (Lee, 2004; Lee and Lee, 2004a), which may occur unilaterally or bilaterally.

This strategy results in altered hip joint position, posterior tilting of the pelvis, loss of the lower lumbar lordosis (usually at L4 and L5), and inferior compression of the sacroiliac joints (Figure 5).

In this position there is loss of the bony support that the pubic bone can provide, as the pelvic inlet has lost its neutral almost vertical position (Nguyen et al., 2000). Loss of this support subjects the fascia and muscles of the pelvic floor to increased tensile forces repetitively during everyday function, and over time these repeated stresses could contribute to changes in myofascial integrity.

Another common postpartum strategy is the overuse of the external oblique (EO) muscle and underuse of the deep lower abdominal wall (TrA). This pattern is referred to as the "chest-gripping" strategy (Lee, 2004; Lee and Lee, 2004a) because of the restriction it creates in the upper part of the abdominal canister (ribcage) and the relative loss of activation in the lower abdomen (Figure 6).

It is common for patients with this strategy to report increased pressure in the lower abdomen and the inability to stop the lower abdomen from bulging. It is our clinical hypothesis that this reflects the greater increase in intra-abdominal pressure that activity in the EO as compared to TrA creates. With this strategy, both the internal organs and the myofascial structures that support them are constantly under higher loads than is ideal, leading to changes in structure and function over time. There is some evidence to support this hypothesis, as patients with incontinence have been shown to have increased resting tone in the EO and PFM in standing and in response to postural perturbations (Smith et al., 2007b), and also have altered strategies for trunk control (Smith et al., 2006b, 2007b; Thompson et al., 2006; Pool-Goudzwaard et al., 2005).

Both the "butt-gripping" and "chest-gripping" strategy, especially if asymmetric, create asymmetrical tension lines through the myofascial system, altering the stiffness and symmetry through the support tissues, their length–tension relationships, and potentially changing the angle of action of the pelvic floor muscles.

Recent work of Peng et al. (2007) highlights the importance of the direction of the vector of lift produced by a pelvic floor muscle contraction for continence; the optimal vector delivers an effective closing force to the urethra, whereas a strong contraction in the wrong vector will not result in urethral closure. Non-optimal vectors of myofascial activity can also impact support for pelvic organs, musculoskeletal control and load transfer, and respiratory efficiency.

It has been noted that there is often a delay in the development of symptoms of pelvic floor dysfunction (UI, prolapse) and childbirth (the assumed cause of the dysfunction) (Dietz and Schierlitz, 2005). Epidemiological data highlights that the development of pelvic floor dysfunction is also related to other disorders such as low back pain and breathing disorders (Pool-Goudzwaard et al., 2005; Smith et al., 2006a, 2007a). Wilson et al. (2002) followed 7800 women after vaginal

Figure 6 This individual is trying to 'hollow' their lower abdomen, i.e. recruit their transversus abdominis. All that is hollowing with this strategy is her upper chest and the overactivation of the external oblique muscles significantly restricts lateral costal expansion of her chest and thus her ability to breathe optimally. Reproduced with permission from Lee & Lee ©.

delivery and tracked the prevalence of UI. Of note, 31% of the women who had regained their continence in the early postpartum period were now incontinent 5–7 years later. This later appearance of symptoms may be explained by the time it takes for altered neuromuscular control strategies to impact other systems and result in clinical symptoms.

In summary

- Myofascial defects of the pelvic floor complex can occur during pregnancy and delivery and be immediately apparent in the early postpartum period.
- Compensatory strategies for trunk control can develop around these deficits and contribute to the development of further impairments.
- Conversely, the myofascia may "survive" the trauma of pregnancy and delivery only to succumb to the forces induced over time when non-optimal strategies for load transfer through the abdominal canister occur postpartum.
- The symptoms that patients present with—low back pain, pelvic girdle pain, incontinence, pelvic organ prolapse, respiratory difficulties—will depend on the piece of "The Puzzle" that is most impacted, or that is most predisposed to dysfunction due to past experiences, injuries, or genetic and hormonal influences. In both cases, careful assessment of all the systems involved guides the clinician in directing treatment decisions, and as most patients present with non-optimal strategies either as a result or cause of their symptoms, retraining of postural and movement strategies is an essential piece for restoration of function and performance.
- This requires a broad perspective that considers the inter-connectedness of multiple systems and regions of the body.

Theoretical considerations for breathing and hypocapnia

Breathing is a vital function and thus has reflex control housed in the more primitive part of the brain, the brainstem. However, higher centres can override the reflex either consciously or unconsciously (Thomson et al., 1997). Emotional states such as stress or fear can "completely overwhelm" the reflex centres and cause an increase in ventilation (Levitsky, 2003).

