Biomechanics of the Sacroiliac Joints and the Pelvic Floor

Annelies Pool-Goudzwaard

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Anneke Louise Pool - Goudzwaard

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Biomechanics of the Sacroiliac Joints and the Pelvic Floor

Biomechanica van de sacroiliacale gewrichten en de bekkenbodem

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Voor mijn ouders
Voor Jan, Sabrina, Stephanie, Lisanne & Jesper

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Er gaat een ongelooflijke kracht uit van liefde voor het leven -

ter nagedachtenis aan Peter

General Introduction

General Introduction

Low Back Pain (LBP) is a burden for western society because of the increasing incidence and costs for treatment, absenteeism and disability[1]. Its prevalence is estimated to be 25-30% in a adult lifetime span[2]. In a study among the Dutch population of 25 years and older an annual prevalence is reported of 41.6% in men and 46.2% in women[3]. Although most LBP is benign and self limiting[4], 62% of the patients still report LBP after 12 months[5]. Therefore, LBP can become chronic and in addition lead to disability[6,7,8]. The Quebec Task Force[9] defines three phases in LBP: the acute (0-6 weeks), the subacute (6-12 weeks) and the chronic phase (longer than 12 weeks). Physical risk factors mentioned in the literature are lifting, working with heavy loads, rotation and flexion of the trunk[6,10], vibrations and accidents[11,12]. In addition, psychological and psychosocial factors are reported to aggravate and perpetuate LBP, such as the patients´ attitudes and beliefs, psychological distress, illness behaviour, low social support and high quantitative work demands[6,7,8,13,14]. Hence, LBP is a biopsychosocial problem[6,8,13,14], also expressed in the definition of pain by the International Association for the Study of Pain (IASP)[15].

In today's treatment of subacute and chronic LBP psychological and psychosocial factors are taken into account. The emphasis lies on behavioral treatment, using either operant, cognitive or respondent techniques[16,17,18]. This behavioral treatment focuses on the reduction of disability through modification of environmental contingencies and cognitive processes[19]. The primary focus is on increase of activity tolerance[17,19,20,21]. An increase of activity tolerance can be reached by graded activity and graded exposure techniques using operant conditioning principles as well as psychophysiologic concepts and concepts from cognitive psychology[17,19,20,21]. So, in behavioral treatment of LBP patients underlying organic disease is not the primary focus[19]. There are various reasons for this negation of underlying organic disease such as: a) medical examinations fail to find physical causes in the majority of back pain patients[22], b) the degree of physical disability can be due to inactivity to avoid pain, reinforced by operant conditioning, rather than a result of the physical condition[16,18,20], c) pain can depend on cognitive processes[23], such as misinterpretations of proprioceptive signals[24] and negative thoughts like low self efficacy expectancies[25] and d) the patient's condition can depend on the degree of kinesiofobia[25,26,27]. However, negation of underlying pathology and of biological aspects of pain in the behavioral treatment of LBP patients is questionable. Since these aspects remain an essential pillar of LBP as a *bio*psychosocial problem, they should not be ignored [6,16,22,23]. After all, the definition of pain by the IASP[15] puts equal weight on the sensory and emotional aspects of pain, since among others pain is a sensation about a certain part of the body[6]. Hence, knowledge of sensory aspects of pain due to pathology or other biological changes can be of importance in the treatment of LBP patients.

The present study deals with the biological aspects of LBP and their relevance for clinical assessment and therapeutic interventions. In order to study these aspects thoroughly special attention has been paid to the anatomy and biomechanics of the lumbopelvic region. It has to be emphasized, however, that knowledge of the anatomy and biomechanics of this region covers only a part of the biological pillar of LBP as biopsychosocial problem. Therefore, the reader should be aware that clinical assessment and therapeutic interventions based on this anatomical biomechanical study will show shortcomings. The psychological and psychosocial aspects of LBP should also be taken into account.

A vast amount of literature is available on the aetiology of LBP and its biological aspects. Many studies focus on the mechanical behaviour of lumbar structures such as intervertebral discs[28,29,30,31], zygapophysial joints[32], lumbar ligaments and muscles[33,34,35]. The Researchgroup Musculoskeletal System of the Erasmus Medical Center, Rotterdam, however, diverted the attention to the lumbosacral and pelvic structures. This resulted in new ideas such as the model of selfbracing of the lumbopelvic region[36,37]. This model combined

with the concept of the deep muscle corset[38,39] concerns lumbopelvic stability. In this thesis lumbopelvic stability is defined as the ability of the spine and pelvis to limit patterns of displacement under physiological loads, so as not to damage or irritate the spinal cord or nerve roots, and in addition to prevent incapacitating deformity or pain due to structural changes. This definition is in line with the definition of clinical stability by the committee on the spine of the American Academy of Orthopaedic Surgeons[40].

Ligaments contribute to passive lumbopelvic stability by limiting patterns of displacement of the joints of the lumbar spine and pelvis, restricting mobility of these joints to those positions which can bear physiological load. Muscles will contribute to active lumbopelvic stability by controlling the relative positions of these joints, providing a safe transfer of physiological loads. In this respect ligaments and muscles are essential for the stability of the lumbopelvic region and consequently an important topic for anatomical and biomechanical research.

Stability of the lumbopelvic region is of special interest in patients with nonspecific LBP[36,41,42]. LBP is said to be nonspecific if no specific cause can be identified[6,43]. Impairment of lumbopelvic stability, in particular of the sacroiliac (SI) joints, may result in deficient load transfer through this region and lead to pain disorders such as nonspecific LBP[36,41,42]. So, for treatment of patients with nonspecific LBP due to impairment of lumbopelvic stability insight into the possible role of lumbopelvic structures on the stability of the SI joints is important. The primary aim of this study was to gain insight into the stabilizing effect of the lumbopelvic structures on the SI joints. Not all lumbopelvic structures could be taken into account. The focus has been narrowed to those structures considered to be important sources of LBP[44,45,46]. Consequently, special attention has been paid to the long dorsal sacroiliac and the iliolumbar ligaments. These ligaments are of special interest because of their surmised role in providing stability of the SI joints. Knowledge of the anatomical relations of the iliolumbar ligaments is of importance since these structures connect the lumbar and pelvic region. Because of the disagreement in the literature[33,47,48,49] on the sites of attachments of this ligament, an anatomical study has been performed to gain insight into the anatomical relations prior to the biomechanical study.

In addition to these two ligaments, the largest ligamentous structure of the lumbopelvic region has been studied, both anatomically and biomechanically. The thoracolumbar fascia forms a site of attachment for several muscles and originates directly as well as indirectly via the spinal ligaments from the lumbar vertebrae. Its ability to transfer load was of special interest for the model on stability of the lumbopelvic region.

In studying the role of the muscles in lumbopelvic stability special attention has been paid to the pelvic floor muscles. The main reasons for this special interest were a) the pelvic floor muscles may have the capacity to stabilize the pelvic ring and b) an altered motor control of these muscles has been demonstrated in a group of pregnancy related LBP patients[50,51]. It has been suggested that this altered motor control is due to a deficient stability of the SI joint[50,51]. To test the influence of the pelvic floor muscles on the stability of the SI joints, a biomechanical study has been performed. In addition, the association between tension in these muscles, pelvic floor dysfunctions and LBP was studied in vivo.

This thesis is divided in eight projects. A state of the art in 1998, chapter 2, forms the beginning of this study. In this chapter the selfbracing model, developed by the Researchgroup Musculoskeletal System of the Erasmus Medical Center, is described. Furthermore, attention is paid to the consequences of this selfbracing model for therapeutic interventions in nonspecific LBP patients. These therapeutic interventions are based in part on an anatomical study of the thoracolumbar fascia (chapter 3) and on an anatomical and biomechanical study of the long dorsal sacroiliac ligament (chapter 4).

An anatomical study on the iliolumbar ligament (chapter 5), assessing the origins and attachments of the iliolumbar ligament, has been followed by a biomechanical study testing its influence on SI joint stability (chapter 6).

In chapter 7 attention has been paid to the influence of pelvic floor muscles on SI joint stability. The following hypothesis has been derived from this in vitro study: patients with pelvic instability will increase the activity level of the pelvic floor muscles, in order to stabilize the SI joints. This overactivity of the pelvic floor muscles, however, can have an impact on the continence mechanism and lead to voiding dysfunctions. To assess the association between the activity of the pelvic floor muscles and the voiding dysfunctions in patients with pregnancy related LBP a patient survey has been carried out (chapter 8). To grasp the relation between overactivity of the pelvic floor muscles and the continence mechanism, background knowledge is presented in the appendix of chapter 8.

During the process of this thesis not only the model of selfbracing of the lumbopelvic region has evolved, also my vision on LBP has been developed. From a relatively narrow biological vision on the aetiology of LBP my scope has been widened to a biopsychosocial vision on LBP. I do realise the shortcomings of therapeutic interventions focussing on LBP as a physical, biological problem alone, as described in chapter 2. It is essential that psychological and psychosocial aspects of LBP are also taken into account in today's treatment of LBP[15,16,17,19].

This thesis is restricted to the anatomical and biomechanical aspects of the lumbopelvic region. Therefore, the clinical consequences for assessment and therapeutic interventions derived from this study focus on biological aspects of LBP alone. Still, these new insights on the stability of the lumbopelvic region and compensation mechanisms in LBP patients are of importance in the assessment and treatment of these patients (See chapter 9). Therefore, instead of negation of underlying organic disease in behavioral treatment of LBP patients, I want to plea for an integration of biological and physical aspects of LBP.

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2 Insufficient lumbopelvic stability – a clinical, anatomical and biomechanical approach to 'nonspecific' low back pain

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Manual Therapy 1998;3:12-20

Abstract

A clinical, anatomical and biomechanical model is introduced based on the concept that under postural load specific ligament and muscle forces are necessary to intrinsically stabilise the pelvis. Since load transfer from spine to pelvis passes the sacroiliac (SI) joints, effective stabilisation of these joints is essential. The stabilisation of the SI joint can be increased in two ways. Firstly, by interlocking of the ridges and grooves on the joint surfaces (form closure); secondly, by compressive forces of structures like muscles, ligaments and fascia (force closure).

Muscle weakness and insufficient tension of ligaments can lead to diminished compression, influencing load transfer negatively. Continuous strain of pelvic ligaments can be a consequence leading to pain.

For treatment purposes stabilisation techniques followed by specific muscle strengthening procedures are indicated. If there is a loss of force closure, for instance in peripartum pelvic instability, application of a pelvic belt can be advised.

Introduction

For modern society low back pain (LBP) is an expensive disease. The yearly prevalence varies from 15-20% in the USA to 25-40% in European countries, and the lifetime prevalence is as high as 60-90%[33]. The minority of patients who recover within 3 months account for 75-90% of the total expenses related to this health care problem, exceeding 60 billion dollars per year in the united states[32]. Notwithstanding the high prevalence, in 70-80% of the cases, the cause of LBP is not clear. We wondered what the reason could be for such a deficiency in our understanding.

The models used to understand and treat LBP are generally based on descriptive anatomy. This branch of anatomy was developed to determine the structures that comprised the body and to categorise them. Categories such as spine, pelvis and lower limbs are primarily based on bony anatomy. Functional anatomy of the locomotor system, which is strongly linked to biomechanics, attempts to explain how bones, ligaments and muscles operate as a system. Consequently, the use of categories such as spine and pelvis can be misleading[40]. For example 'spinal' muscles, like the multifidus muscle, are strongly connected to the pelvis and to the ligaments around the sacroiliac (SI) joints. The use of descriptive anatomy is not satisfactory for answering complex questions such as: what are the reasons why so many patients suffer from LBP? Or how do the spine, the pelvis and the lower limbs function as an integrated system? Using descriptive anatomic models, it is tempting to regard pain in the area of the SI joints as a separate syndrome and not as a low back pain or lumbar syndrome[44] .

Could it be that better knowledge of the functional anatomy of the spine, the pelvis and lower limbs could lead to the understanding of the aetiology of so called 'nonspecific' low back pain? To answer this question this research group has focused its investigations on the role of the SI joints.

Why sacroiliac joints?

Focusing on the functional anatomical relations between spine and pelvis we wondered why such flat joints typically occur at a site, where transfer of large forces can be expected[26,27]. After all, joints with relatively flat surfaces are vulnerable to shear forces[26]. Would ankylosed SI joints not be more appropriate for force transfer?

For many decades clinicians have been convinced the SI joints were not mobile, but this notion is not based on research findings. Especially in the last two decades research has proven otherwise; mobility in the SI joints is usual, even in old age[11,17,20,31-,34]. One advantage of mobile SI joints could be their ability to function as a shock absorber between lower limbs and the spine[26], while another advantage could be the afferent output of the joint capsule (proprioception), which is innervated by the dorsal rami of sacral nerves S1-S4[12].

Form closure

Since the SI joints have to transfer large loads, it can be assumed that the shape of the joints is adapted to this task. The joint surfaces are relatively flat which is favourable for the transfer of compressive forces and bending moments[26,27]. However, as stated already, a relatively flat joint is vulnerable to shear forces. The SI joints are protected from these forces in three ways. Firstly, due to its wedge-shape the sacrum is stabilised by the innominates. Secondly, in contrast to normal synovial joints the articular cartilage is not smooth. Before birth the SI joint articular cartilage is already unusual in its irregularity[6,25]. These modifications of the cartilage are more prominent in men than in women[35]. The gender difference may be related to childbearing and possibly to a different localisation of the centre of gravity in relation to the SI joints. Thirdly, by studying frontal slides of intact joints of embalmed specimens we can show the presence of cartilage covered bone extensions protruding into the joint, the so called ridges and grooves[9,35]

(See Fig.1). They seem irregular, but are in fact complementary, which serves a functional purpose[35]. This stable situation with closely fitting joint surfaces, where no extra forces are needed to maintain the state of the system, given the actual load situation, we termed form closure[26,27,35] (See Fig.2A).

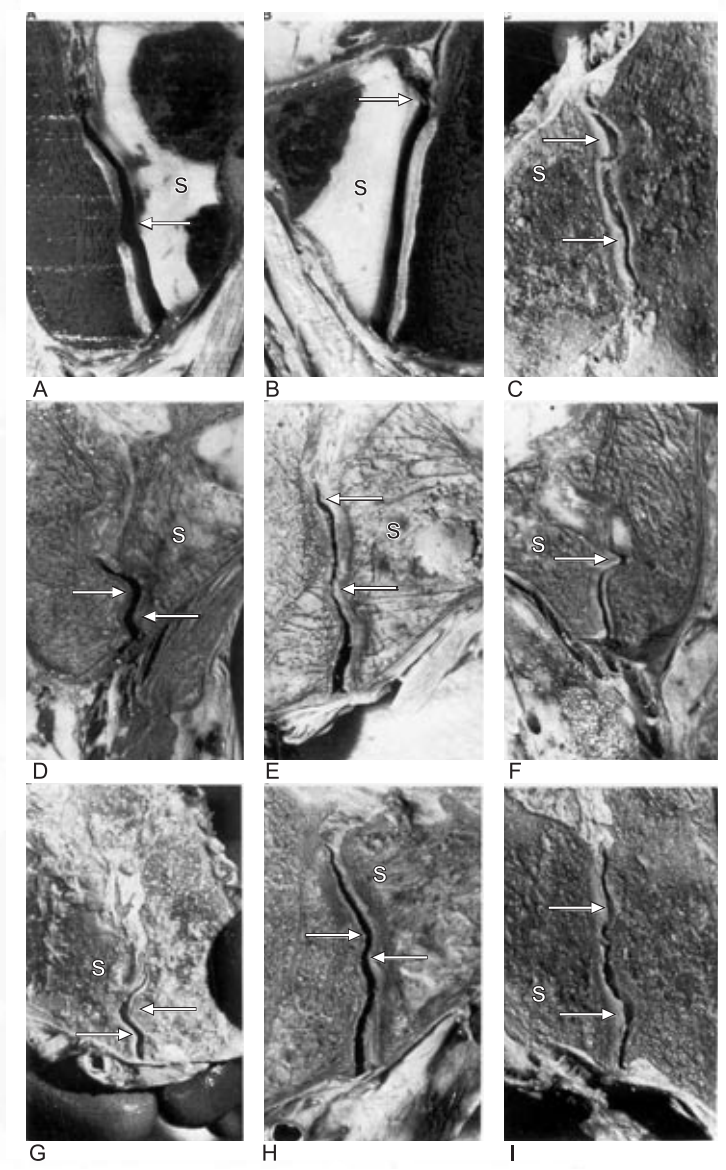

Figure 1. Ridges and grooves in the SI joint, covered with intact cartilage. From Vleeming A et al. Relation between form and function in the sacroiliac joint, Part 1: clinical, anatomical aspects.

Force closure

If the sacrum would fit in the pelvis with perfect form closure, mobility would be practically impossible. However, during walking mobility as well as stability in the pelvis must be optimal. Extra forces may be needed for equilibrium of the sacrum and the ilium during loading situations. How can this be reached?

The principle of a Roman arch of stones resting on columns may be applicable to the force equilibrium of the SI joints[26]. Since the columns of a Roman arch cannot move apart, reaction forces in almost longitudinal direction of the respective stones lead to compression and help to avoid shear[26]. For the same reason, ligament and muscle forces are needed to provide compression of the SI joint. Especially during unilateral loading of the legs the system has to become active. Due to compression of the SI joints friction of the joint increases. This mechanism of compression of the SI joints due to extra forces, to keep an equilibrium, is called force closure[26,27,35,36,37] (See Fig.2B). Force closure can be generated especially by structures with a fibre direction perpendicular to the SI joint and can be accommodated to the specific loading situation. Several ligaments, muscles and even a fascia can contribute to force closure.

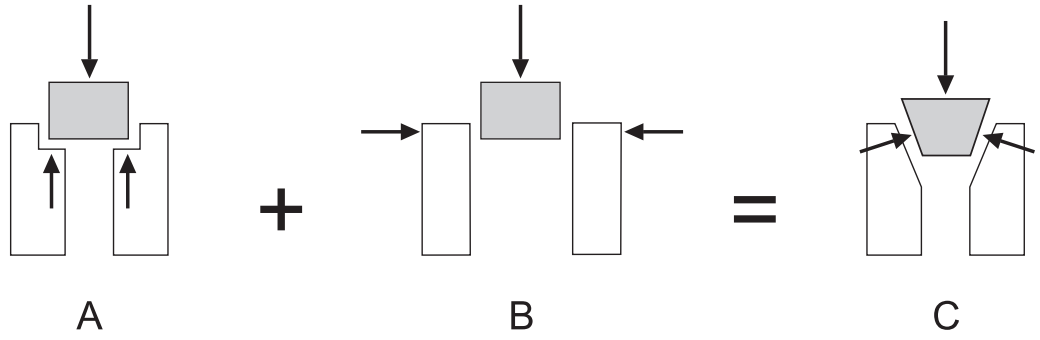

Figure 2. Form closure (Fig.2A.) and Force closure (Fig.2B.) lead to a selfbracing mechanism (Fig.2C.). From: Snijders CJ et al. Transfer of lumbosacral load to iliac bones and legs, Part 1.Biomechanics of selfbracing of the sacroiliac joints and its significance for treatment and exercise.