Pain is also thought to be a ventilatory stimulant (Levitsky, 2003). Lumbopelvic pain is known to alter trunk muscle function (Hodges and Richardson, 1999; Radebold et al., 2001) and non-optimal strategies for function are thought to impair lumbopelvic stability, continence and respiration (Hodges et al., 2007). Breathing behaviour is vulnerable to changes associated with emotion, pain (Levitsky, 2003) or altered trunk muscle function, factors also seen in individuals with musculoskeletal dysfunction (Watson et al., 1997; Moseley and Hodges, 2004a).

Altered breathing changes physiology principally through its affect on CO_2. CO_2 is considered a waste product of cellular metabolism yet only 15% is excreted. The rest is used to regulate hydrogen ion concentration or pH. The normal range of arterial CO_2 is 35–45 mm Hg. When ventilation exceeds metabolic demands (overbreathing), the level of Hg drops below 35 mm Hg (Levitsky, 2003). Overbreathing occurs when the rate of breathing is either too rapid and/or the volume of the breath is too big, thereby blowing off excess CO_2. Consequently, CO_2 content in the body fluids (blood, extracellular fluid, cerebrospinal fluid) is reduced and hypocapnia (defined as a CO_2 level below 35 mm Hg (Thomson et al., 1997)) occurs.

During hypocapnia, the pH of the body fluids becomes alkaline causing decreased tissue oxygenation and constriction of smooth muscles including those found in the vessels, gut and bronchi (Nixon and Andrews, 1996). These changes can lead to symptoms in many body systems and may have profound effects on fascia. Since there appears to be smooth muscle in the form of myofibroblasts in fascia (Hinz, 2006; Schleip, 2006), it is likely that fascial smooth muscle would respond similarly although this has not yet been established.

The body's response to decreased hydrogen concentration in the body fluids is to mine the *intra*cellular fluids for hydrogen ions. Sodium and potassium ions in the extra cellular fluid are exchanged with hydrogen ions in the cell. This exchange alters the chemistry of the extra cellular fluid including the ground substance of fascia. Additionally, the kidneys excrete more extra cellular fluid (Levitsky, 2003), which decreases its volume within the fascial tissues.

In summary, the response in the fascia to over-breathing includes altered composition and decreased volume of the ground substance and constriction of the smooth muscle cells.

Hypocapnia, pregnancy and fascia

Arterial, alveolar and cerebrospinal CO_2 is progressively reduced in pregnancy starting before 6 weeks gestation (Jensen et al., 2007, 2008) reaching 30 mmHg at 30 weeks due to progesterone's ventilatory stimulation effect (Thomson et al., 1997). Interestingly, other ventilatory stimulants such as adrenaline, noradrenaline, nicotine and angiotensin do not cause hypocapnia (Thomson et al., 1997).

Paraesthesias, muscle cramping and poor concentration are common complaints during pregnancy and are also symptoms of hypocapnia. Clinically, it has been noted that retraining breathing during pregnancy can alleviate some of these symptoms.

However, it is important to acknowledge that hypocapnia may also be an adaptive mechanism during pregnancy. Mechanical tension is required for the transition of the fibroblast to the myofibroblast (containing alpha smooth muscle actin) (Hinz, 2006).

A current clinical hypothesis is that the alkaline state of hypocapnia may facilitate the contraction of the abdominal fascia (via alpha smooth muscle actin), which is under increasing mechanical tension during pregnancy. This may be a protective mechanism to counteract the effects of increasing abdominal size in the presence of the tissue softening effects of pregnancy-related hormones. Further studies are necessary to understand the role of decreasing CO_2 during pregnancy and the potential effect on pregnancy-related symptoms.

Whether hypocapnia is related to DRA or to pregnancy-related laxity (not avulsion or tearing) of the endopelvic fascia has not been investigated.

Case presentation—postpartum diastasis rectus abdominis

Christy is a 32-year-old mother who has a heavy job installing cable for home television. She has two children born 19 months apart; the youngest was just over 1 year at the time of her first consultation. Her first baby presented breech and was delivered by a planned Caesarean section and her second child was also delivered via Caesarean after her labour failed to progress. Her presenting complaints were of pain over the right SIJ and buttock (VAS 4/10) aggravated by vertical loading tasks such as walking and standing as well as forward bending and supine lying. She found relief by constantly changing positions. She had just returned to work after her maternity leave and noticed that her pain was escalating. She did not report any SUI at this time.