We termed the shear prevention system, characterised by the combination of form and force closure, the selfbracing or selflocking mechanism of the SI joint [26,27,35,36,37] (See Fig.2C). We will now describe the contribution of ligaments, the thoracolumbar fascia and muscles to the selfbracing mechanism*.

The selfbracing mechanism

Ligaments.

Both interosseous and short dorsal sacroiliac ligaments originate from the sacrum and attach to the ilium close to the joint surfaces. During nutation of the sacrum the tension in these ligaments increases, leading to more friction at the joint surfaces and hence more stability of the SI joints[31]. Nutation of the sacrum occurs during loading situations such as transferring from lying supine to sitting and standing[11,17].

We assume that tension of the sacrotuberous ligament (See Fig.3) can also stabilise the SI joints, since loading of the ligament in embalmed specimens showed a decrease of mobility in the SI joint[38,39,46]. The sacrotuberous ligament originates from the dorsal side of the sacrum and attaches to the ischial tuberosity. Its tension can be influenced in four ways.

* *In the present thesis 'selflocking mechanism' has been changed in 'selfbracing mechanism' to enlarge readability by the use of similar terms .*

Firstly, load tests on embalmed specimens showed increased tension in the sacrotuberous ligament by applying tension to the long head of the biceps femoris muscle[38,39,46]. One explanation could be an anatomical feature, since in half of the specimens (n=12) the fibres of the tendon of biceps femoris were continuous with the sacrotuberous ligament[38,39]. Another explanation of this phenomenon is the tilting backwards of the ilium due to traction on the ischial tuberosity by increased tension in biceps femoris increasing nutation in the SI joint leading to increased tension in the sacrotuberous ligament[38,39,46]. Secondly, the tension of the sacrotuberous ligament can be influenced by increased tension of the gluteus maximus and piriformis muscles because of the anatomical connection between the muscles and the ligament[38,39]. Thirdly, the thoracolumbar fascia can enlarge the tension in the ligament due to the anatomical connections between the deep lamina of the superficial layer of the fascia and the sacrotuberous ligament[40]. Finally, tension in the sacrotuberous ligament also increases during nutation[38]. Apparently the sacrotuberous ligament can inhibit nutation. We wondered which ligament could inhibit counternutation.

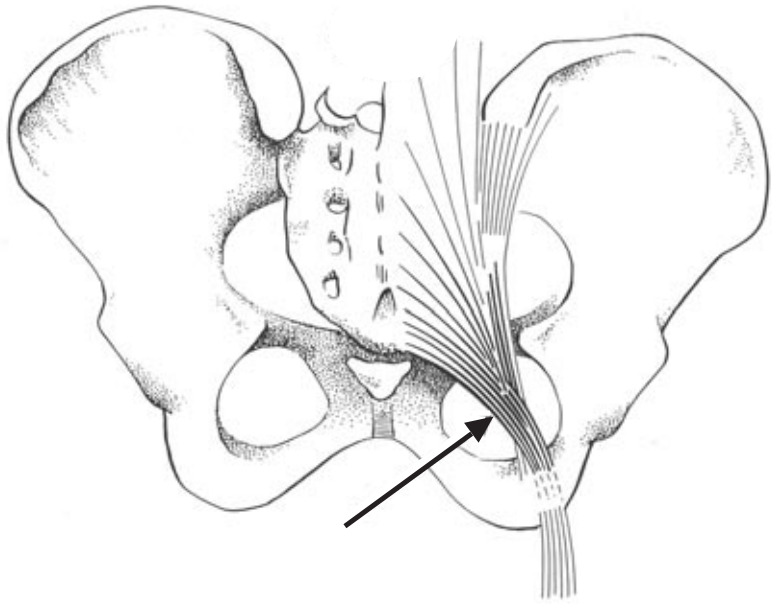

Figure 3. The sacrotuberous ligament. From: Vleeming A et al. The function of the long dorsal sacroiliac ligament.

In our opinion, the long dorsal sacroiliac ligament (See Fig.4) can fulfil this task. It originates from the dorsal surface of the sacrum at the level of S2-S4 and attaches to the Posterior Superior Iliac Spine (PSIS)[41]. This ligament is easily palpable in the area directly caudal to the PSIS, although in an international survey among medical practioners less than 10% could identify the long dorsal sacroiliac ligament[41,43]. The ligament is so solid and taut that it can easily be mistaken for a bony structure when palpated.

The tension in the long dorsal sacroiliac ligament can be increased in two ways: Firstly, tension in this ligament strongly increases during incremental loading of the ipsilateral sacrotuberous ligament. The same is true, but to a lesser degree, for incremental loading of the ipsilateral part of the erector muscle. The tension of this ligament can be decreased by traction to the gluteus maximus muscle[41].

Apparently then, the sacrotuberous ligament and the long dorsal sacroiliac ligament have opposite functions. However, both ligaments also have a direct effect on each other. This is due to an anatomical connection between these ligaments caudal to the PSIS. Increased tension of the sacrotuberous ligament can directly increase tension of the long sacroiliac ligament, and vice versa[41]. In this way extensive slackening of both long dorsal sacroiliac ligament and sacrotuberous ligament is precluded. Such a mechanism could be essential for a flat joint, which is susceptible to shear forces[26,27].

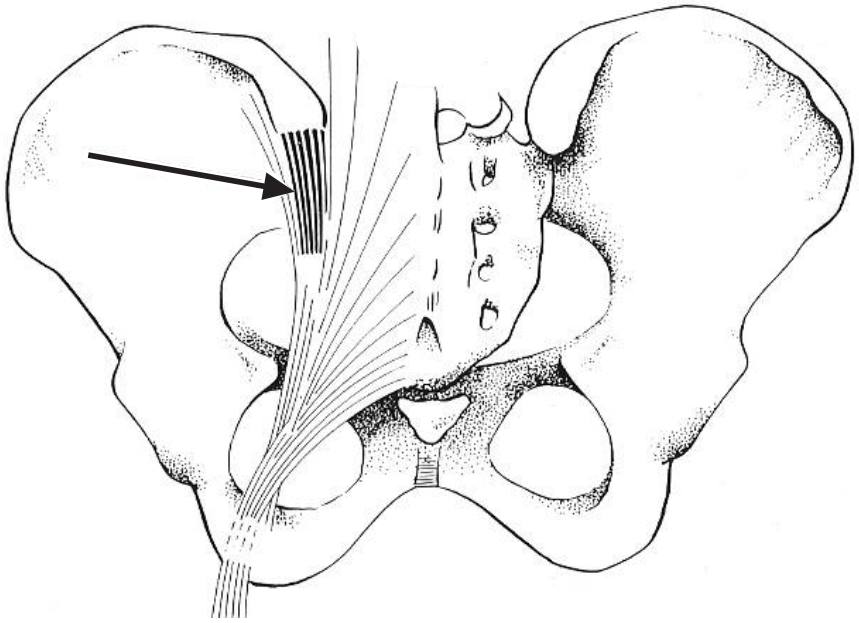

Figure 4. The long dorsal sacroiliac ligament. From: Vleeming A et al. The function of the long dorsal sacroiliac ligament.

Thoracolumbar fascia

The thoracolumbar fascia surrounds the dorsal muscles of the trunk. It proceeds from both sacrum and iliac bones and inserts to the linea nuchae[4,5,40]. The fascia forms an attachment for several upper limb and trunk muscles, e.g. the latissimus dorsi, the gluteus maximus and the trapezius muscle are connected to the superficial layer (See Fig.5). The transversus abdominis and internal oblique muscle are connected to the deep layer of the thoracolumbar fascia (See Fig.6)[4,5,40]. In addition, the sacrotuberous ligament is connected to the deep layer[40].

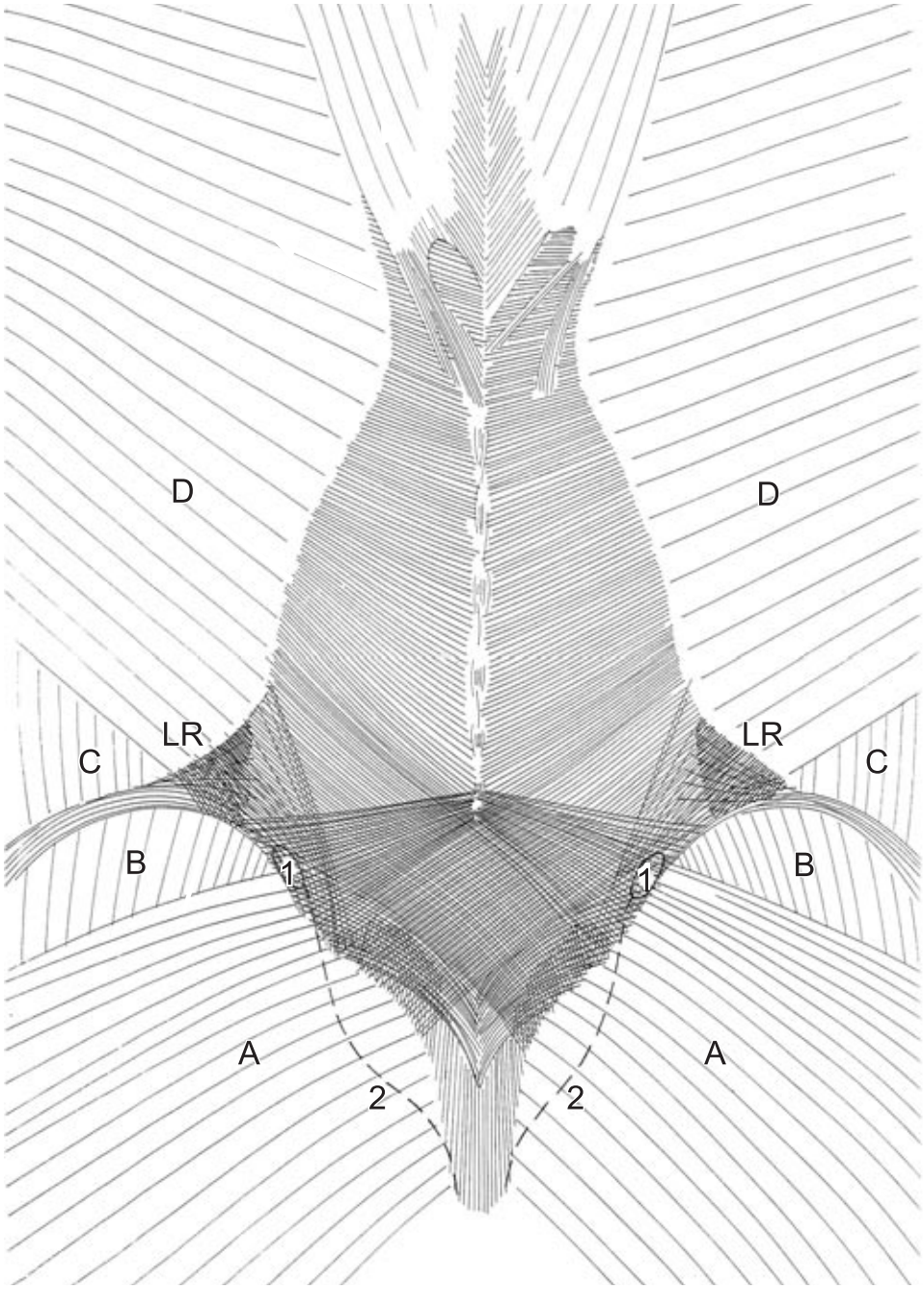

Figure 5. The superficial layer of the thoracolumbar fascia and its attachments to: A. the gluteus maximus, B. the gluteus medius, C. the external oblique, D. the latissimus dorsi. 1. SIPS, 2. The sacrum. From: Vleeming A et al. The posterior layer of the thoracolumbar fascia: its function in load transfer from spine to legs.

In transferring forces between spine, pelvis, and legs, the thoracolumbar fascia plays an important role, especially in rotation of the trunk and stabilisation of the lower lumbar spine and SI joints (lumbopelvic stability). We assume that an increase of tension in the thoracolumbar fascia can lead to more compression on the SI joint, increasing force closure[40].

The tension of the fascia can be increased in two ways, firstly, due to contraction of the muscles that are attached to the thoracolumbar fascia. Secondly, contraction of the erector spinae muscle and especially the multifidus muscle can increase its tension by inflating it (the 'pump it up' phenomenon)[4,40].

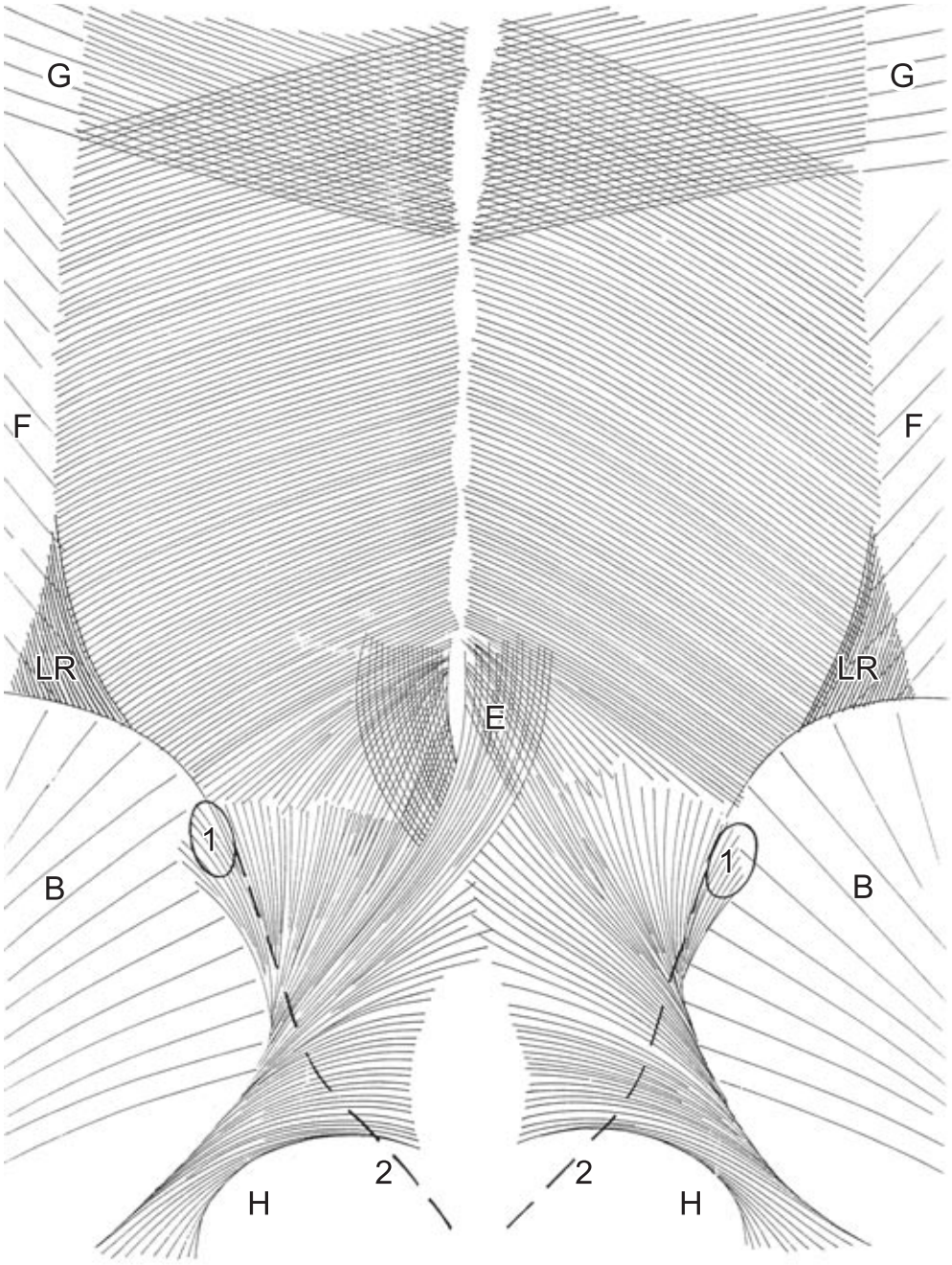

Figure 6. The deep layer of the thoracolumbar fascia and its attachments to: B. the gluteus medius, E. attachments between the deep layer and the erector spinae muscle, F. the internal oblique, G. the seratus posterior inferior, H. the sacrotuberous ligament. 1. SIPS, 2. The sacrum. From: Vleeming A et al. The posterior layer of the thoracolumbar fascia: its function in load transfer from spine to legs.

Due to the connections of the thoracolumbar fascia with upper and lower limb muscles, the fascia is capable of transmitting forces from the lower to the upper extremities and vice versa. Importantly, the effect of contraction of the latissimus can be large because forces derived from its caudal part are fully transferred to the thoracolumbar fascia. The gluteus maximus and the latissimus dorsi merit special attention because they can conduct forces contra laterally since, at the levels of L4-S2, fibres of the superficial layer of the fascia cross the midline[40]. Via the thoracolumbar fascia the gluteus and contralateral latissimus dorsi muscles are coupled. Recently it has been suggested that these muscles, normally categorised as 'hip' and 'arm' muscles could act as trunk rotators[40]. EMG studies show that both muscles contract during rotation of the trunk[2,21]. This implies that increase of force closure can be expected during rotation of the trunk[21].

Musculature

Several muscles are supposed to contribute to force closure of the SI joint. We have described three muscle slings- a longitudinal, a posterior oblique and a anterior oblique sling- that can be energized[44].

The longitudinal sling consists of the combination of the multifidus muscle attaching to the sacrum, the deep layer of the thoracolumbar fascia and the sacrotuberous ligament, which is connected to the long head of the biceps[44]. Tension in this longitudinal sling will stabilise the SI joint in three ways. Due to contraction of the sacral part of the multifidus muscle the SI joint has a tendency to nutate[27] increasing tension in the interosseus and short dorsal sacroiliac ligaments leading to more force closure of the SI joint[26,35]. Secondly, these muscles can contribute to force closure by inflating the thoracolumbar fascia[40]. Finally, contraction of the erector spinae muscle as well as the long head of the biceps can help to increase force closure due to its anatomical connection with the sacrotuberous ligament. As described earlier, tension of the sacrotuberous ligament increases force closure.

The posterior oblique sling (See Fig. 7A) can be energised by the coupled function of the latissimus dorsi and the gluteus maximus muscle[43,44]. The muscles function as synergists[21]. Contraction can directly optimise stabilisation of the SI joint. Force closure also can be increased indirectly, due to the anatomical connections of the gluteus maximus muscle and thoracolumbar fascia with the sacrotuberous ligament, as described previously[38,39,40].

The anterior oblique sling (See Fig.7B) can be energised by the external and internal abdominal muscles and also by the transversus abdominis muscles, because of the connections between these muscles via the rectus sheath[27,44]. These muscles can help to increase force closure[27]. As shown by an EMG study a significant decrease of activity of the oblique abdominal muscles occurs as a result of leg crossing[28]. A possible explanation of this phenomenon is an increase of friction of the SI joint surfaces due to leg crossing[28]. Less force closure by the oblique abdominals is needed. So, crossing the legs seems to be a very functional habit[28].

Other EMG studies in healthy subjects by Hodges and Richardson[14] show activity of the transversus abdominis muscle, a deep trunk muscle, occurring prior to any limb movement, this activity is different from other trunk muscles[14]. Richardson and Jull[23] concluded that this muscle has a primary responsibility for lumbar segmental stability. Another important component of the muscular lumbar segmental stability system is the multifidus muscle[45]. It appears that a co-contraction motor program of transversus abdominis and multifidus muscle is required for specific segmental stability[2].

In our opinion the multifidus and transversus abdominis muscle act not only as lumbar stabilisers but also as pelvic stabilisers. It might well be that other muscles are involved, e.g. the pelvic floor and the respiratory diaphragm.

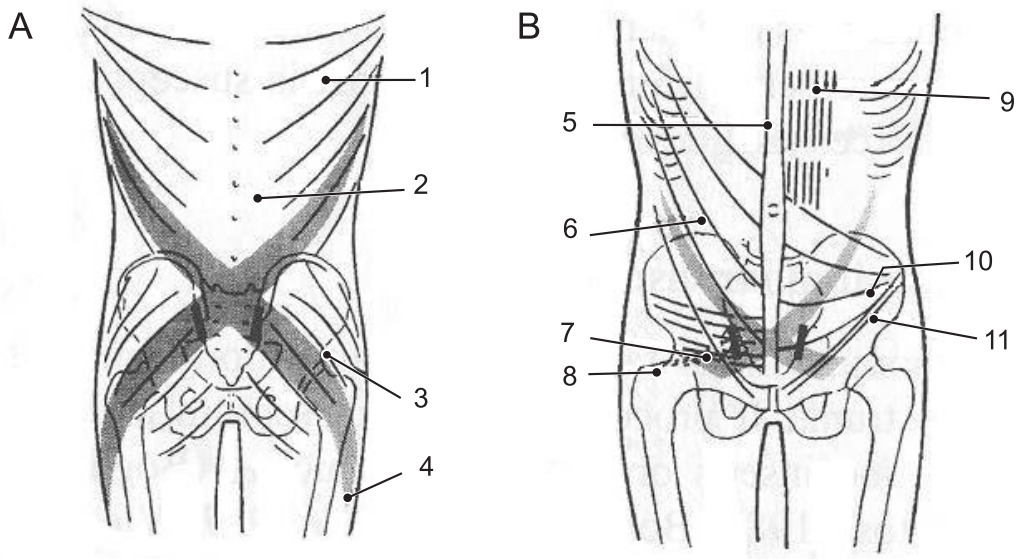

Figure 7A - The posterior oblique sling. 1. the latissimus dorsi, 2. the thoracolumbar fascia, 3. the gluteus maximus, 4. the iliotibial tract
Figure 7B - The anterior oblique sling. 5. linea alba, 6. external oblique muscle, 7. transversus abdominis muscle, 8. piriformis muscle, 9. rectus abdominis muscle, 10. internal oblique, 11. lig. inguinale. From: poster presentation. 'Biomechanical model on the aetiology of low back pain'. Snijders CJ et al.

Insufficient selfbracing

In general the ligamentous structures surrounding the SI joints are assumed to be sufficient to stabilise the joints. We do not agree with this assumption since we have produced evidence to show that the ligaments alone are not capable of transferring lumbosacral load effectively from the spine to the iliac bones[35,36,37]. This is especially relevant for heavy loading situations and for conditions where sustained load resulting in creep occurs, such as in standing and sitting. According to the selfbracing mechanism, resistance against shear forces is the result of the specific properties of the joint articular surfaces and the compression of body weight (form closure), as well as muscle action and ligament force (force closure). This implies that several factors can lead to insufficient selfbracing: force closure can decrease by changes in ligamentous tension e.g. laxity of joint capsule and ligaments, reduced muscle strength or inadequate coordination between muscles.

Decrease of force closure

In addition to the diminished muscle power and/or unbalanced muscle function of several muscles (e.g. erector spinae, the gluteus maximus, the external and internal obliques and the latissimus dorsi muscle) insufficient ligament tension can lead to a decrease in force closure. Such an insufficiency of the ligaments can occur due to an unusual position of the SI joints this can influence the afferent output of the joint capsule. There may be a causal relationship between different afferent output of the joint capsule and changes in the motor pattern of the multifidus and transversus abdominis muscles[13,14]. This function of the transversus abdominis muscle has clearly been shown

in LBP patients[14]. The difference in timing of the transversus abdominis muscle after a few days pain is remarkable; the motor programme of the muscles changes[14] . Hides et al[13] reported a unilateral wasting of the segmental cross sectional area of the multifidus muscle measured by ultrasound imaging technique in patient with acute unilateral LBP. Inhibition due to perceived pain via a long loop reflex which targeted the vertebral level of pathology to protect the damaged tissues is the likely mechanism of wasting[13]. Through this change of motor pattern, coordination between the possible initiators of force closure is disturbed, the transversus abdominis and multifidus muscle will be disturbed .

In addition, laxity of the SI joint capsule can diminish optimal force closure. This is seen especially during pregnancy when hypermobility of the SI joint occurs, probably due to the presence of certain hormones leading to laxity of ligaments and joint capsule[15]. Due to hormonal laxity combined with muscular weakening and hence diminished compression selfbracing can become insufficient, which can lead to peripartum pelvic pain[18,19,29,30].

It has been assumed that during pregnancy women bend the upper body backwards to obtain equilibrium with the increasing weight in the abdomen[29]. In fact the spine becomes straighter by a flattening of the lumbar curvature leading to a less nutated position of the SI joint[11, 17,31]. This relative counternutated position is especially seen late in pregnancy when women counterbalance the weight of the foetus[29]. Diminished nutation can also be the effect of a pain withdrawal reaction, as in women with a painful symphysis following delivery[19]. In counternutation the SI joint is particularly less stable, which can enhance the instability problem.

Some patients with peripartum pelvic pain show extreme pelvic hypermobility. As a result the stabilisation of the SI joints becomes deficient.

Consequences of insufficient selfbracing

An epidemiological study showed the occurrence of Long (dorsal) Ligament Pain Syndrome (LLPS) in 21% of low back pain patients[22]. The assessment of LLPS was related to pain within the boundaries of the long dorsal sacroiliac ligament directly palpable caudal to the PSIS. The interobserver agreement of establishing LLPS was found to be good[22].

In a recent survey (n= 394) on peripartum pelvic pain patients, 42% indicated pain in the area caudal to the PSIS, within the boundaries of the long dorsal sacroiliac ligament[19]. Increased tension of this ligament could clarify why pain is specifically felt directly caudal to the PSIS. Not only in patients with peripartum pelvic instability but also in patients with nonspecific LBP can show increased tension which can be the result of counternutation or diminished nutation. We assume that palpation of this ligament directly caudal from the PSIS is an important pain provocation site for assessment of ligamentous tension in patients with LBP and lumbopelvic instability.

According to the selfbracing model, the SI joints become especially vulnerable to shear forces if loaded in counternutation. Counternutation, which is coupled to a supine position and flattening of the spine, can lead to abnormal loading, not only of the SI joints but also in the lumbar intervertebral joints and discs.

Based on the presented data low back disorders like sciatica, soft tissue lesions or herniation of discs, are not necessarily separate syndromes; they can be the results of insufficient stabilisation of the pelvis and lower spine.

Load transfer with an unstable SI joint can bring excessive loads of surrounding tissues and hence pain in local structures. Pain referral maps of the SI joint show pain occurrence in the lower back and the buttock sometimes radiating to one leg[24].

Clinical assessment and therapy

Clinical assessment

When peripartum pelvic instability is involved, the pain can begin during pregnancy, often in the third month or either directly or a few weeks after the delivery. For patients with LBP and/or pain in the buttock sometimes radiating in one leg, it is important to know the history of the pain, the exact site of pain and the spinal position which eases the pain. The information of this assessment can lead to more insight on how the SI joint and L5-S1 are involved and whether the long dorsal ligament is tensed.

It is important to find answers to questions like: are the SI joints hypermobile? or Is nutation in the SI joints diminished? However, in assessing the mobility of the SI joint caution is needed as mobility tests of the SI joint are not reliable. Pain provocation tests seem to be more valid[3,16,22,24].

To assess stability of the SI joints clinicians can use the Active Straight Leg Raise test (ASLR)[18]. Lying supine the patient is asked to lift one leg, five cm above the couch. The ASLR test is positive for an unstable pelvis if the patient is unable to lift the leg, or if the patient experiences diminished strength on one side. The test is repeated while the patient is wearing a pelvic belt, which has been shown to have a stabilising effect on the pelvis[19]. In the case of impairment of the selfbracing mechanism it will be easier to lift a leg wearing the belt. Another stabilising effect can be reached by manual pressure on the lateral sides of the anterior superior iliac spines or contraction of the obliques, using the anterior oblique sling.

The next stage in testing muscular lumbopelvic stability involves testing the strength and coordination of the transversus abdominis and multifidus muscles, the erector spinae, gluteus maximus, the oblique abdominis and latissimus dorsi muscles since these muscles contribute to a proper force closure.

In case of peripartum pelvic pain patients an additional assessment is possible using X-ray photography. After delivery the pubic symphysis is usually widened from the normal 4 mm. to 8 mm.[1] A more specific relation between pelvic instability and the X-ray photography is to look for a vertical shift of the pubic bone during standing on one leg: the Chamberlain technique. During weight bearing on one side alternating left and right lower limbs radiographs in the posteroanterior direction are made. Chamberlain suggested that the side of the high pubic bone was the abnormal side. However the vertical shift is not, as Chamberlain describes a shift of the pubic bone and ilium on the weight bearing side to a more cranial position, but a shift to a more caudal position on non weight bearing side[19]. A shift to caudal implies an unstable symphysis pubis and SI joint.

Direct measurement of the mobility of the SI joints is still not possible; however, using Colour Doppler Imaging Images of the left and right SI Joints can be compared[7,8]. This non-invasive method seems to be reproducible. The outcome of this research shows that the most important criterion of hyper- and hypomobility of the SI joints is not mobility itself, but the difference in mobility between left and right SI joint. However, it is still too early to draw clinical conclusions.

Therapy

By testing the muscular and articular lumbopelvic stability, on the basis of the ASLR, pain provocation tests and muscular strength and coordination it is possible to formulate a therapeutic plan.

Firstly, a clinician should strive for optimal mobility in the SI joints. Diminished nutation or relative counternutation can increase instability and leads to heightened tension in the long sacroiliac ligaments. A simple technique nutating the sacrum and tilting the ilium backwards, can give an immediate relief of pain directly caudal of the PSIS, as DonTigny[10] has shown.

Secondly, a patient can train muscular lumbopelvic stability by emphasizing a motor program related specifically to the transversus abdominis and multifidus muscles[23]. Through an stabilisation program, using an abdominal hollowing technique, both muscles become active, stabilising the lumbopelvic region[23]. This stabilising program consists of three phases. During the first phase, a motor program is created of both transverse abdominis and multifidus muscles. The aim is to contract these muscles without any movement of extremities and trunk. In the second phase, both muscles have to keep the lumbopelvic region stabilised during movements of both extremities. During the third phase, the transverse abdominis and multifidus muscle must be active during trunk movements. As latest research shows, motor programming and stabilisation of the lumbopelvic region can be trained effectively[13,23].

Finally, the strength and coordination of the erector spinae can be increased by extension of the trunk. The strength of the oblique abdominal muscles, the gluteus maximus and the latissimus dorsi muscles can be increased during rotation of the trunk[42]. All these muscles can optimise force closure. However, it is very important that these muscles are not trained separately before stabilisation of the lumbopelvic region is sufficient, by emphasising the motor programm of the transverse abdominis and multifidus muscles. For instance, when the gluteus maximus muscle is trained, especially in case of hypermobile joints, an asymmetrical movement of the pelvis will be the result and can provoke the pain. During strengthening of the muscles the emphases should be on training the three slings.

For patients with peripartum pelvic instability due to hypermobility, therapy should include advice about activities of daily living. It is important for the patient to be advised on walking patterns, climbing stairs, sitting, lifting etc.
Strong contraction of the iliopsoas muscle should be avoided. Contraction of this muscle can lead to a large asymmetric force placed the SI joint, which can lead to more pain if the SI joints are insufficiently stabilised. As soon as stability increases by training coordination, stability and muscle strength, the patients will experience a less negative influence of the iliopsoas muscle. This stabilising effect can also be reached by a pelvic belt[19]. The belt significantly increases force closure, as research on embalmed specimen shows, and is probably too small to inhibit muscle activity[19].

Furthermore, it is necessary that a patient with peripartum pelvic instability is informed that too much rest can lead to loss of muscle strength, coordination, stability and muscular and physical endurance. Too much rest is likely to increase the symptoms. Periods of short rest in the case of acute pain can be advised and activities that do not lead to an increase in pain can be continued.

Acknowledgment

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3

The posterior layer of the thoracolumbar fascia

Its function in load transfer from spine to legs

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Abstract

Study Design: The superficial and deep lamina of the posterior layer of the thoracolumbar fascia have been studied anatomically and biomechanically. In embalmed human specimens, the posterior layer has been loaded by simulating the action of various muscles. The effect has been studied using raster photography.

Objectives: To study the role of the posterior layer of the thoracolumbar fascia in load transfer between spine, pelvis, legs and arms.

Summary of Background Data:It has not been determined whether muscles such as the gluteus maximus, latissimus dorsi, erector muscle, and biceps femoris are functionally coupled via the thoracolumbar fascia. The caudal relations of the posterior layer of the thoracolumbar fascia have not been previously studied.

Methods: Dissection was directed to the bilaminar posterior layer of the thoracolumbar fascia of 10 human specimens. The superficial and deep lamina were studied using visual inspection and raster photography. Tension to the posterior layer of the fascia was simulated by traction to various muscles and measured by studying the displacement in the posterior layer.

Results: Traction to a variety of muscles caused displacement of the posterior layer. This implies that *in vivo*, the superficial lamina will be tensed by contraction of various muscles, such as the latissimus dorsi, gluteus maximus and erector muscle, and the deep lamina by contraction of the biceps femoris. Caudal to the level of L4 (in some specimens, L2-L3), tension in the posterior layer was transmitted to the contra lateral side.

Conclusions: Anatomic structures normally described as hip, pelvic, and leg muscles interact with so-called arm and spinal muscles via the thoracolumbar fascia. This allows for effective load transfer between spine, pelvis, legs, and arms-an integrated system. Specific electromyographic studies should reveal whether the gluteus maximus muscle and contra lateral latissimus dorsi muscle are functionally coupled, especially during rotation of the trunk. In that case, the combined action of these muscles assists in rotating the trunk, while simultaneously stabilizing the lower lumbar spine and sacroiliac joints.

Key words

low back pain, lumbar spine, sacroiliac joint, spinal stability, thoracolumbar fascia

Introduction

To understand and treat low back pain, models are generally used based on descriptive anatomy. This branch of anatomy was developed to determine the structures our body consists of, and to categorise them. Categories such as spine, pelvis, and legs are primarily based on bony anatomy.

Functional anatomy of the locomotor system, which is strongly linked to biomechanics, attempts to explain how bones, ligaments, and muscles operate as a system. Consequently, use of categories such as spine and pelvis can be misleading. From a biomechanical and neurophysiologic point of view, they are fully integrated. 'Back muscles,' for instance, are categorized in descriptive anatomy as typically spinal. However, parts of these 'back muscles' bridge the sacroiliac (SI) joints. For example, in humans, the multifidus muscle shows an extensive attachment to both the sacrum and the iliac crest[6].

Using descriptive anatomic models, it is tempting to regard pain in the area of the SI joints as a separate syndrome, not as part of low back pain. However, these joints are fully integrated in the spine-pelvis-leg mechanism[8]. To function properly, this mechanism needs stability over the pelvis and the SI joints. Effective load transfer across the SI joints requires specific action of a variety of muscles, leading to sufficient compression of the SI joint and preventing shear[8,9]. In enlarging compression, the biceps femoris and gluteus maximus muscles are important[3,7,12,13,16-18]. Both muscles are attached to the sacrotuberous ligament, which functionally bridges the SI joint. Obviously, pain in the area of the SI joints is not necessarily a local problem. It can be symptomatic of a failed load transfer system[8,9].

The strong thoracolumbar fascia can be used for load transfer[9]. The posterior layer of this fascia is of special interest because of its multiple connections. The main interest is whether muscle-induced tension of this fascia can assist in transferring load between spine, pelvis, legs and arms.

Methods

Dissection was directed to the posterior layer of the thoracolumbar fascia of 10 human specimens (6 male, 4 female; ages between 65 and 90 years). Specimens were embalmed by vascular perfusion with a medium containing 2.2% formaldehyde. The posterior layer of the thoracolumbar fascia was studied by visual inspection. For documentation, raster photography was used on three specimens (1 female, 2 male) using a raster of 1.20 x 1.60 m with numbered windows (10 x 10 cm wide), fixed at a distance of 20 cm from the thoracolumbar fascia. By magnifying the photos of the individual windows, the orientation of the fibers could be described in detail.

Tension to the muscles attached to the superficial lamina of the posterior layer of the thoracolumbar fascia was simulated by traction, using adjustable traction power units (Eltrac 471-1471.905; Enraf Nonius, Delft, The Netherlands). A force of 50 N was used, applied to the muscle and its fascia by means of an adapted forceps, pulling in the direction of the muscle fibers. The forceps was rigidly fixed to that part of the muscle and its fascia located nearest to the superficial lamina. In a custom-made frame, traction was applied with the power units to the following muscles: latissimus dorsi (at the level of T11 and L3-L4), gluteus maximus and medius, external oblique, and trapezius (See Fig.1). The effect of the traction was estimated by measuring the distance in cm between the attachment site of the forceps and the most remote displacement of the superficial lamina. Displacement of markers attached to the posterior layer was measured using raster photography.