Strategies for function and performance

Standing posture

Significant distension of the lower abdominal wall was noted in standing (Figure 7a and b) and the extensive stretching of her skin and superficial fascia was immediately apparent when she lay supine (Figure 8). Her standing posture revealed an anterior pelvic sway and an intrapelvic torsion to the right (IPTR = left anteriorly rotated innominate relative to the right with the sacrum rotated to the right). In addition, her left femoral head was translated anterior relative to the left innominate (non-centered hip joint).

Forward bending

The right torsion of her pelvis (IPTR) increased during forward bending (Figure 9) and her left femoral head failed to centre in the acetabulum during this task. The right SIJ failed to remain in a self-locked or stable position during forward bending whereas the left remained stable.

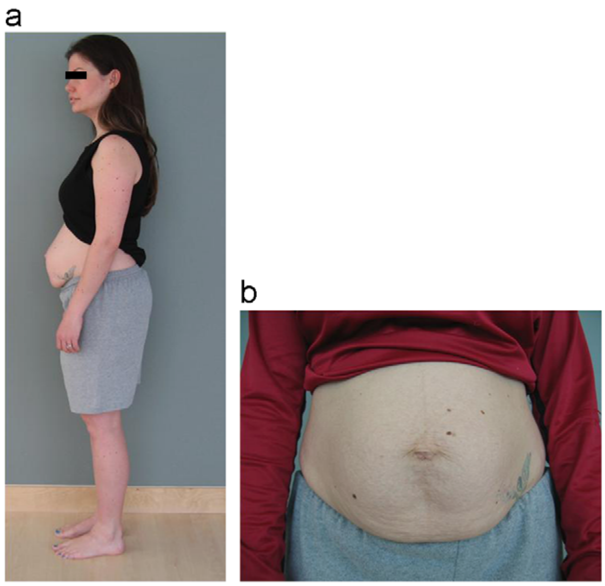


Figure 7 (a) Note the profile of Christy's lower abdomen in this lateral view in standing. Also of note is the anterior pelvic sway. (b) This is a close-up anterior view of Christy's abdomen in standing. Reproduced with permission from Lee & Lee ©.

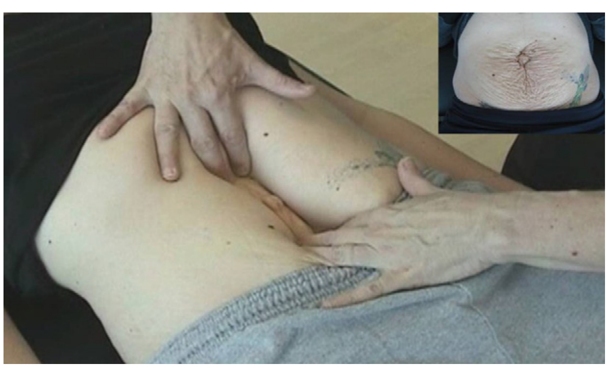


Figure 8 In supine lying, the extensive damage to Christy's anterior abdominal wall is clearly seen. A wide diastasis was easily palpated between the left and right rectus abdominis muscle bellies. Reproduced with permission from Lee & Lee ©.

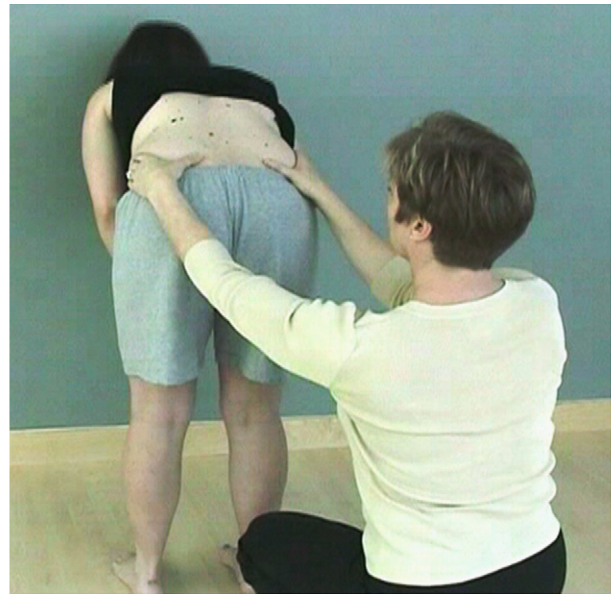


Figure 9 During forward bending, the intrapelvic torsion to the right which was noted in standing increased and the left femur failed to centre during this task. Reproduced with permission from Lee & Lee ©.