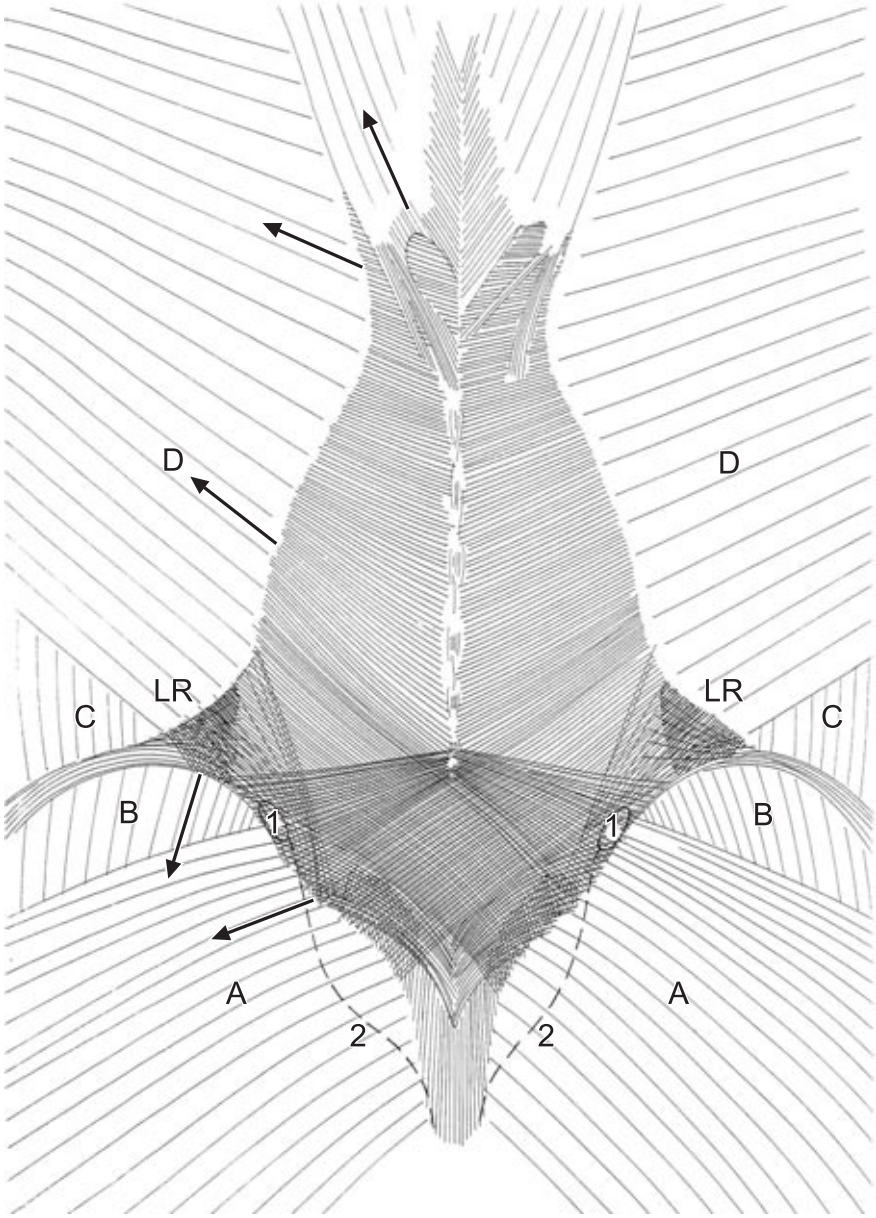

Figure 1. The superficial layer of the thoracolumbar fascia and its attachments to: A. the gluteus maximus, B. the gluteus medius, C. the external oblique, D. the latissimus dorsi. 1. SIPS, 2. The sacrum. Arrows indicate, from cranial to caudal, traction to trapezius, latissimus dorsi cranial, latissimus dorsi caudal, external oblique, gluteus medius and gluteus maximus muscles, respectively.

Subsequently, the superficial and deep lamina of the posterior layer were separated with a blunt forceps cautiously inserted into the loose connective tissue between the laminae. The forceps were carefully moved from the midline laterally and caudally up to the site where the fibers of the superficial lamina fuse with the fascia of the latissimus dorsi. Dissection was necessary to separate the more caudal parts of the superficial and deep lamina, generally starting at the level of L5. Special attention was given to the connections with the sacrotuberous ligament. Traction (50 N) was applied to the tendon of the long head of the biceps femoris (directed to either lateral or medial) and to the muscle and its fascia of the serratus posterior inferior and the internal oblique muscles. (See Fig.2). The effect of tension on the deep lamina was studied as described for the superficial lamina.

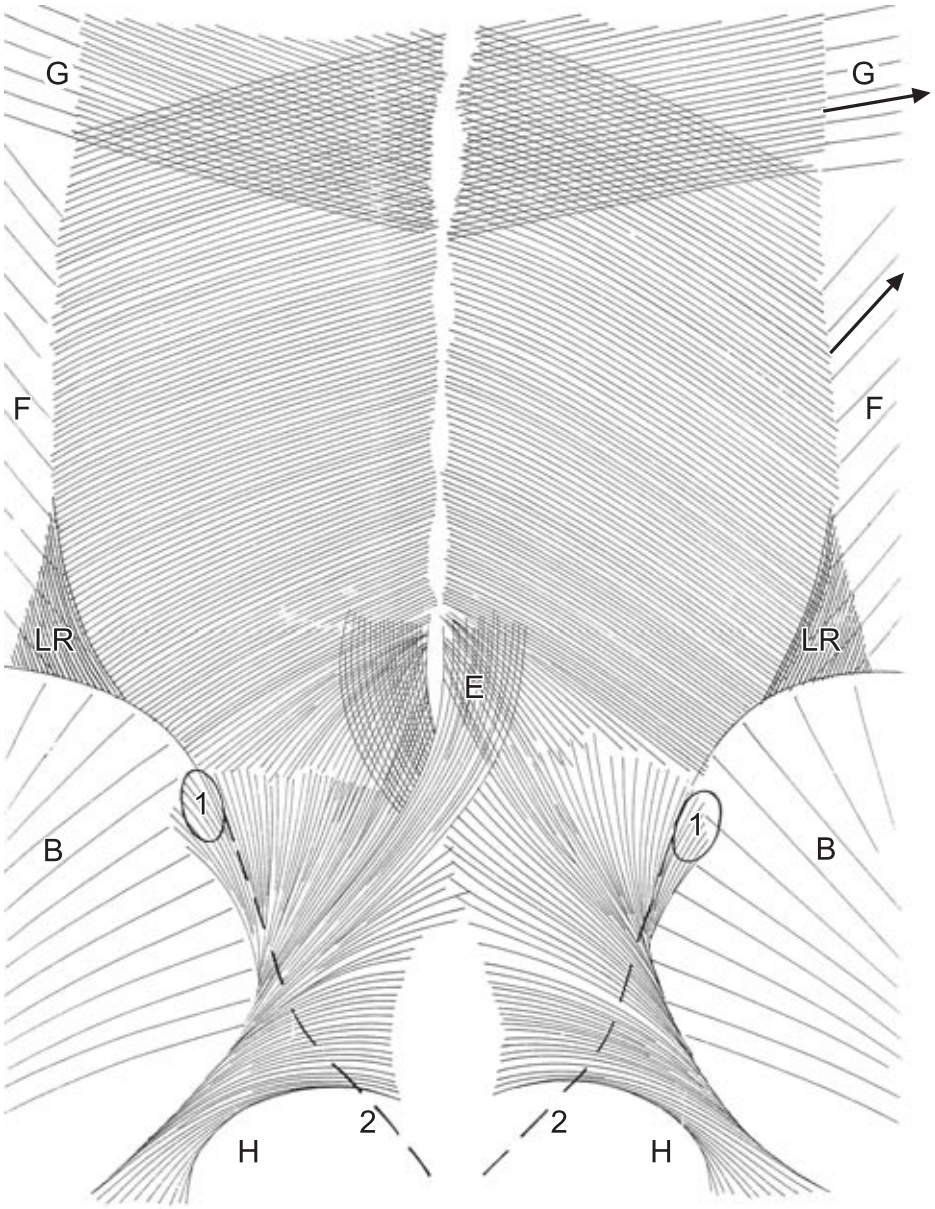

Figure 2. The deep layer of the thoracolumbar fascia and its attachments to: B. the gluteus medius, E. attachments between the deep layer and the erector spinae muscle, F. the internal oblique, G. the seratus posterior inferior, H. the sacrotuberous ligament. 1. SIPS, 2. The sacrum. Arrows indicate, from cranial to caudal, traction to serratus posterior inferior and internal oblique muscles, respectively.

Results

Anatomy

In all preparations, the posterior layer of the thoracolumbar fascia covers the back muscles from the sacral region through the thoracic region as far as the fascia nuchae. At the levels of L4-L5 and the sacrum, strong connections exist between the superficial and deep lamina. The transverse abdominal and internal oblique muscles are indirectly attached to the thoracolumbar fascia through a dense raphe formed by fusion of the middle layer[1] of the thoracolumbar fascia and both laminae of the posterior layer. This 'lateral raphe' [1,2] is localised lateral to the erector spinae and cranial to the iliac crest.

Superficial Lamina.

The superficial lamina of the posterior layer of the thoracolumbar fascia is continuous with the latissimus dorsi, gluteus maximus, and partly the external oblique muscle of the abdomen and the trapezius muscle (See Fig.1). Cranial to the iliac crest, the lateral border of the superficial lamina is marked by its junction with the latissimus dorsi muscle.

The fibers of the superficial lamina are orientated from craniolateral to caudomedial. Only a few fibers of the superficial lamina are continuous with the aponeurosis of the external oblique and the trapezius. Most of the fibers of the superficial lamina derive from the aponeurosis of the latissimus dorsi and attach to the supraspinal ligaments and spinous processus cranial to L4. Caudal to L4-L5, the superficial lamina is generally loosely (or not at all) attached to midline structures such as supraspinal ligaments, spinous processes, and median sacral crest. In fact, they cross to the contralateral side, where they attach to the sacrum, posterior superior iliac spines, and iliac crest. The level at which this phenomenon occurs varies. It is generally caudal to L4 but in some preparations it occurs already at L2-L3.

At sacral levels, the superficial lamina is continuous with the fascia of the gluteus maximus. These fibers are orientated from craniomedial to caudolateral. Most of these fibers attach to the median sacral crest. However, at the level of L4-L5, and in some specimens as caudal as S1-S2, fibers partly or completely cross the midline, attaching to the contralateral posterior superior iliac spine and iliac crest. Some of these fibers fuse with the lateral raphe and with fibers derived from the fascia of the latissimus dorsi. Because of the different fiber directions of the latissimus dorsi and the gluteus maximus, the superficial lamina has a cross-hatched appearance at L4-L5, and in some preparations also at L5-S2.

Deep Lamina.

At lower lumbar and sacral levels, the fibers of the deep lamina are oriented from craniomedial to caudolateral (See Fig.2). At sacral levels, these fibers are fused with those of the superficial lamina. Because fibers of the deep lamina are continuous with the sacrotuberous ligament, an indirect link exists between this ligament and the superficial lamina. There also is a direct connection with some fibers of the deep lamina.

In the pelvic region, the deep lamina is connected to the posterior superior iliac spines, iliac crests, and the long posterior sacroiliac ligament[11]. This ligament originates from the sacrum and attaches to the posterior superior iliac spines.

In the lumbar region, fibers of the deep lamina derive from the interspinous ligaments. They attach to the iliac crest and more cranially to the lateral raphe, to which the internal oblique is attached. In some specimens, fibers of the deep lamina cross to the contra lateral side between L5-S1. In the depression between the median sacral crest and the posterior superior and inferior iliac spines, fibers of the deep lamina fuse with the fascia of the erector. More cranially, in the lumbar region, the deep lamina becomes thinner and freely mobile over the back muscles. In the lower thoracic region, fibers of the serratus posterior inferior muscle and its fascia fuse with fibers of the deep lamina.

Kinematics

Traction to the Superficial Lamina.

Depending on the site of the traction, quite different results were obtained (See Fig.3). Traction to the cranial fascia and muscle fibers of the latissimus dorsi muscle showed limited displacement of the superficial lamina (homolaterally up to 2-4 cm). Traction to the caudal part of the latissimus dorsi caused displacement up to the midline. This midline area is 8-10 cm removed from the site of traction. Between L4-L5 and S1-S2, displacement of the superficial lamina occurred even contralaterally. Also, traction to the gluteus maximus caused displacement up to the contralateral side. The distance between the site of traction and visible displacement varied from 4 to 7 cm. In Figure 1, the contralateral effect of traction to the caudal part of the latissimus dorsi is small compared with the gluteus maximus, although the ipsilateral effect is larger. This is expected because of the relatively large

distance between the impact site on the latissimus dorsi and the midline, compared with that of the gluteus maximus. The effect of traction to the external oblique varied markedly between the different preparations. In all preparations, traction to the trapezius muscle resulted in a relatively small effect (up to 2 cm). There was no effect seen of traction to the medial gluteal muscles.

Traction to the Deep Lamina.

Traction to the biceps tendon, applied in the lateral direction, resulted in displacement of the deep lamina up to the level L5-S1. Obviously, this load transfer is conducted by the sacrotuberous ligament[13,16]. In two specimens, displacement occurred at the contralateral side, 1-2 cm away from the midline. Traction to the biceps tendon directed medially showed homolateral displacement in the deep lamina, up to the median sacral crest. Traction to the internal oblique did not result in visible displacement. In two specimens, fibers of the deep lamina were damaged by the traction to the serratus posterior inferior muscle, whereas in one specimen, displacement was visible up to 3.5 cm away from the site of traction.

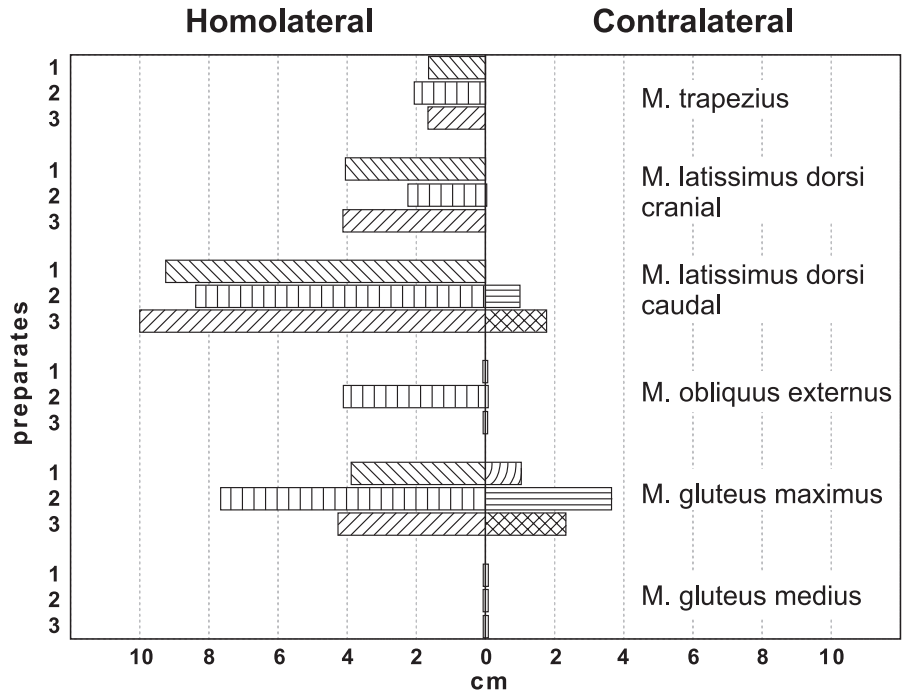

Figure 3: The effect on the superficial lamina of traction to the aponeurosis and muscle fibers of different muscles. Data reflect the distance (in cm) between site of traction and most distant visual displacement of fibers of the homolateral and contralateral superficial lamina, in three preparations (1, 2, and 3).

Discussion

The present study confirms some previous studies and disagrees with others. The bilaminar structure of the posterior layer of the thoracolumbar fascia has been described by several authors[1,2,4-6]. Bogduk, Macintosh, and Twomey [1,2] described the orientation of the fibers of the superficial and deep lamina as, respectively, caudomedial and caudolateral. The present study confirmed the orientation of the laminae and their attachments. According to most studies[1,2,4], the latissimus dorsi is mentioned as the significant structure from which fibers of the superficial lamina originate. The gluteus maximus as the origin for formation of the superficial fascia is ignored. Bogduk and Macintosh[1] stated that fibers located caudally

from L3 decussate to the contralateral site, although it was not possible to trace the precise origin of these fibers because of strong fusion to midline structures. The present study confirmed the phenomenon of crossing fibers. The level of the crossing varies from L2-S2. In contrast to the study of Bogduk and Macintosh[1], no connections were found between the serratus posterior inferior and the superficial lamina: Its fascia was exclusively connected to the deep lamina.

Bogduk, Macintosch, and Twomey [1,2] described the deep lamina as a structure consisting of bands of collagen fibers extending from the lumbar spinal processes to the iliac crest and lateral raphe. However, we cannot confirm the existence of bands of collagen fibers; we found a continuous layer. Those authors paid no attention to the sacral part of the deep lamina. As a result, the connections with the sacrotuberous ligaments were omitted. Therefore, the biomechanical model, as proposed by Bogduk and Twomey [2], is incomplete. The bracing effect of the thoracolumbar fascia on the lower lumbar spine and SI joints, essential for proper load transfer between spine and legs[8,9], can be adequately described only if the caudal part of the thoracolumbar fascia is included.

As shown by the traction tests, the tension of the posterior layer of the thoracolumbar fascia can be influenced by contraction or stretching of a variety of muscles. In our experience, the effect of traction in embalmed human bodies is smaller than that in unembalmed bodies. Furthermore, specimens of relatively high age were used. The effects measured in this study probably would be larger in young, healthy individuals. It is noteworthy that muscles, especially those like the latissimus dorsi and gluteus maximus, are able to exert a contralateral effect. This implies that both the gluteus maximus muscle and contralateral latissimus dorsi muscle tense the posterior layer. Hence, parts of these muscles provide a pathway for uninterrupted mechanical transmission between pelvis and trunk. It could be argued that the lack of connection between the superficial lamina of the posterior layer and the supraspinous ligaments in the lumbar region is a disadvantage for stability. However, it would be disadvantageous only if strength, coordination, and effective coupling of the gluteus maximus and the caudal part of the contralateral latissimus dorsi were diminished. We assume that the strength increase of the mentioned muscles accomplished by specific or torsional trunk training can influence the quality of the posterior layer. In this concept, the posterior layer of the thoracolumbar fascia plays an integrating role in rotation of the trunk and in load transfer, and thus stability of the lower lumbar spine and pelvis.

Recently, a biomechanical model of the SI joints was proposed[8,9]. It was stated that joints with predominantly flat surfaces are well suited for transferring large moments of force, but are vulnerable to forces in the plane of the joint surfaces[8,9].Therefore, flat joint surfaces go with restricted joint excursions. In a model of the SI joints[12] based on anatomic and biomechanical findings, the principle of form and force closure was discussed. Form closure refers to a stable situation with closely fitting joint surfaces, where no extra forces are needed to maintain the state of the system, given the actual load situation. In this situation, no lateral forces are needed to counterbalance the effects of the vertical load. With force closure, a lateral force is needed.

The SI joint, with its undulated form and symmetrical ridges and depressions, combined with compression and the generated friction, is an example of a joint remaining stable through a combination of form and force closure[14]. If force closure is not sufficient - e.g. due to insufficient muscle action and hence insufficient ligament strain- form closure becomes important.

Pelvic instability (and peripartum pain) can be relieved by applying a pelvic belt, a device that self-braces the SI joints[10,15]. Force closure is increased by such a belt, located just cranially to the greater trochanter and caudally to the SI joints[8,15]. The belt can be used

with small force, resembling the action of laces of a shoe. By exerting compression on the lower lumbar spine and pelvis, the posterior layer of the thoracolumbar fascia can accomplish force closure physiologically. The present study showed that the coupled function of gluteus maximus and contralateral latissimus dorsi creates a force perpendicular to the SI joints.

Finally, there is a possible role of the erector muscle in load transfer. Between the lateral raphe and the interspinous ligament, the deep lamina encloses the erector muscle. Here, contraction of the erector muscle will longitudinally increase the tension in the deep lamina directly by pulling and indirectly by dilating the complete posterior layer of the thoracolumbar fascia. Consequently, it can be assumed that training of muscles like the gluteus maximus, latissimus dorsi, and erector can help increase force closure by strengthening the posterior layer of the thoracolumbar fascia.

Conclusion

In transferring forces between spine, pelvis, and legs, the posterior layer of the thoracolumbar fascia may play an important role, especially in rotation of the trunk and stabilization of the lower lumbar spine and SI joints. The gluteus maximus and the latissimus dorsi merit special attention because they can conduct forces contralaterally, via the posterior layer. The effect of contraction, especially of the latissimus dorsi, will be large because forces derived from its caudal part are fully transferred to the thoracolumbar fascia.

The design of training methods to relieve low back pain requires knowledge of the functional anatomy of the thoracolumbar fascia and of its role in load transfer. Further studies must reveal whether muscles like the gluteus maximus and the caudal part of the latissimus dorsi need to be emphasized in training programs. Because of the coupling between gluteus maximus and contralateral latissimus dorsi muscle via the posterior layer of the thoracolumbar fascia, caution is needed in categorizing structure as belonging exclusively to arms, spine, or legs.

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4

The Function of the Long Dorsal Sacroiliac Ligament

Its Implication for Understanding Low Back Pain

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Spine 1996;21:556-562

Abstract

Study Design: In embalmed human bodies the tension of the long dorsal sacroiliac ligament was measured during incremental loading of anatomical structures that are biomechanically relevant.

Objectives: To assess the function of the long dorsal sacroiliac ligament.

Summary of Background Data: In many patients with non specific low back pain or peripartum pelvic pain, pain is experienced in the region in which the long dorsal sacroiliac ligament is located. It is not well known that the ligament can be easily palpated in the area directly caudal to the posterior superior iliac spine. Data on the functional and clinical importance of this ligament are lacking.

Methods: A dissection study was performed on the sacral and lumbar regions. The tension of the long dorsal sacroiliac ligament (n = 12) was tested under loading. Tension was measured with a buckle transducer. Several structures, including the erector spinae muscle, the posterior layer of the thoracolumbar fascia, the sacrotuberous ligament, and the sacrum, were incrementally loaded (with forces of 0-50 Newton). The sacrum was loaded in two directions, causing nutation (ventral rotation of the sacrum relative to the iliac bones) and counternutation (the reverse).

Results: Forced nutation in the sacroiliac joints diminished the tension and forced counternutation increased the tension. Tension in the long dorsal sacroiliac ligament increased during loading of the ipsilateral sacrotuberous ligament and erector spinae muscle. The tension decreased during traction to the gluteus maximus muscle. Tension also decreased during traction to the ipsilateral and contralateral posterior layer of the thoracolumbar fascia in a direction simulating contraction of the latissimus dorsi muscle.

Conclusions: The long dorsal sacroiliac ligament has close anatomical relations with the erector spinae muscle, the posterior layer of the thoracolumbar fascia, and a specific part of the sacrotuberous ligament (tuberoiliac ligament). Functionally, it is an important link between legs, spine, and arms. The ligament is tensed when the sacroiliac joints are counternutated and slackened when nutated. The reverse holds for the sacrotuberous ligament. Slackening of the long dorsal sacroiliac ligament can be counterbalanced by both the sacrotuberous ligament and the erector muscle. Pain localized within the boundaries of the long ligament could indicate among other things a spinal condition with sustained counternutation of the sacroiliac joints. In diagnosing patients with non specific low back pain or peripartum pelvic pain, the long dorsal sacroiliac ligament should not be neglected. Even in cases of arthrodesis of the sacroiliac joints, tension in the long ligament can still be altered by different structures.

Key words

low back pain, sacroiliac joint, anatomy, biomechanics, long dorsal sacroiliac ligament, sacrotuberous ligament

Introduction

The understanding of low back pain will be seriously hampered by neglecting the sacroiliac (SI)-joints as essential elements for load transfer between spine and legs. In fact, recent studies show that the SI-joints are a significant source of pain in patients with chronic low back pain[2,3,5,7,8,11,18,20,21]. Generally, pain in the area of the SI-joints is not regarded as part of low back pain. This is due to incomplete knowledge of the specific anatomy of the SI-joints among many clinicians. In an international survey among medical practitioners[31], less than 10% could identify the long dorsal sacroiliac ligament (long ligament), which is easily palpable in the area directly caudal to the posterior superior iliac spine (PSIS). This ligament connects the PSIS (and a small part of the iliac crest) with the lateral crest of the third and fourth segment of the sacrum.[9] In standard anatomical textbooks the location of the long ligament and its relation with the sacrotuberous ligament varies widely. Directly caudal to the PSIS the ligament is covered by the fascia of the gluteus maximus muscle. Here, the ligament is so solid and stout that one can easily think a bony structure is being palpated.

The region directly caudal to the PSIS is of special interest because in a recent study on patients (n = 394) with peripartum pelvic pain, 42% indicated pain in this area.[14] Furthermore, in patients with non specific low back pain (n = 61), 44% of the women experienced pain, mostly bilaterally, when palpated in this area.[16] Of the men, 47% experienced pain in this area, approximately half of them bilaterally. Increased tension of the long ligament could clarify why pain is specifically felt in the area caudal to the PSIS. The question is raised whether the tension of the long ligament can be increased by displacement in the SI-joint and/or by muscle activity. In that case the long ligament might be important for load transfer. To our knowledge no literature exists on the function of this prominent ligament.

Materials and Methods

Anatomy

A dissection study was performed on specimens of five males and one female, aged 70-92 years, embalmed by vascular perfusion with a solution containing 2.2% formaldehyde. After 6 weeks immersion, the specimens were transferred to a solution with phenoxyethanol. During the experiments the specimens were lying prone and fixed to the research table by two belts in the sagittal plane running centrally over the iliac crests.
By careful dissection, the fascia of the gluteus maximus muscle and the posterior layer of the thoracolumbar fascia were exposed. The fascia of the gluteus maximus muscle and its fibers were removed by blunt dissection, leaving the connection between muscle and dorsal sacroiliac ligaments intact. The anatomical relationships of the long ligament were described with special reference to its connections with superficially the gluteus maximus, sacrotuberous ligament, and the posterior layer of the thoracolumbar fascia, and medially the aponeurosis of the erector spinae (ES).

Biomechanics

To study the biomechanical relation between long ligament and connected structures, a custom-made frame was used. Measurements were performed under controlled conditions, including room temperature and air humidity. Forces were simulated with weights from 0-50 Newton (N), with increments of 10 N. Unilateral forces were applied, left and right, to the following structures:

- biceps femoris, impact site 5 cm caudal to the ischial tuberosity
- sacrotuberous ligament, impact site 4 cm cranial to the ischial tuberosity
- fascia and superficial fibers of the gluteus maximus, impact site 2 cm lateral of the long ligament
- posterior layer of the thoracolumbar fascia, impact site 4 cm toward the cranium from the PSIS.

During traction to the thoracolumbar fascia, the effect of traction was measured both on the ipsi- and contralateral long ligaments. In other cases tension was measured only in the ipsilateral long ligament. Ligament tension was recorded by a custom-made 'buckle' transducer (1.2 × 4 cm)[1,19] tailored to the size of the ligament and centred over the long ligament (Figure 1). It cannot be ruled out that at the site of the buckle some fibers occur which are directly derived from the ischial tuberosity. The transducer could be applied with minimal disruption of the anatomical integrity of the ligament. For this goal, a stainless steel 'U' bar was constructed to connect the transducer to the ligament.

Signals from the buckle transducer were amplified by a custom-made bridge amplifier and registered by a four-channel plotter (BBC Goerz Metrawatt SE 620; Gossen Metrawat, Neurenberg, Germany). The transducer was extensively tested and showed a high test-retest reliability.

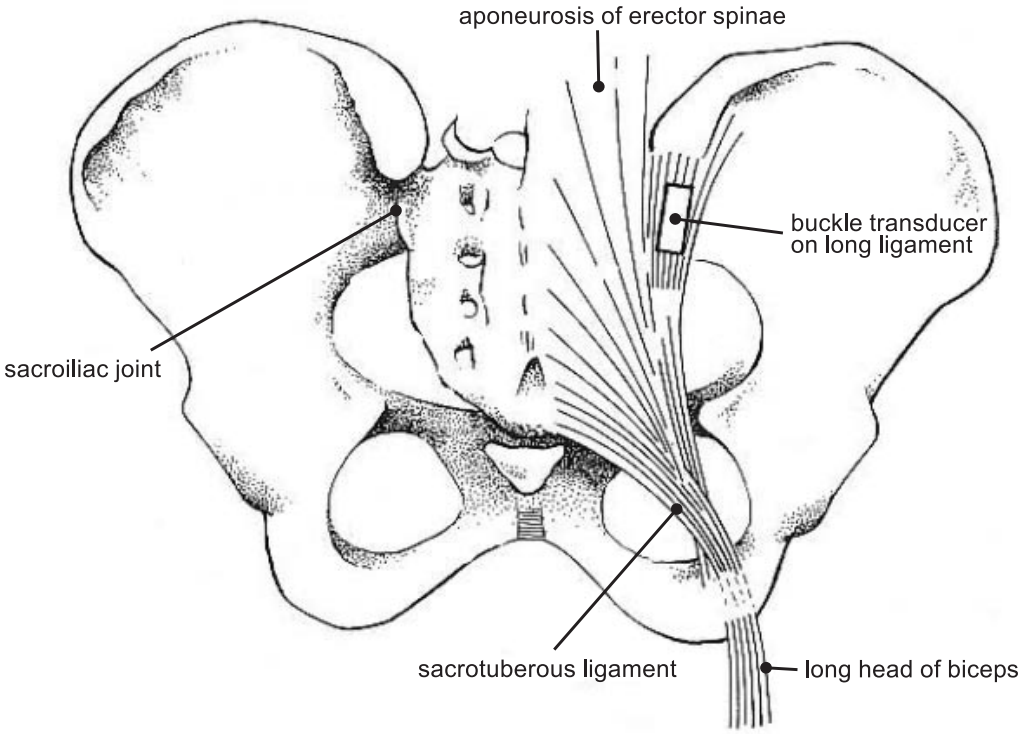

Figure 1. Schematic drawing of the relations between pelvis, sacrotuberous ligament and long ligament

To simulate the action of the latissimus dorsi and the transversus abdominis muscle in tensing the thoracolumbar fascia through the lateral raphe,[33] forces were applied to the posterior layer of the thoracolumbar fascia. For the latissimus dorsi the forces were directed to cranio lateral (60 deg; relative to the spine), for the transversus abdominis muyscle to lateral (90 deg; relative to the spine).

To expose the ES muscle, subsequently a mid sagittal incision of 3 cm was made through the thoracolumbar fascia. Traction was applied to the aponeurosis and muscle fibers of the ES muscle, at an impact site 5 cm toward the cranium from the PSIS.
All measurements were repeated three times. Slight damage of the tensed structures could not be avoided. As a consequence, not all measurements include 12 ligaments (Table 1).

Table 1. Relations Between Loads Applied and Tension of the Long Ligament

Structure	Estimated Slope*	SE	P Value	No. of Ligaments
Sacrotuberal ligament	1.2495	0.0365	< 0.0005	12
Erector spinae	0.3441	0.0323	< 0.0005	12
Gluteus maximus	- 0.1422	0.0353	< 0.0005	8
Biceps femoris	0.0151	0.0395	0.702	6
TLFipsi 60 degrees	- 0.2058	0.0323	< 0.0005	11
TLFipsi 90 degrees	- 0.0509	0.0323	0.115	8
TLFcontra 60 degrees	- 0.0909	0.0323	0.005	9
TLFcontra 90 degrees	0.0188	0.0395	0.634	6
Nutation	- 0.5631	0.0255	< 0.0005	4
Counternutation	0.4323	0.0249	< 0.0005	4

* Estimated slope refers to the separate slope coefficients with the forces applied.
TLF = thoracolumbar fascia (posterior layer).

Nutating and Counternutating Forces

In two male specimens, the effect of SI-joint motion on the tension of the right and left long ligaments was registered. To accomplish motion we used a stainless steel 2 mm cable to which forces were applied of 0-50 N, with increments of 10 N. To induce nutation in the SI-joints (ventral rotation of the sacrum relative to the iliac bones), the cable passed through a hole 2 cm cranial of the apex of the sacrum. It was fixed to the ventral side of the sacrum and was pulled posteriorly, directed 40 deg; upward from the transverse plane. To induce counternutation, the cable was fixed to the sacrum through a hole in the sacral basis, pulling posteriorly 60 deg; downward.

To obtain a force 'in the direction of a muscle' the position of the embalmed specimen was changed with respect to the direction of a tightened rope while observing the distribution of the force over the muscle fibers. The forgoing holds for the thoracolumbar fascia as well. Unequal distribution manifests itself in asymmetry and in unilateral bulging. The position of the specimen was changed until equal distribution was obtained.

Because the fixation of the almost intact pelvis with straps is not rigid, some deformation depending on the applied load may be expected. However, the innominates were not screwed to the frame, since Miller et al[15] demonstrated “that fixation of the hip bones which precludes lateral separation of the iliac from the sacrum results in considerable restriction of the mobility of the SI-joints”.

It is assumed that the variation in the direction of the applied forces, due to the influences mentioned before, has no influence on the results of the study, because the direction of the forces was at the dorsal side of the axis of the sacroiliac joints in all tests.

Statistical Analysis.

To analyse the effect of loading on tension of the long ligament, repeated measures analysis of variance was used. The relation between loading force and tension of the long ligament is assumed to be linear with no intercept. For the within-covariance matrix of the repeated measurements a linear structure was specified. The statistical analysis is performed on the arithmetic average of the buckle output of the right and left long ligaments. The explanatory variables in the analysis are the forces applied and the interaction of force and loaded structure.

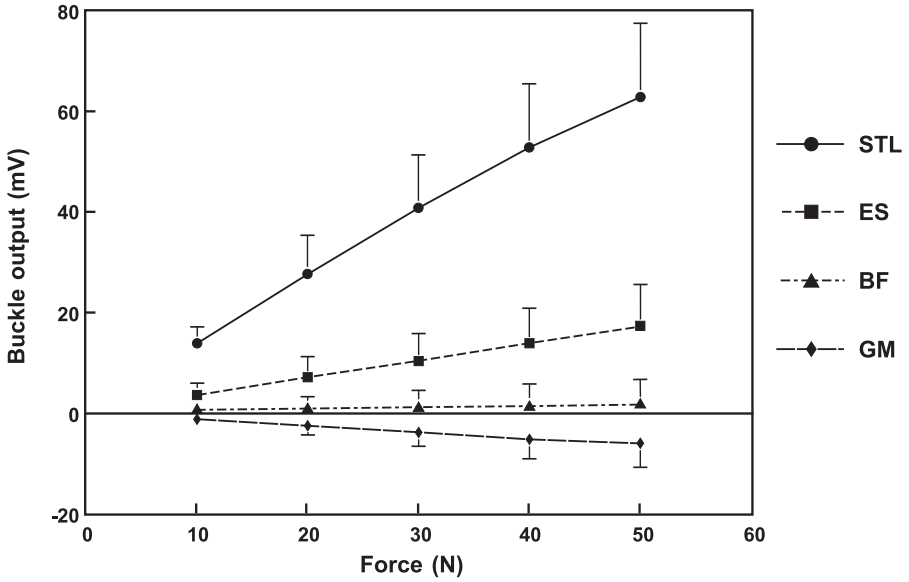

Figure 2. Relation between forces applied (in Newton) and tension of the long ligament (in Mv), STL = sacrotuberous ligament. ES =erector spinae. BF = biceps femoris muscle. GM = gluteus maximus muscle

Results

Anatomy

In all specimens parts of the fascia of the gluteus maximus are continuous with the superficial lamina of the posterior layer of the thoracolumbar fascia. The deep fascia of the gluteus maximus and the muscle itself show multiple connections with the sacrotuberous ligament. It is also connected to the long ligament.

At the cranial side the long ligament is attached to the PSIS and the adjacent part of the ilium, at the caudal side to the lateral crest of the third and fourth sacral segments. In some specimens fibers pass also to the fifth sacral segment. From the sites of attachment on the sacrum fibers pass to the coccyx. They are not considered to be part of the long ligament.

The lateral expansion of the long ligament in the region directly caudal to the PSIS varies between 15-30 mm. The length, measured between to the PSIS and the third and fourth sacral segments, varies between 42-75 mm. The lateral part of the long ligament is continuous with fibers passing between ischial tuberosity and iliac bone. The variation is wide. Medial fibers of the long ligament are connected to the deep lamina of the posterior layer of the thoracolumbar fascia and to the aponeurosis of the ES muscle. After dissection of the ES aponeurosis, the connections between ligament and fibers of the multifidus muscle become visible.

Biomechanics

The effect of traction to the sacrotuberous ligament, the aponeurosis of the ES, the gluteus maximus, and the long head of the biceps femoris on tension of the long ligament is shown in Figure 2. The results can be summarized as follows:

1. Tension in the long ligament increases strongly during incremental loading of the ipsilateral sacrotuberous ligament.
2. The same holds for incremental loading of the ipsilateral part of the ES muscle but the effect is about 25% of the values obtained with loading of the sacrotuberous ligament.

3. Tension of the long ligament decreases with incremental loading of the ipsilateral gluteus maximus.
4. The mean effect of loading the unilateral biceps femoris is negligible.

Figure 2 and Table 1 show furthermore that the statistical assumption of straight lines through the origin is a valid one for each of the loaded structures. The same holds for loading of the thoracolumbar fascia. The slopes of the sacrotuberous ligament, the ES muscle, the gluteus maximus, and the thoracolumbar fascia at 60 deg; both ipsilateral and contra lateral, are significantly different from zero. Tension increases by loading the sacrotuberous ligament and the ES muscle. It decreases by loading the gluteus maximus muscle and the thoracolumbar fascia in the direction of the latissimus dorsi muscle. Furthermore, incremental loading of the sacrum leading to nutation causes a statistically significant decrease of tension, counternutation an increase (Figure 3, Table 1).

The extent of the effect on the long ligament of loading the sacrotuberous ligament and the ES muscle is significantly different ($P < 0.0005$). This also holds for the effect of loading the gluteus maximus and the biceps femoris muscles ($P = 0.003$).