Backward bending

The right torsion of her pelvis (IPTR) increased during backward bending; however, there was no loss of control either SIJ during this task.

One leg standing

Christy found it more difficult to stand on her right leg and flex the left hip (right one leg standing test ROLS). With respect to intrapelvic mobility during this task, asymmetry of motion was noted between the left and right SIJs. The left innominate posteriorly rotated less during the ROLS test than the right during the LOLS test although neither side moved very well. There was failure to control movement on the weight-bearing side during this task (the left innominate rotated anteriorly relative to the sacrum during the LOLS and the right innominate rotated anteriorly relative to the sacrum during the ROLS) (Figure 10).

Active straight leg raise task

Christy had difficulty lifting either leg off the table in the supine position and found that anterior compression of her pelvis made the task easier for both the right and left legs. Manual approximation of the linea alba (Figure 11) made the ASLR task the easiest for both legs. This suggested that the separation of her abdominal wall was impacting the efficiency of this task.

Clinical reasoning at this point: Christy was using non-optimal strategies for all tasks evaluated. The right intrapelvic torsion noted in standing did not change with sagittal movement (forward bending, backward bending) implying that she was very committed to the strategy, which was creating the malalignment. The strategies used in all tasks except for backward bending failed to provide motion

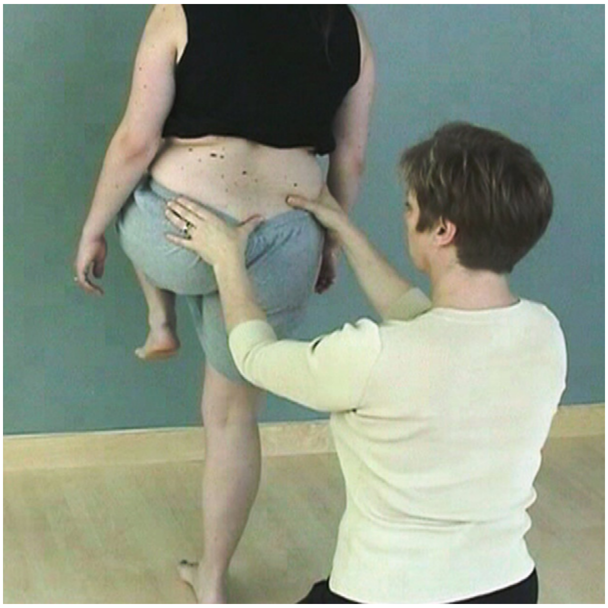


Figure 10 During the one leg standing test both SIJs unlocked; however, the right side unlocked earlier during this task (innominate anteriorly rotated as she shifted her weight to the right leg). Reproduced with permission from Lee & Lee ©.

Figure 11 Active straight leg raise test. Christy found it difficult to raise either leg off the table and the task was made easier when compression was applied to the anterior pelvis, simulating the force of transversus abdominis and the anterior abdominal fascia. The ASLR task was made the easiest when the lateral margins of the left and right rectus abdominis were approximated thus supporting the midline fascial structures. Reproduced with permission from Lee & Lee ©.

control of the right SIJ. In addition, there was a non-optimal axis for left femoral motion at the hip joint in all tasks evaluated (anterior translation), indicating a significant commitment to the strategy she used for load transfer through the hip.

The next step was to determine what was causing these non-optimal strategies that failed to control motion of the right SIJ and created a non-optimal axis of motion for the left hip joint. Given the appearance of the anterior abdominal wall, the myofascial system was assessed first.

Myofascial system—the linea alba

Just above the umbilicus the inter-recti distance measured 3.28 cm on ultrasound (normal is no greater than 2.7 cm according to Rath et al. (1996)) (Figure 12a). At the midway point between the pubic symphysis and the umbilicus the inter-recti distance was 1.21 cm (Figure 12b) (normal is >.9 cm) and at the midway point between the umbilicus and the xyphoid the inter-recti distance was 1.80 cm (Figure 12c) (normal is >1.0 cm). During a curl-up, the separation between the two recti was easily palpated and did not close (Figure 13a). During the initial movement, doming of the abdomen in the midline could be seen. The aortic pulse was easily palpated through the linea alba both at rest and during a curl-up and of concern was the lack of palpable tension in the linea alba during the curl-up task. There did not appear to be a good barrier in the midline to protect this vital artery. This was confirmed via ultrasound imaging (Figure 13b) in that during the curl-up, no increase in echogenicity of the midline fascia was seen at the level of the umbilicus and for several centimetres above and below this point. An interesting finding was noted just above the pubic symphysis (Figure 14). The outer layer of the midline fascia appeared normal (hyperechoic) whereas the deeper layer appeared to be separated during the curl-up task. The significance and meaning of this finding was not immediately clear other than it is not the usual appearance seen on ultrasound exams (based on clinical experience).