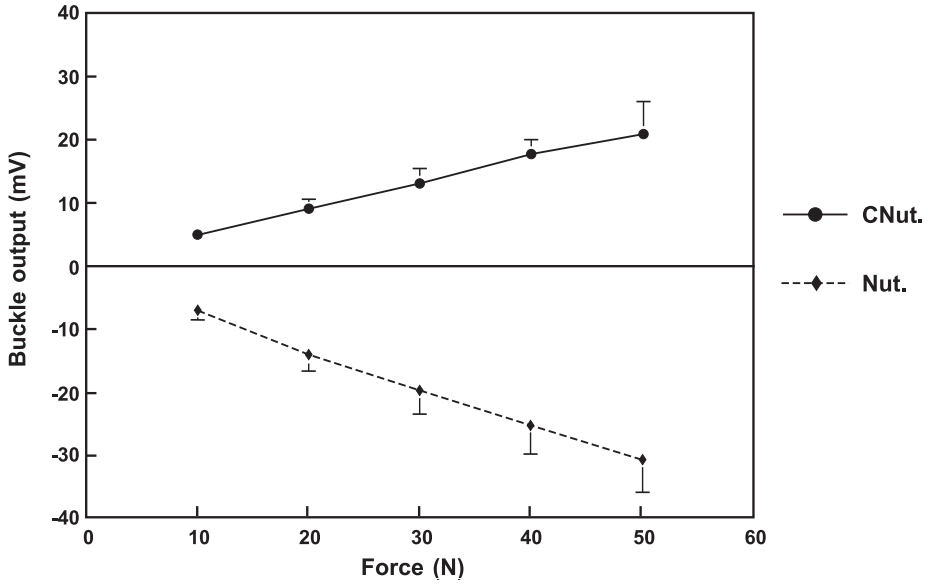

Figure 3. Relation between nutating (Nut.) and counternutating (CNut) forces and tension of the long ligament.

Discussion

In the literature, specific data on the functional and clinical relevance of the long ligament are not available. In several anatomical atlases and textbooks the long ligament and the sacrotuberous ligament are portrayed as fully continuous ligaments. Generally the drawings convey the impression that the ligaments have identical functions. As shown by the contrasting effects of nutation and of counternutation on these ligaments, this is not the case. Essentially the long ligament connects sacrum and PSIS, whereas the main part of the sacrotuberous ligament connects sacrum and ischial tuberosity. However, part of the fibers derived from the ischial tuberosity pass to the iliac bone (Figure 1). These fibers function as site of origin for the gluteus maximus muscle. Generally they are denoted as part of the sacrotuberous ligament, although tuberoiliac ligament would be more appropriate. In the Nomina Anatomica such a ligament does not exist. In fact, this also holds for the long (dorsal sacroiliac) ligament, reflecting one of the problems of topographical anatomy.

The observations presented in this study imply that the tension of the long ligament can be altered by displacement of the SI-joint as well as by action of various muscles. These observations are of special interest since in many patients with low back pain or peripartum pelvic pain, palpation of the area caudal to the PSIS, where the long ligament is located, provokes pain.[14,16]

The present study shows that nutation of the SI-joint induces relaxation of the long ligament whereas counternutation increases tension. This is in contrast to the effect on the sacrotuberous ligament: nutation leads to increase of tension, counternutation to relaxation (Figure 4).[26,27,36] Increased tension in the sacrotuberous ligament during nutation can be due to sacroiliac movement itself[26,27,36] as well as to increased tension of the biceps femoris and/or gluteus maximus muscle. Obviously, this mechanism can help to control nutation. Since counternutation increases tension in the long ligament, this ligament can assist in controlling counternutation (Figure 4A).

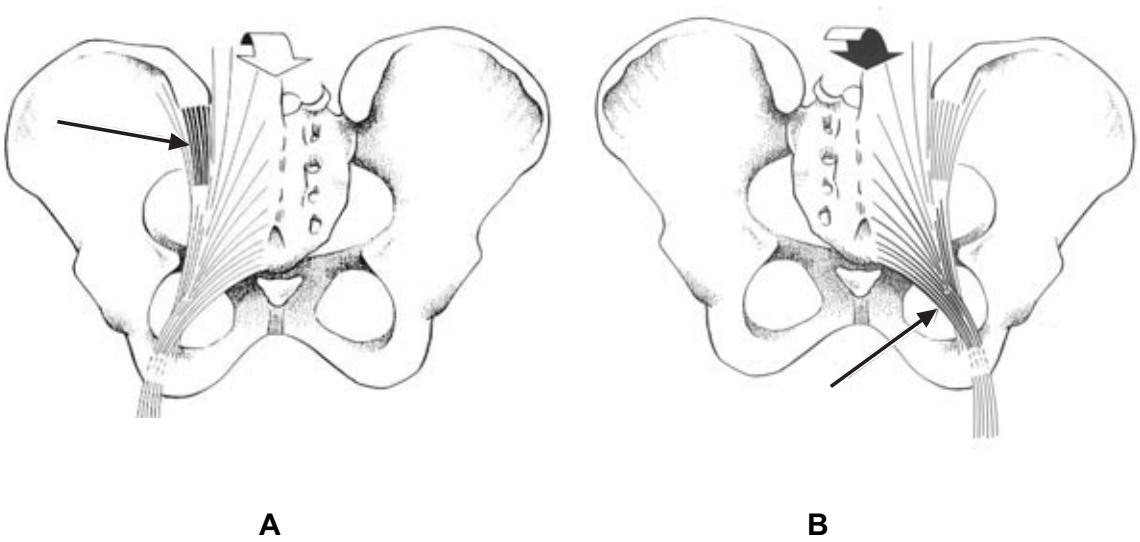

Figure 4. Schematic drawing of the controlling effect of the long ligament in counternutation (A) and of the sacrotuberous ligament in nutation (B).

Apparently ligaments with opposite functions such as the long and sacrotuberous ligaments do not interact in a simple way. After all, loading of the sacrotuberous ligament leads to increased tension of the long ligament. This effect will be due to the connections between long ligament and tuberoiliac ligament and possibly also to a counternutating force generated by the loading of the sacrotuberous ligament. A comparable complex relation may hold for the long ligament and the ES. Since the caudal part of the ES muscle is mainly connected to the sacrum,[12,13] action of the ES muscle will induce nutation. As a result the long ligament will slacken. However, the present study shows increase of tension in the long ligament by traction to the ES muscle. This counterbalancing effect is due to the connections between ES muscle and long ligament and opposes the slackening. In vivo this effect may be smaller because of the moment of force acting on the sacrum is raised by the pull of the ES muscle and the resulting compression force on the spine.[24] This spinal compression was not applied in this study. Both antagonistic mechanisms, between long and sacrotuberous ligaments and between long ligament and ES muscle, may serve to preclude extensive slackening of the long ligament. Such mechanisms could be essential for a flat joint like the SI-joint, which is susceptible to shear forces.[23,24]

It can be safely assumed[30] that impairment of a part of this interconnected ligament system will have serious implications for the joint since load transfer from spine to hips and vice versa are primarily transferred via the SI-joints.[4,23,24]

As shown in the present study, traction to the biceps tendon hardly influences tension of the long ligament. This is in contrast to the effect of the biceps femoris on the sacrotuberous ligament.[26,27,36] The observations may well be related to the spiralling of the sacrotuberous ligament.[36] Most medial fibers of the ligament tend to attach to the cranial part of the sacrum, whereas most fibers arising from a lateral part of the ischial tuberosity tend to the caudal part of the sacrum (see Figure 1). The fibers of the biceps tendon, which approach a relatively lateral part of the ischial tuberosity, mainly pass to the caudal part of the sacrum. As a consequence the effect of traction to the biceps femoris on the tension of the long ligament can only be limited.

Obviously, the effect on the long ligament of loading the posterior layer of the thoracolumbar fascia depends on the direction of the forces applied (Table 1). Traction to the fascia mimicking the action of the transversus abdominis muscle has no effect. Traction in cranio-lateral direction, mimicking the action of the latissimus dorsi muscle, results in a significant decrease in tension of the ipsilateral and contralateral ligament. As shown in another study[33] traction to the latissimus dorsi influences the tension in the posterior layer of the thoracolumbar fascia, ipsilateral as well as contra lateral, especially below the level of L4. Thus slackening of the long ligament could be the result of increased tension in the posterior layer by the latissimus dorsi. This itself may lead to a slight nutation which probably leads to more effective compression and force closure of the SI-joints. As shown in the present study slackening of the long ligament can also occur due to action of the gluteus maximus muscle, which is ideally suited to compress the SI-joint.

In former studies it was reported how in the SI-joints stability is provided. The SI-joint, with its undulated form and symmetrical ridges and depressions, combined with compression and generated friction, is an example of a joint remaining stabile through a combination of form and force closure.[28,29] Movement of the iliac bones relative to the sacrum leading to nutation (see Figure 4B) increases the tension in sacrotuberous (and interosseus) ligaments and thus will compress the joint.[27] It has to be added that the range of movement in the SI-joint differs intra-individually; normally, this range is very small.[6,10,25,32,35]

It is inviting to draw prompt conclusions when palpation of the long ligament directly caudal to the PSIS is painful. This must be avoided for the following reason: Pain in this area may be due to pain referred from the SI-joint itself[7,8] but also to counternutation of the SI-joints. Counternutation is part of a pattern of flattening the lumbar spine,[6,10,25] which occurs especially late in pregnancy when women counterbalance the weight of the foetus.[22] However, such a posture combined with counternutation could also result from a pain-withdrawal-reaction to impairment elsewhere in the system. Hence, even specific pain of the long ligament could be a side effect. An example of such a condition could be the following: Pain of the pubic symphysis following delivery[14,17] could preclude normal lumbar lordosis and hence nutation due to pain of an irritated symphysis. After all, lumbar lordosis leads to nutation in the SI-joints.[6,10,25,32,35] Nutation implies that the left and right PSIS approach each other slightly while the pubic symphysis is caudally extended and cranially compressed.[10,34] In this example, the patient will avoid nutation and flattens the lower spine, leading to sustained tension and pain in the long ligament. It seems justified to conclude that when palpation of the long ligament is painful, one must examine whether extension of the lower spine and nutation in the SI-joints is possible.

In dealing with low back pain or peripartum pelvic pain the long ligament should not be overlooked since localized pain within the boundaries of the long ligament could indicate a spinal condition with sustained counternutation of the SI-joints. However, if pain is not exclusively felt in the long ligament but also in the medial buttock region this could be part of a typical pain referral pattern of the SI-joint itself.[7,8]

Conclusion

Anatomically, the long ligament, which can be easily palpated directly caudal to the PSIS, can be viewed as a pelvic structure. However, the ligament has close relations with among others the erector spinae muscle, the posterior layer of the thoracolumbar fascia and the sacrotuberous ligament. Therefore, functionally it is an important link between legs, spine and arms.

The long ligament is tensed when the SI-joints are counternutated and slackened when nutated. During nutation both erector muscle and sacrotuberous ligament can counterbalance the slackening of the long ligament. The anatomical connections between ligaments and muscles with opposing functions could serve as a mechanism to preclude excessive slackening of ligaments.

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5

The sacroiliac part of the iliolumbar ligament

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Abstract

The iliolumbar ligament (IL) has been described as the most important ligament for stability of the lumbosacral junction. In addition, it may play an important role in stabilizing the sacroiliac (SI) joints. To gain insight into its presumed stabilizing effect on the SI joints, the anatomy of the IL was studied in 17 cadavers. Specific dissection shows the existence of a sacroiliac part of the iliolumbar ligament (SIPIL) clearly distinct from the ventral SI ligaments. The existence has been verified by MRI and by cryosectioning of the pelvis in the frontal and transverse plane. Fiber direction, length, width and thickness of the SIPIL are described. The SIPIL is mainly orientated in the frontal plane, perpendicularly to the SI joint. The existence of this SIPIL is in line with the assumption of the IL having a direct effect on the stability of the SI joints.

Keywords

lumbopelvic region, sacroiliac joint, biomechanics, low back pain

Introduction

In the literature the IL is described as an important ligament in the lumbopelvic region. Immunohistochemically a multitude of mechanoreceptors and nociceptors has been shown in the IL[1,2,3,4], which is extending from the transverse processes of the fourth and fifth lumbar vertebra to the iliac crest. Indeed, a multitude of mechanoreceptors can be expected in case of a function in monitoring movement and stabilization of the lumbosacral region. Sims & Moorman[5] describe the IL as a primary source of chronic low back pain. Furthermore, several biomechanical studies emphasize the importance of the IL in stabilizing the lumbosacral junction[6,7,8,9]. This stabilizing function is in line with a study of Pun et al[10] showing the presence of the IL in rhesus monkeys and its absence in quadrupeds with a more horizontal spine. Besides its importance in stabilizing the lumbosacral junction, Luk et al[11] suggested that in humans the IL could play a role in locking the sacrum between the iliac bones. To analyze the role of the IL in the stabilization of the SI joints first the definition of stabilization must be clarified since stability can be interpreted in multiple ways. We define stability as the ability of a joint to bear loading without uncontrolled displacements. Stability is dependent of the relative positions of the bones: the joint can bear loading in a certain position while the joint can not bear the same loading in an other position. Ligaments will contribute to stability by restriction of the relative positions to those positions in which the joint can bear loading. To study which relative positions of the SI joint can be restricted by the IL first its topographical anatomy and the orientation towards the SI joint has to be clarified.

The IL has been described as consisting of one[12], two[11,13,14,15,16,17], three[18], four[19] or even five separate bands[20]. Most authors describe the origin of the IL at the transverse processes of L5[6,7,8,9,11,12,13,14,15,16,17,18,19,20] and occasionally L4[6,7,8,9,16,17,18,19,20,21]. The IL inserts at the medial part of the iliac crest. In contrast, Hanson and Sonesson[15] found no evidence for a ligament attaching to the L4 transverse processes. In some textbooks attachments of the IL to the anterior layer of the thoracolumbar fascia are described[17,18,19]. According to O'Rahilly[19] and confirmed by Willard[21] some fibers of the IL blend with the intertransverse ligaments between L5-S1 and L4-L5 and blend with the interosseus SI ligaments. The aim of the present study is to assess whether a part of the IL can be defined as a Sacroiliac ligament. If so, its fiber direction, length, thickness and width are of interest.

Materials en methods

In 10 female and 7 male cadavers (age 72-86) skin, fat and muscles were removed by blunt dissection keeping all ligamentous structures intact. All attachments of the IL were analyzed. After detailed description, the transverse processes of L5 were carefully removed keeping fibers belonging to the SIPIL intact. The attachments of these fibers were exposed and documented. By a calibrated scale the length, thickness and width of these fibers were measured. In the transverse plane, an imaginary coordinate system was placed at the base of the sacrum, with the y- axis located in the middle of the promontory of the sacrum, and the x-axis perpendicularly to the y-axis placed at the lateral aspect of the upper surface of the sacrum (Fig.1).

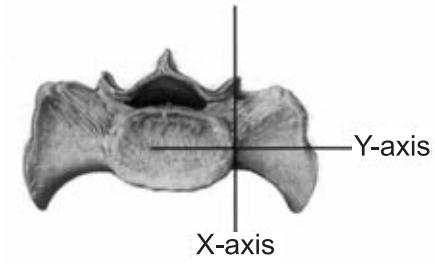

Figure 1.The coordinate system at the base of the sacrum in the transverse plane

Two angles were measured: the angle between the fibers of the SIPIL and the x-axis in the transverse plane, alpha (Fig. 2) and the angle between fibers of the SIPIL and the y-axis in the frontal plane, beta (Fig. 3). Magnetic resonance imaging (MRI) (Philips gyro scan T10-NT) was used to verify the existence of a SIPIL in the frontal and transverse plane. Cryosectioning was performed (2mm) in the same plane as the MRI.

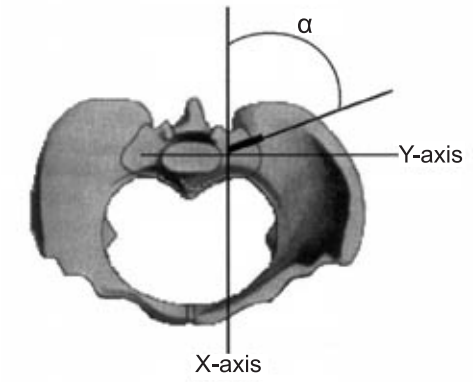

Figure 2. Alpha: angle of the sacroiliac part of the iliolumbar ligament (SIPIL) in the transversal plane

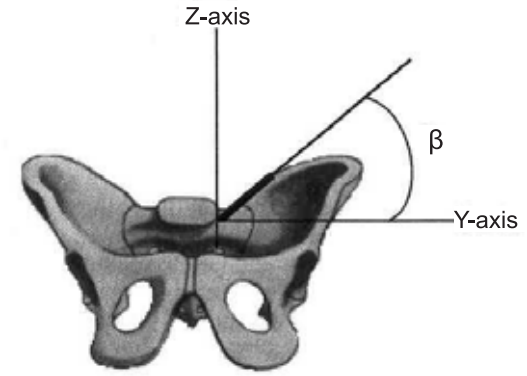

Figure 3. Beta: angle of the sacroiliac part of the iliolumbar ligament (SIPIL) in the frontal plane

Results

In its entirety the IL is a fan shaped structure, consisting of various parts, highly variable in number and form. Although several parts melt together a few parts and fibers can be distinguished. In all specimens (n =34),

1. a dorsal band originates from the tip of the transverse process of L5. It inserts at the upper part of the iliac tuberosity of the sacropelvic surface below the medial part of the origin of the quadratus lumborum muscle (Fig. 4 and Fig.5).
2. a direct attachment of this dorsal band to the deep ventral layer of the thoracolumbar fascia or fascia of the quadratus lumborum muscle (Fig. 4).
3. a ventral band originates from the lower and frontal part of the transverse process of L5; in three specimens also from the caudal aspect of the endplate of the vertebral body of L5. The insertion is at the ventrocranial part of the iliac tuberosity of the sacropelvic surface (Fig. 4 and Fig.5).
4. a lumbosacral ligament originates from the ventrolateral aspect of the vertebral body of L5 and inserts at the most ventrolateral part of the base of the sacrum, near the SI joint. These fibers blend with the ventral SI ligaments (Fig. 4).

5. a SI part occurs. It originates from the cranial surface of the ala of the sacrum directly caudal of the transverse processes of L5 and inserts at the ventromedial part of the iliac tuberosity of the sacropelvic surface, caudal to the anterior band (Fig. 4). See table 1 for details on length, thickness, width and orientation to the x- and y-axis of the SIPIL. MRI (Fig. 6) in the frontal plane as well as cryosectioned slices in the frontal (Fig. 7) and transverse plane (Fig. 8) show the existence of a SIPIL.
6. fibers of the SIPIL merge with the thin and membranous intertransverse ligament of L5-S1 (Fig. 4).
7. fibres of the SIPIL also merge with the interosseus SI ligaments (Fig. 4). The superolateral part of the SIPIL however is divided of the interosseus ligaments by fat tissue, as confirmed by MRI (Fig. 7).

In 10 specimens, the IL has bilaterally an attachment to the ventrocaudal aspect of the transverse process of L4. In these specimens, fibers of the iliolumbar ligament blend with the membranous intertransverse ligaments between L4-L5 (Fig. 4).

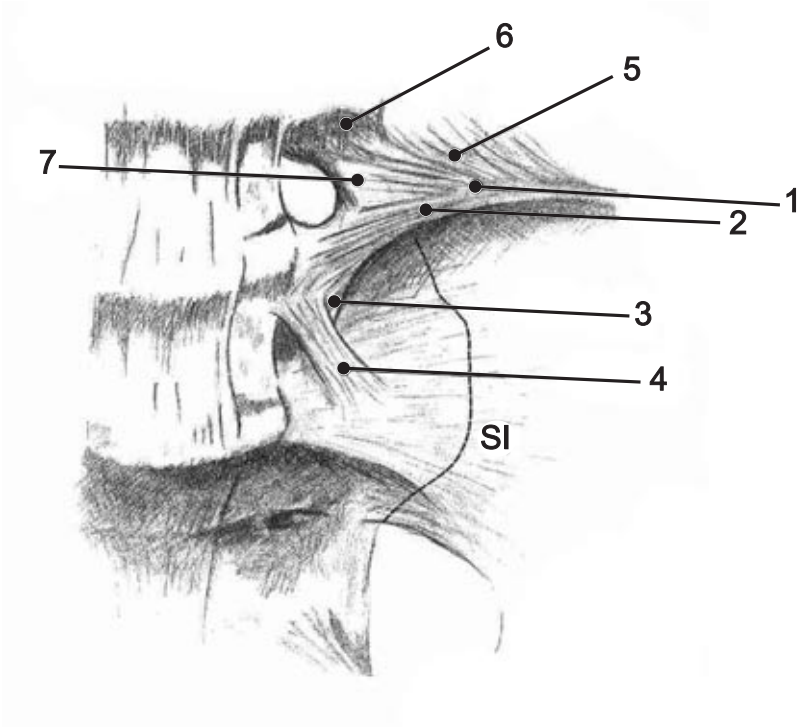

Figure 4.
A ventral view of the ligamentous structures in the lumbopelvic region with the iliolumbar ligament consisting of the following fibers and bands:

1. *dorsal band*
2. *ventral band*
3. *sacroiliac part of the iliolumbar ligament (SIPIL)*
4. *attachment to L4*
5. *fusion with the intertransverse ligaments between L4-L5*
6. *fusion with the intertransverse ligament of L5-S1*
7. *fusion with the deepest layer of the thoracolumbar fascia.*
8. *lumbosacral ligament*

SI, approximate site of the sacroiliac joint (interrupted line)

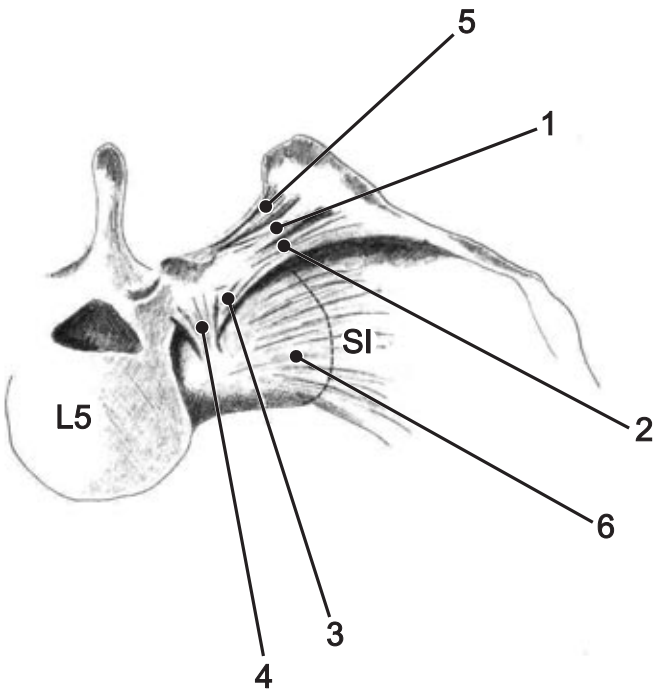

Figure 5.
A cranial view of the ligamentous structures in the lumbopelvic region with the iliolumbar ligament consisting of the following fibers and bands:

1. *dorsal band*
2. *ventral band*
3. *sacroiliac part of the iliolumbar ligament (SIPIL)*
4. *lumbosacral ligament*
5. *dorsal sacroiliac ligaments*
6. *ventral sacroiliac ligaments*

SI, approximate site of the sacroiliac joint (interrupted line); L5, 5th lumbar vertebra

In all specimens the following muscles are attached to the IL:

1. muscle fibers of the *erector spinae* attach sidelong to the dorsal side of the dorsal band of the IL, although these fibers can easily be removed by scraping.
2. the most medial muscle fibers of the *iliacus* are attached to the caudal part of the ventral band of the IL.
3. the most medial muscle fibers of the *quadratus lumborum*, mainly deriving from L4 and L5, attach to the most lateral part of the dorsal band of the IL.

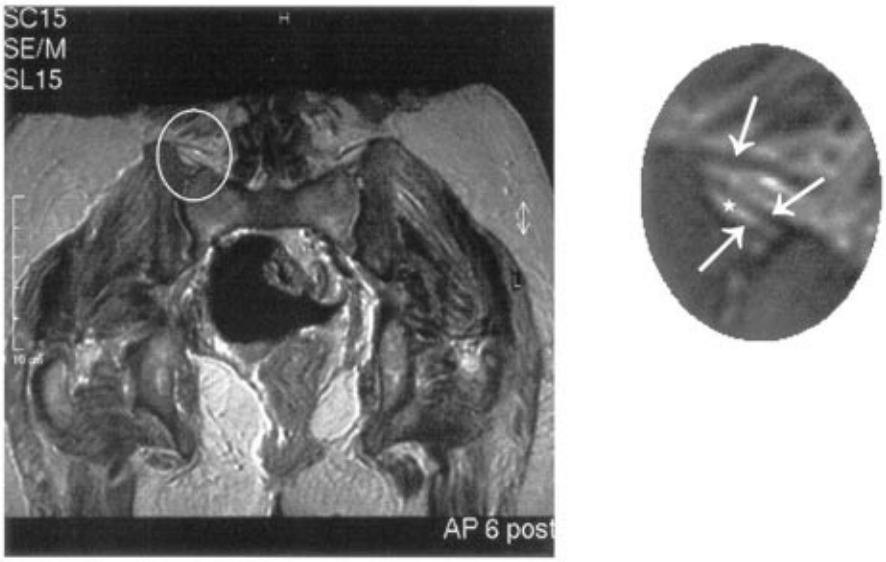

Figure 6.MRI in the frontal plane of the IL and the SIPIL. Note the separation of the superolateral part of the SIPIL (black structure pointed at with white arrow) and the interosseus SI ligaments by fat tissue (asterix).

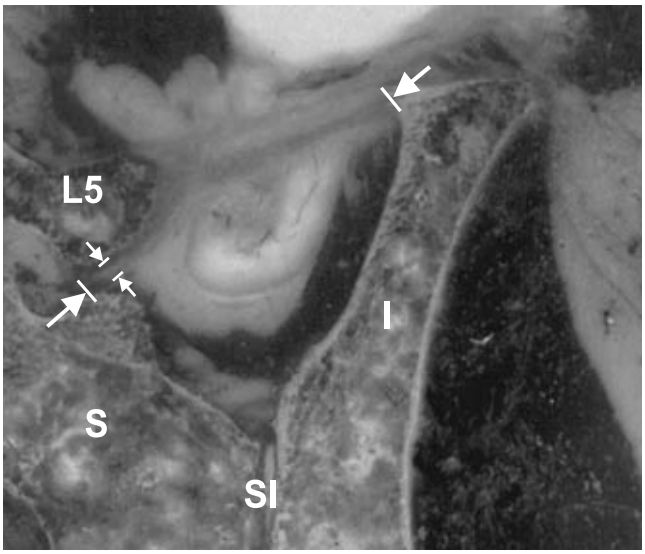

Fig.7. Cryosectioned slice of a part of the pelvis on the left side in the frontal plane. Note the separation of the superolateral part of the SIPIL (white arrow) and the interosseus SI ligaments by fat tissue (asterix).
I: Ilium
S: Sacrum
SI: SI joint
L5: transverse process of the fifth lumbar vertebra
Between the arrows: the SIPIL.

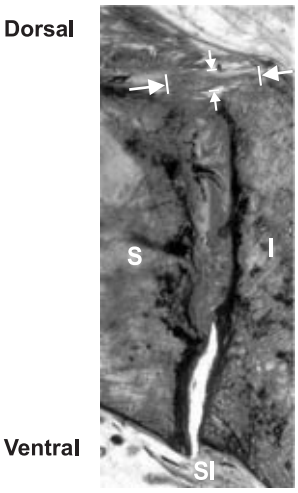

Figure 8. Cryosectioned slice of a part of the pelvis on the left side in the transverse plane, with the SIPIL (white arrow).

Discussion

In all specimens we found a specific part of the IL which originates from the ala of the sacrum and inserts at the iliac crest. This finding is an extension of the work of O'Rahilly[19] and Willard[21]. They describe a part of the IL attaching to the iliac crest blending with the interosseus ligaments of the SI joint. The attachment of a part of the IL to the sacrum implies a role of the IL in stabilization of the SI joint. However, no biomechanical studies are available to prove such an assumption.

The SIPIL is mainly orientated in the frontal plane, perpendicular to the SI joint. So the direct stabilizing effect of the SIPIL can be expected in the frontal plane, resistance to 'adduction' of the ilium with respect to the sacrum. A stabilizing effect of the SIPIL on movement of the sacrum in the sagittal plane (nutation and counternutation) can hardly be expected. Although the SIPIL blends with the intertransverse ligament of L5-S1, a direct influence of the SIPIL on L5-S1 is less likely since the intertransverse ligaments are thin and membranous.

The differences in angle a between male and female as well as differences in length, width and thickness (table 1) can be explained by the sexual divergence of the adult pelvis. The iliac blades are more vertical in female and do not extend so far upwards as in males[18].

Table 1: Dimensions and orientation of the SIPIL in male and female

	Women (n=10)	*Men (n=7)*
Dimensions (mm)		
Length	31.0 (5.6)	30.5 (5.6)
Width	12.7 (4.6)	14.5 (4.1)
Thickness	1.6 (0.5)	1.5 (0.4)
Orientation (degrees)		
Angle alpha	77.9 (4.9)	83.7 (3.6)
Angle beta	50.2 (6.8)	52.1 (7.2)

This study shows the existence of various parts of the IL. Although highly variable in number and form, major parts could be identified in all specimens of this study. The numerous insertions and fiber directions reflect the diversity of the biomechanical functions of the IL. This diversity is not honored by authors describing one[12] or two separate bands of the IL[11,13,14,15,16,17]. Several biomechanical studies have shown the importance of the IL in restricting lateral bending and flexion-extension of the lumbosacral joint and maintaining stability of the lumbosacral junction[6,7,8,9]. However, these studies do not mention the connections of the IL to L4 nor to the base of the sacrum. These connections imply a more diverse role of the IL than previously described. Biomechanical studies are needed to gain more insight in the role of the IL in stabilizing the SI joint and L4-L5.

Conclusions

The existence of a SIPIL as part of the IL, as shown in the present study, implies a direct effect of the IL on the biomechanics of the SI joint.

Acknowledgements

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6

The iliolumbar ligament – its influence on stability of the sacroiliac joint

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Abstract

Study Design: In human specimens the influence of the iliolumbar ligament on sacroiliac joint stability was tested during incremental moments applied to the sacroiliac joints.

Objectives: To assess whether the iliolumbar ligament is able to restrict sacroiliac joint mobility in embalmed cadavers.

Summary of Background Data: Firstly, the sacroiliac joint can play an important role in non specific low back pain; hence, its mobility and stability are of special interest. Secondly, the iliolumbar ligament is considered to be an important source of chronic low back pain. Data on a functional relation between the iliolumbar ligament and sacroiliac joint mobility are lacking.

Methods: In 12 human specimens an incremental moment was applied to the sacroiliac joint to induce rotation in the sagittal plane. After the assessment of the relationship between rotation angle and moment in the intact situation, specific parts of the iliolumbar ligaments were transected. After each partial transection the measurements were repeated.

Results: Sacroiliac joint mobility in the sagittal plane was significantly increased after a total cut of both iliolumbar ligaments. This increase was in particular due to the transection of a specific part of the iliolumbar ligament, the ventral band.

Conclusions: The main conclusions are: a) the iliolumbar ligaments restrict sacroiliac joint sagittal mobility, b) the ventral band of the iliolumbar ligament contributes most to this restriction.

Relevance

In embalmed human cadavers, the mobility of the sacroiliac joint increases after sequential cutting of specific parts of the iliolumbar ligaments. It can be expected that severance of this ligament during surgery will lead to increase of mobility and hence loss of stability of the sacroiliac joint. As a consequence adjacent structures will be affected. This may well be a cause of pain in patients with failed back surgery

Key words

iliolumbar ligament, sacroiliac joints, low back pain, biomechanics, joint restriction, stability, mobility, iliolumbar pain syndrome, failed back surgery

Introduction

In the majority of cases low back pain (LBP) manifests itself in the lower lumbar region, with pain radiating to the iliac crest, into the buttocks or even the leg. Therefore, most studies on the aetiology of LBP focus on the mechanical behaviour of the lumbosacral area and specifically on the intervertebral discs[1,2,3,4]. However, modern imaging techniques have shown that spinal abnormalities such as disk herniation are common in persons without back pain[5]. Furthermore, in the majority of LBP patients, only rarely a specific cause can be identified[6]. For these LBP patients the expression non specific LBP is used[6].

Recently, several anatomical, biomechanical and neuropsychological studies on the lumbopelvic region have supported the view that loss of stability of the sacroiliac joints (SIJ) can be crucial in the aetiology of non specific LBP[7,8,9]. Main conclusions from these studies are: a) in all loading conditions muscle forces are necessary for lumbosacral stability [10,11,12], b) mechanoreceptors in the massive ligamentous system of the lumbosacral area are important for the activation of muscles for posture control [8,13,14,15,16] and c) ligaments that restrict the range of motion of the SIJ play an important role in the stability of the SIJ[7,17,18].

Stability can be interpreted in multiple ways. In this study we define stability as the ability of a joint to bear loading without uncontrolled displacements. Stability depends on the relative positions of the respective bones: in certain positions the joint can bear loading, in others it can´t. Uncontrolled displacements will allow the joint to adopt positions in which the joint can not bear loading. Ligaments contribute to stability by controlling the relative positions of the joint, restricting the mobility of the joint to those positions in which the joint can bear loading. Hence, the ligaments contribute to stability by restriction of mobility.

To assess the contribution of the ligamentous system to stability of the SIJ, all relevant ligaments in the lumbosacral area have to be taken into consideration. Surprisingly, the function of one of the major ligaments in this region, the iliolumbar ligament (IL), is poorly understood. Several authors describe its influence on flexion-extension, lateroflexion in the L5-S1 facet joint and torsional stability of the L5-S1 facet joint [19,20,21,22]. However, no study exists in relation to the mechanics of the SIJ. This is remarkable since the IL actually crosses the SIJ[23].

Knowledge of the function of the IL is of special interest since the assumption has been made that the IL is the primary cause of many cases of LBP [24,25,26,27].
In the present study we analyse whether the IL is able to contribute to SIJ stability by restricting SIJ mobility.

Materials and Methods

In this study we consider an increase of SIJ mobility after sectioning the IL, as evidence that the IL is able to restrict SIJ mobility. To test the SIJ mobility we applied different moments of force to the SIJ and measured the amount of rotation in the sagittal plane. The relation between SIJ rotation and load is shown in Figure 1 (thick S-curve). After sectioning of the IL the same moments of force have been applied to the SIJ. We hypothesize that section of the IL results in a steeper S-curve, indicating that the same moment of force results in more rotation. We consider a steeper curve as an indication for increased mobility of the SIJ (see Figure 1, thin S-curve). To quantify the changes due to sectioning, we use lineair regression to calculate the slope.

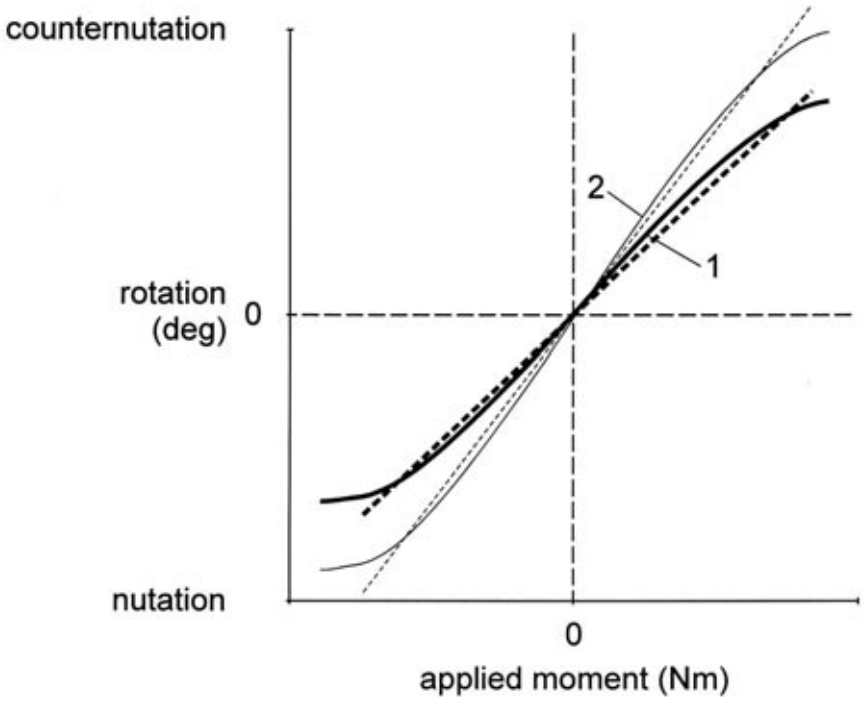

Figure 1. Two S- curves representing the relation between the amount of rotation in the SI joint and the applied load. The solid thick line represents the curve with the IL intact, while the solid thin line represents the curve with the IL cut. The dotted thick line represents the slope before sectioning the IL, the thin dotted line represents the slope after sectioning.

The following set-up was used: In twelve embalmed specimens (seven female and five male; average age 76 years, SD ± 7 years), consisting of the pelvis, L4 and L5, with all ligaments intact, the moment- rotation relationships of the left and right SIJ were studied. The sacrum was secured in a custom made rig by pointed screws driven into the compact bone, from the base to the apex of the sacrum. To distribute the fixation force over the sacrum the space between the fixation plate and the sacrum was filled with a cold-setting polymer (Demotec 50, Niederau, Germany) (Figure 2). A metal plate was screwed to each of the iliac bones (Figure 3, A).

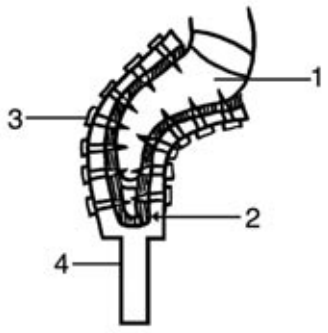

Figure 2. Fixation of the sacrum (sagittal plane).
1. sacrum, 2. cold-setting polymer between sacrum and fixation plate,
3. pointed screws, 4. custom-made rig.