Clinical reasoning at this point: As a consequence of her pregnancy, Christy's abdominal wall had sustained a significant stretch. What was the impact of this stretch on the ability of the deep muscle system to control motion of her pelvis and low back? Could her compensation strategy for transferring loads be causing the non-optimal axis of motion for her left hip joint? To answer this question, an assessment of the neural system was required.

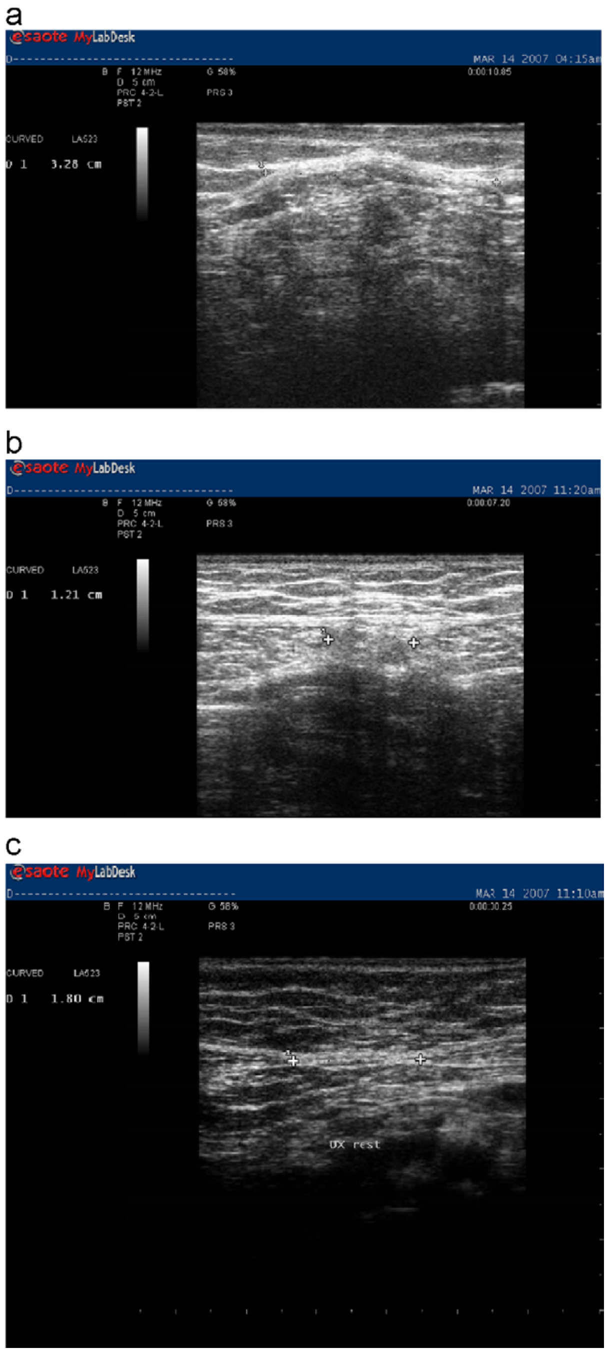


Figure 12 (a) An ultrasound image of Christy's linea alba at rest just above the umbilicus. The inter-recti distance is 3.28 cm at this point. (b) The inter-recti distance half way between the pubic symphysis and the umbilical point is 1.21 cm. (c) The inter-recti distance half way between the umbilical point and the xyphoid is 1.80 cm. Reproduced with permission from Lee & Lee ©.

The neural system

Transversus abdominis

Prior to this consultation, Christy had been working with another physiotherapist to restore the timing and co-activation of TrA and the pelvic floor. On palpation of her anterolateral abdomen bilaterally, a contraction of TrA could not be felt on either side when she was given a cue to contract her PFM or her TrA. However, when viewed via ultrasound imaging, both the left and the right TrA were contracting optimally (Figure 15a and b). In addition, there appeared to be a 'larger than normal' lateral slide (based on clinical observations; there is no evidence to compare this to) of the medial fascia of TrA and less corseting of the muscle portion of TrA was seen.

The pelvic diaphragm

The pelvic diaphragm was assessed via transabdominal ultrasound imaging and asymmetric movement of the bladder base was noted. The left side of the bladder base lifted more (with a cue to contract) and descended less (with a cue to relax) than the right (Figure 16a and b). When the muscles of the left hip/buttock were palpated, hypertonicity of the left piriformis and deep external rotators was found.

Clinical reasoning at this point: Initially, it would be reasonable to think that her deep anterior abdominal wall was not functioning since her ASLR improved with anterior compression of her pelvis and no palpable tension could be felt in TrA in response to a verbal cue. However, the findings from the ultrasound imaging negate this conclusion since TrA could be seen to contract optimally with cuing. Likely, the laxity of the anterior fascial system was preventing the contraction of TrA from transmitting any force through the midline, thus no tension was felt and insufficient support was provided for the pelvis during the ASLR task. Was this the reason for the loss of control of intrapelvic motion in the vertical loading tasks?

The asymmetry of the bladder base lift and descent noted via ultrasound imaging suggests that there is an imbalance in tension or tone in the muscles which impact the endopelvic fascia, namely the levator ani and the obturators. In addition, the hypertonicity of the left piriformis and deep external rotators of the hip could be responsible for altering the axis of femoral motion resulting in displacement both at rest (supine lying) and during functional postures and movements (standing, forward bend, backward bend). This is consistent with the torsion of her pelvis to the right (IPTR) in

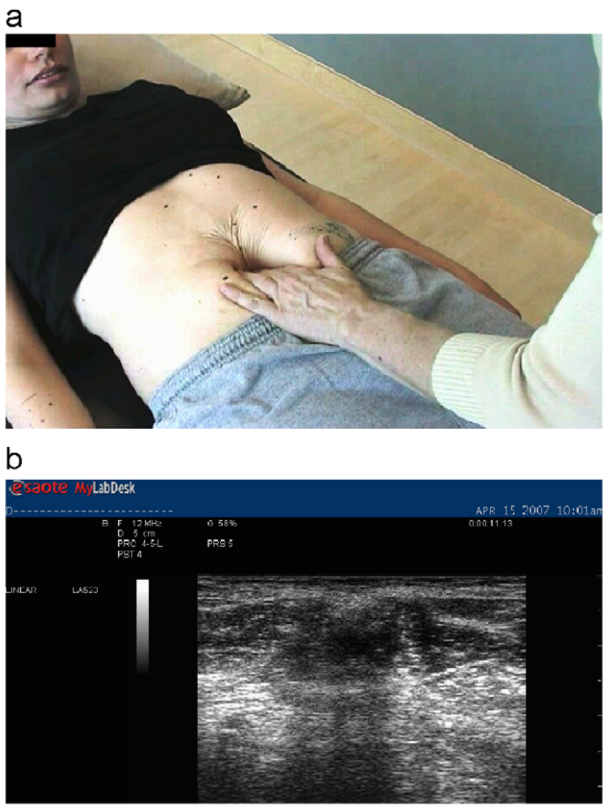


Figure 13 (a) The linea alba remained quite soft to palpation during a curl-up task, no palpable barrier to the deep abdominal structures could be felt. (B) This was confirmed by ultrasound imaging, note the apparent lack of fascial tension in the inter-recti space (inferred from the echogenicity of the fascial structures). Reproduced with permission from Lee & Lee ©.

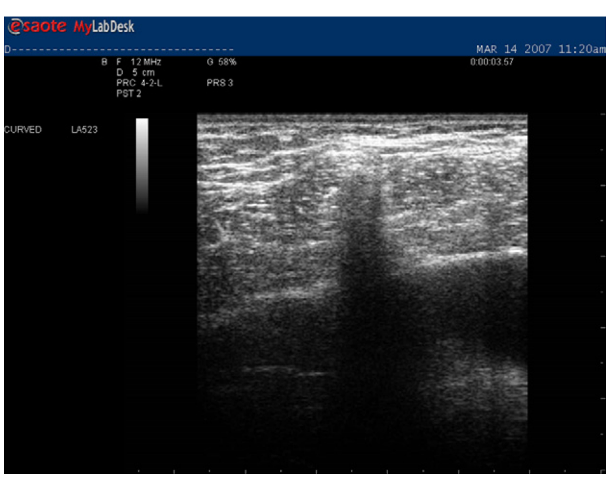


Figure 14 An ultrasound image of the linea alba midway between the pubic symphysis and the umbilicus during Christy's curl-up task. There appeared to be an invagination of abdominal contents between the two recti, a finding not usually seen. Reproduced with permission from Lee & Lee ©.

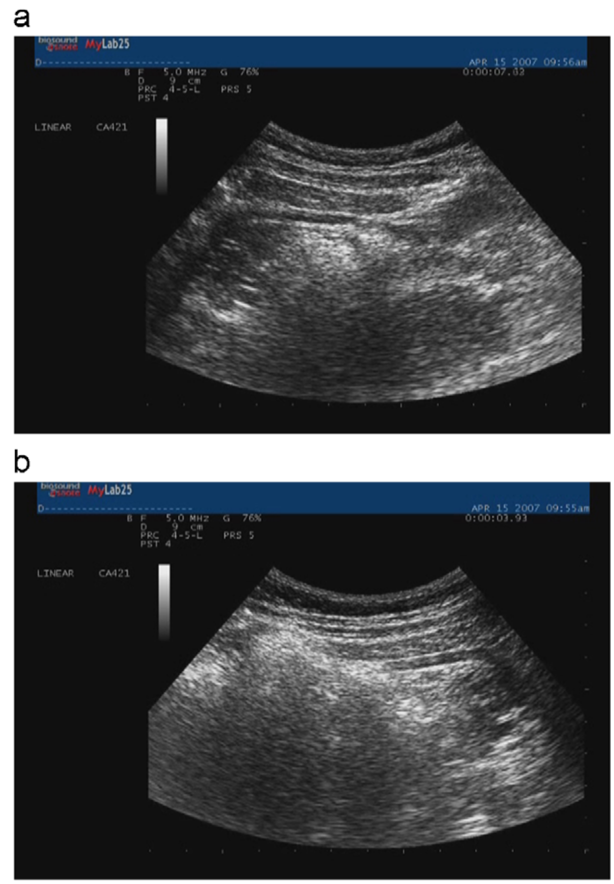


Figure 15 Ultrasound image of the (a) right (b) left abdominal wall below the level of the ASIS. This is an optimal contraction of transversus abdominis on both the left and right sides although no tension of the TrA fascia could be felt during this contraction. Together these findings suggest that there is minimal tension generated in the midline fascial structures during this contraction of TrA. Reproduced with permission from Lee & Lee ©.

standing as well as the increase in this torsion during forward and backward bending.

Was the neuromuscular system able to effectively control movement in the neutral zone (NZ) of both the pubic symphysis and the left and right sacroiliac joints or was the anterior abdominal fascial laxity too extensive? To answer this question the articular system (pubic symphysis, SIJs and hip joints) needed to be assessed as well as the impact of the myofascial and neural systems on the articular system.

The articular system

The pubic symphysis was dynamically stable and pain free on stress testing. The amplitude of the NZ

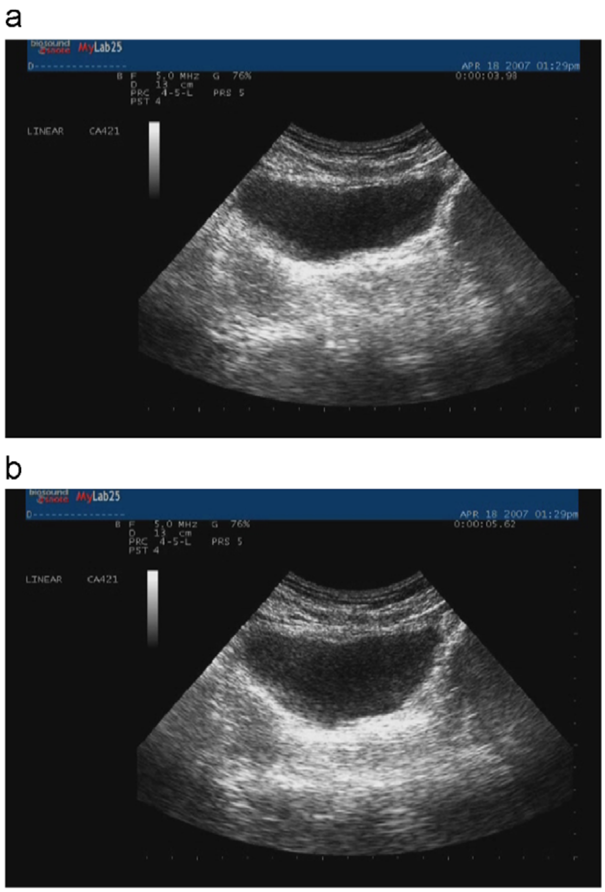


Figure 16 (a) Ultrasound image, transabdominal view of the bladder base during an attempt to lift the pelvic diaphragm. Note the asymmetry of the lift, the left side (right side of this image) is lifting higher than the right. (b) After the pelvic floor lift (relaxation), the bladder base remains asymmetric suggesting that the left side of the pelvic diaphragm has higher resting tone than the right. EMG analysis and manual palpation would be required to verify this hypothesis. Reproduced with permission from Lee & Lee ©.

of motion of the left and right sacroiliac joints was different; the left SIJ NZ motion was reduced compared to the right and the inferior pole of the left SIJ was compressed such that a parallel glide of the innominate relative to the sacrum was not possible at the level of S3 and S4. The right SIJ felt "looser" than the left; however, when the joint was close-packed, the NZ of motion was reduced to zero. The left femoral head was anterior in the supine position when the leg was resting on the table and returned to its normal centred position at 60° of passive hip flexion.

A submaximal voluntary contraction of the deep muscle system did not reduce the NZ of motion of the right SIJ UNLESS the lateral border of the left and right rectus abdominis muscles were approximated while the joint play test was performed.

Clinical reasoning at this point: The pubic symphysis and the right sacroiliac joint were stable with respect to their ligamentous integrity. The left SIJ could not be tested for articular stability at this time since the neuromuscular compression of the inferior pole prevented the joint from being able to achieve the close-packed position. The non-optimal position of the left femoral head from 0° to 60° of flexion explains the resultant position of the left hip in standing and the increase in the intrapelvic torsion with forward and backward bending tasks. This non-optimal femoral position was perhaps generating enough tension in the endopelvic fascia to control the motion of the left SIJ during functional tasks, as the findings from the myofascial tests suggest that there is insufficient fascial integrity of the anterior abdominal wall to provide support to the lumbopelvis.

The NZ of motion of the right SIJ could only be controlled by the deep muscles once the abdominal fascia was approximated. This suggests that the midline fascial laxity was significantly impacting the ability of the neuromuscular system to force close and control motion of the right SIJ. This hypothesis is consistent with the findings of loss of motion control of the right SIJ in vertical loading tasks. Since the TrA and pelvic floor muscles were functioning well and in spite of this the NZ of motion of the right SIJ could not be controlled, it is highly likely that an anatomical correction of the anterior abdominal wall is required before restoration of function with optimal strategies for load transfer can occur.

Treatment planning—patient goals

Christy's goals were to become pain free and to return to her prepregnancy level of function

Treatment planning—therapeutic interventions (multi-modal programme)

1. Release the compensatory strategy she had developed for load transfer through her pelvis and hip.
   (a) Release the left piriformis and deep external rotators of the left hip (dry needling and release with awareness) to reseat the left

Figure 17 The Com-Pressor SI belt with the two removable straps applied to support the anterior abdominal wall. Reproduced with permission from Lee & Lee ©.

femoral head and restore full range of motion of the left hip joint with an optimal axis of motion and decompress the inferior pole of the left SIJ.

2. Correct any remaining malalignment of the pelvis (correct any remaining right intrapelvic torsion with a manual mobilization or muscle energy technique).
3. Provide internal and external support for the abdominal wall and pelvis.
   (a) Provide internal support through proper patterning of the deep muscles without excessive activation of the left hip muscles—retrain and habituate the pattern of synergistic activation of TrA, pelvic floor, and deep multifidus without activation of the deep posterior external rotators of the left hip.
   (b) Provide external support with an appropriately applied Com-Pressor belt. The ASLR test determines the location of the compression straps; Christy required bilateral anterior compression of her pelvis (Figure 17).
4. Postural and movement retraining in standing for standing posture, forward bending, backward bending, single leg loading (walking, lunge) and functional squatting.
5. Organize a referral for surgical consultation for an abominoplasty.

Outcome

With this treatment Christy was able to learn to release her left hip, centre the femoral head and bend forward and back without increasing the right torsion in her pelvis. Without the support of the SI belt, she was not able to squat or single leg load through the right leg without losing control of the right SIJ, the deep muscle system could not generate enough force closure through the lax abdominal fascia. A surgical repair of the anterior abdominal wall (abdominoplasty) has since been scheduled to repair the myofascial deficit incurred as a consequence of her pregnancies.

Summary

Research evidence and clinical experience demonstrate that the biomechanical, and physiological affects of pregnancy and delivery can have a non-optimal impact on the fascial support system of the abdominal canister. Optimal strategies for function and performance depend on the integrity of the articular, neural, myofascial and visceral systems, which can be influenced by psychosocial and systemic physiological factors. Although altered myofascial integrity, function and physiology as a consequence of pregnancy and delivery have been highlighted in this paper, when addressing pregnancy-related pelvic girdle pain, UI and/or breathing disorders the clinician must consider all pieces of the clinical puzzle as each story and presentation will be unique (Lee, 2007).

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