To enable the application of a moment to the iliac bones in the sagittal plane, each plate was connected to a steel axle. Forward movement of the cranial part of the iliac bone with regard to the sacrum results in counternutation (extension) in the SIJ, backwards movement in nutation (flexion). To allow three dimensional translations of the iliac bones, the axle contained two universal joints (Figure 3, B) and a prismatic sliding joint (Figure 3,C). The torque on each axle (left and right) was realised with a string around a pulley (Figure 3,D) fixed at the end of the axle. Tension in the string was applied bilaterally with a traction device (Eltrac, type 1471.905, Delft, Netherlands). In order to calculate the moment applied to the iliac bones, the tensile force in the string was measured with a force transducer (Load cell type TKA 100 A, Sokki Kenkyujo, Tokyo, Japan).

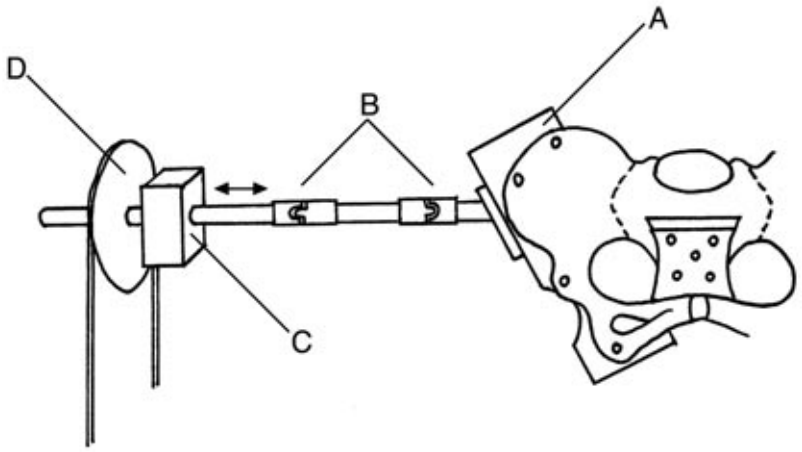

Figure 3. Fixation of the iliac bone to the pulley.
A. plate fixed to the iliac bone, B. axle with two universal joints, C. prismatic sliding joint, D. pulley.

Eight light reflecting markers were placed: two on the left iliac crest, two on the right iliac crest and two on each side of the sacrum. To avoid interference of sacrum deformation, the needles carrying the markers were inserted close to the SIJ. Displacements of the markers in the sagittal plane were recorded with one CCD video camera (HCS Vision Technology MX5) and digitised with a VCS2 Image processing board (Vision Dynamics ltd., Hampstead England). With custom made software we calculated the amount of counternutation and nutation.

During each test an incremental moment was applied to both iliac bones. Every load was applied slowly in 10 seconds and increased in steps of 3 Nm. After each load step the angular movements were registered after 5 seconds. The relation between the applied moment and the measured counternutation and nutation was displayed in a load deformation curve (Figure 4). Firstly the moment was applied up to maximal counternutation (trajectory a in Figure 4). Next, the load was released, so that the iliac bones returned to their neutral position and then increased to maximal nutation (trajectory b in Figure 4), directly followed by the same procedure (release to neutral position and increase of load) to maximal counternutation (trajectory c in Figure 4). Maximal counternutation and nutation were reached when (visually) negligible additional counternutation or nutation occurred during three incremental load steps.

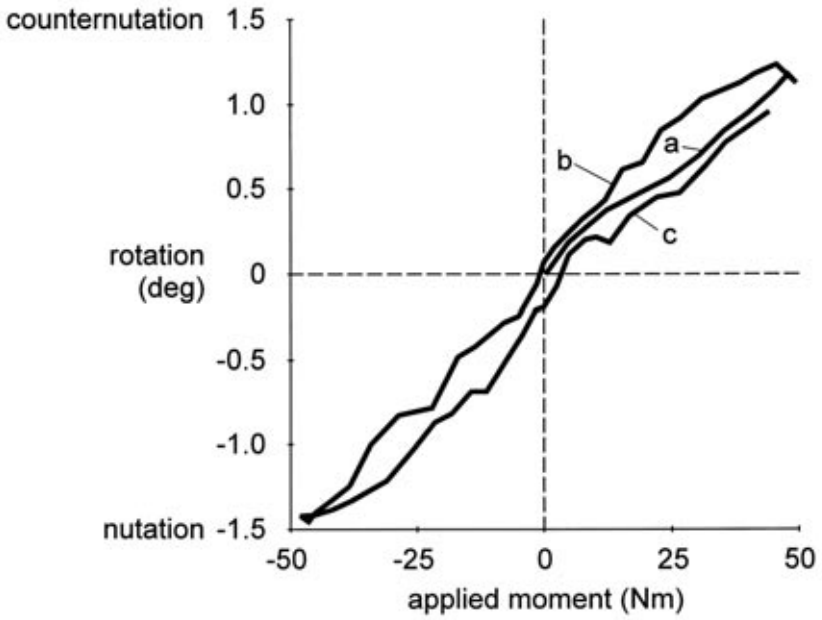

Figure 4. An example of a load deformation curve. The loading protocol was as follows: trajectory a: start at zero, incremental loading to maximal counternutation, trajectory b: unloading to zero and loading to maximal nutation, trajectory c: unloading to zero and loading to maximal counternutation.

To answer the question whether the IL can restrict mobility of the SIJ we focused on three separate parts of the IL (Figure 5): the dorsal band, the ventral band and the sacroiliac part of the IL. On each specimen four subsequent tests were performed leading to four load deformation curves:

1. with the IL intact on both left and right sides,
2. with transections randomly assigned, at both sides, to either the dorsal band or the ventral band or the sacroiliac part of the IL (A, B or C, respectively, in Figure 5),
3. with further transection, at random, of one of the two remaining parts of the IL, either the sacroiliac part of the IL or the dorsal or the ventral band at both sides,
4. with both ILs totally cut.

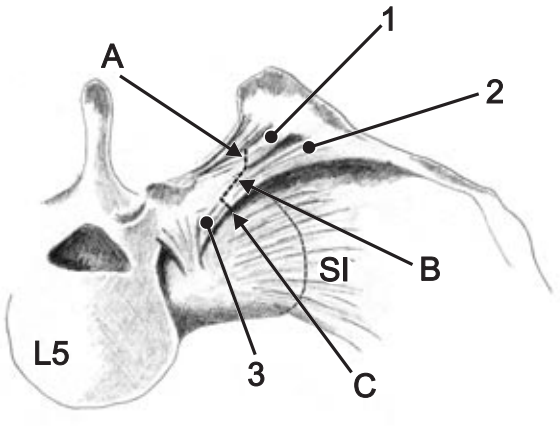

Figure 5. The iliolumbar ligament in the transversal plane with 1: the dorsal band, 2: the ventral band, 3: the sacroiliac part (SIPIL) and SI:approximate site of the sacroiliac joint (dashed). The site of transection assigned to

A: the dorsal band, cutting fibres connecting the tip of the transverse process of L5 with the cranial part of the iliac tuberosity of the sacropelvic surface at the medial part of the iliac crest, keeping fibres of the ventral band and SIPIL intact.

B: the ventral band, cutting fibres connecting the ventrocaudal aspect of the transverse process of L5 with the the ventrocranial aspect of the iliac tuberosity of the sacropelvic surface of the iliac crest, keeping fibres of the SIPIL and dorsal band intact.

C: the sacroiliac part, cutting fibres connecting the cranial surface of the ala of the sacrum with the sacral surface of the iliac tuberosity, next to the disc L5-S1, keeping fibres of the ventral and dorsal band intact.

To compare the data of all four load deformation curves of each specimen, we used a common load range for data analysis (Figure 6). The first loading trajectory of the loading curve from neutral position to maximal counternutation is not used for data analysis. Furthermore, to avoid disturbance of data analysis due to the hysteresis loop, both ends of the load range are not used for data analysis (thin lines in Figure 6). Data analysis is performed on the remaining two trajectories of each load deformation curve: 1. the trajectory between maximal counternutation and maximal nutation and 2. the trajectory between maximal nutation and maximal counternutation (see bold trajectories in Figure 6). For both trajectories one mean slope was calculated by linear regression. Each slope was divided by the slope obtained in the first test (intact situation) to obtain normalized values. An increase of these normalised values was considered to reflect increase of SIJ mobility.

To assess whether SIJ mobility increased after sectioning of both ILs, we compared the first test (intact situation) with the fourth test (both ILs totally cut). We used the paired samples t-test to analyse these data for significance. We also used the paired samples t-test to assess the influence of the individual parts of the IL separately. A mixed model ANOVA (proc mixed of SAS, version 6.12) was used to test whether the changes in slope by intervention and by order of sectioning (period) were significant. Three within explanatory factors were present: side (left, right), intervention (first transection, second transection and both ILs totally cut) and period (order of sectioning). The baseline measurement of the outcome residuals (intact specimen) is used as between-specimen explanatory variable. The dependent variable was slope. The covariance matrix of the residuals is assumed to be of compound symmetry type. Since two specimens were lost (broken fixation plate, ventral capsular tear),10 specimens (20 ILs) were available for data analysis.

In order to test the changes over time without transection four subsequent tests were performed, in three specimens, without transection of the ILs. A mixed model ANOVA was used to test whether the changes in slope were significant.

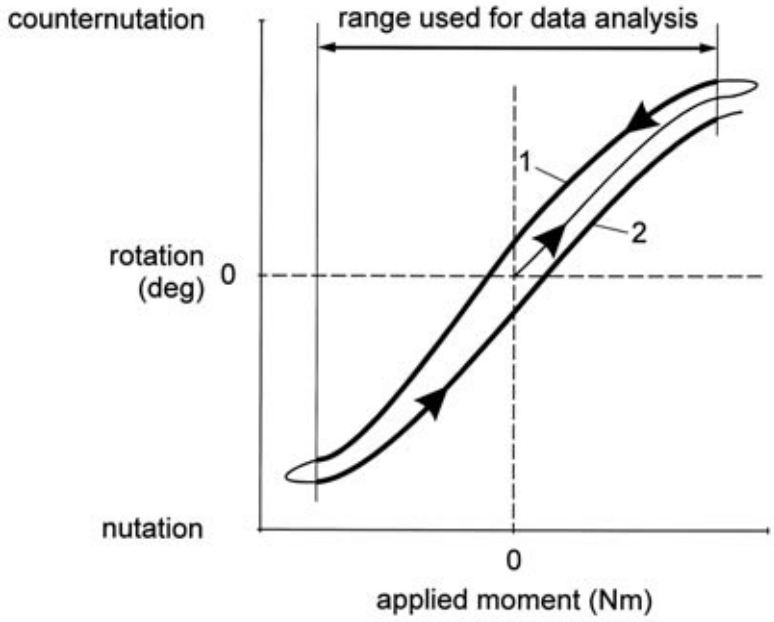

Figure 6. A schematic load deformation curve with the load range used for data analysis . The thin lines are trajectories not used for data analysis. The two trajectories 1 and 2 (thick lines) are used for the calculation of a single slope.

Results

Comparing the data of the intact specimens with those after a total cut of both ILs, the paired t-test showed a significantly steeper slope (p=0.021) of the load deformation curves after the total cut (Table 1). The mean increase of the normalised values in specimens with the IL totally cut was 28.1%. Also after transection of exclusively the ventral bands of the ILs, the paired samples t-test showed a significantly steeper slope (p=0.002) (Table 1). Transection of both dorsal bands as well as transection of both sacroiliac parts of the ILs showed no significant increase of mobility in the SIJ (Table 1). The calculated slopes by lineair regression showed a mean rsq of .92 The minimal rsq was .87 and the maximal rsq was .97. The mixed model ANOVA showed a significant change in intervention (first transection,

second transection and both ILs totally cut, *p*= 0.006) but no significant change in side (left, right, p=0.95) nor in period interaction (order of cutting, *p*= 0.50). Four subsequent tests without transection of the IL in three intact specimens showed a mean increase of the normalised values of 6.1%. These changes were not significant in time (*p*= 0.39).

Table 1:
The means of the slopes of the load deformation curves before and after transection of both ventral bands, both dorsal bands, both sacroiliac parts and the total cut of both ILs.
M1: mean before transection, M2: mean after transection, C1: confidence interval, S: significance

Site of incision (n=20)	M1	M2	Ci Lower	Upper	S
Ventral band	0,099	0,107	- 0,012	- 0,003	,002*
Dorsal band	0,124	0,100	- 0,018	0,066	,253
Sacroiliac part	0,054	0,052	- 0,019	0,021	,899
Total cut	0,046	0,059	- 0,024	- 0,022	,021*

* $P < 0.05$

Discussion

A significant increase of SIJ mobility in the sagittal plane occurs after a total cut of both ILs, as shown by the significantly steeper slope of the load deformation curves. This increase in SIJ mobility was not due to changes over time since four subsequent tests in intact specimens without transection did not show significant changes. Obviously, the IL restricts SIJ mobility in the sagittal plane (nutation and counternutation). This finding does expand the biomechanical functions of the IL reported in earlier studies[19,20,21,22]. These studies were restricted to the influence of the IL on the junction between L5 and sacrum.

Because of the restriction of SIJ mobility by the IL, as shown in this study, this ligament must be important for the stability if this joint. It can be assumed that due to the restriction the SIJ can not adopt postures in which the joint can not bear loading.

Sectioning of exclusively the ventral bands of the ILs also significantly enlarged sagittal mobility in the SIJ (Table 1). As the mixed model ANOVA shows, this increase in SIJ mobility does not depend on the order of incision. The ventral band of the IL is located between the ventro-caudal aspect of the transverse process of L5 and the ventrocranial aspect of the iliac tuberosity of the sacropelvic surface of the iliac crest[23] (Figure 5). Rucco et al.[28] describe the ventral band as expanding like a fan inserting at the iliac crest, with the most ventral fibres orientated dorsomedially-ventrolaterally. (Figure 5)

Regarding the localisation of the ventral band it seems strange that this part of the IL is able to restrict SIJ mobility in the sagittal plane. A possible explanation for this phenomenon can be found in the orientation of the auricular surfaces of the SIJ with respect to the fibre direction of the ventral band of the IL. The shape of the sacrum is a wedge: the ventral aspect of the sacrum is larger than the dorsal aspect[10,11]. Therefore the auricular surfaces of the SIJ are orientated dorsomedially-ventrolaterally. During sagittal rotation in the SIJ we expect most restriction from the ligaments parallel to this orientation of the auricular surfaces. Especially the most ventral fibres of the ventral band are arranged more parallelly to the auricular surfaces of the SIJ than the other components of the IL. So indeed, loading of the ventral band is likely to be induced by sacroiliac rotation in the sagittal plane.

No significant increase of SIJ mobility occurred after transection of the dorsal bands. The dorsal band of the IL is located between the tip of the transverse process of L5 and the cranial part of the iliac tuberosity of the sacropelvic surface at the medial part of the iliac crest[23]. In the transversal plane it forms an angle of approximately 45° to 55° that opens dorso-laterally to the horizontal line formed by the ventral band[28]. For this reason the dorsal band is almost perpendicular to the auricular surfaces of the SIJ and not able to restrict SIJ mobility in the sagittal plane. Restriction of SIJ mobility by the dorsal band can be expected for an outwards/ backwards movement of the cranial part of the iliac bones.

In view of its connection between the ala of the sacrum and the sacral surface of the iliac tuberosity, transection of the sacroiliac part of the IL might increase SIJ mobility. However, since the orientation of the sacroiliac part of the IL is almost in the frontal plane[23], restriction of SIJ mobility can primarily be expected in the frontal plane (outwards movement of the cranial part of the iliac bones). The lack of influence of the sacroiliac part of the IL on sagittal SIJ mobility is in line with the fibre orientation.

In the preparation of the human specimens all tissue cranial to L5 as well as all muscles and fascia´s have been removed. This implies a loss of compression from surrounding tissues and weight of the trunk. As a consequence, a decrease can be expected in the restriction of movement of L5 by surrounding tissues. We assume that if L5 is stabilized by surrounding tissues and by the weight of the trunk it can not give way (or will give way less) when tension in the IL increases. Therefore the effect of the IL on the restriction of SIJ mobility will probably be larger when L5 is stabilized by surrounding tissues and the weight of the upper body. Furthermore, the influence of the IL on SIJ mobility will depend on the position of L5. For instance, due to lateroflexion and rotation of L5 with respect to S1 the tension in the ventral band increases [19,20,21,22]. This possibly leads to further restriction of the mobility in the SIJ at the ipsilateral side during lateroflexion and at both sides during rotation. Further biomechanical studies on the SIJ, with a fixed L5-S1 in several positions, are necessary to assess the influence of the IL when L5-S1 is stabilised.

The experimental approach used in the present study is not possible in vivo. As a consequence of the embalming the load characteristics have been changed since collagen structures become more stiff due to embalming. However, the effect of transection of the IL on restricting mobility of the SI joint will not be changed by the embalment, although we can not pass a judgement on the quantity of this restriction.

The findings of this study are clinically relevant for surgeons operating in the lumbopelvic area. If the IL is severed during surgery, increase of SIJ mobility will occur, probably leading to decreased SIJ stability. This would lead to increased stress in those parts of the IL that remained intact and/or in other ligamentous structures, resulting into pain in tenoperiostal attachments and ligaments. It can be assumed that this is one cause of pain in patients with failed back surgery. So, the outcome of this study implies that the IL must not be severed during surgery.

Naeim et al [25] describe a chronic iliolumbar syndrome as the most common form of LBP due to soft tissue injuries to the IL. According to Broudeur et al [26] and Broadhurst [27] LBP can arise from pain in the IL caused by a periostitis due to stress in the ligament. Since the IL restricts L5-S1 mobility [19,20,21,22] the ligament can be stressed by movements of L5. The present study shows that the IL restricts sagittal mobility of the SIJ as well. Hence, in addition to stress induced by L5 movement, the IL can also be stressed by SI joint movement in the sagittal plane. This indicates that a combination of movement of L5 and the SI joint leads to extra stress and pain. This can be of special interests for clinicians treating LBP patients.

Conclusion

Based on this study we conclude the following:

1. the ILs restrict sagittal SIJ mobility,
2. especially the ventral band of the IL contributes to this restriction,
3. no important role restricting sagittal SI joint mobility could be attributed to the sacroiliac part and the dorsal band of the IL.

Acknowledgments

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7 Contribution of pelvic floor muscles to pelvic ring stability

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Abstract

Study design: A biomechanical study in embalmed specimens, on the relation between applied tension in the pelvic floor muscles, stiffness of the pelvic ring and generation of movement in the sacroiliac joints.

Objective: To gain insight into the effect of tension in the pelvic floor muscles on stability of the pelvis.

Summary of background data: According to a model on selfbracing pelvic floor muscles have the capability to provide stability to the sacroiliac joints. Such stability is a necessity for a proper load transfer through the lumbopelvic region. Hampered load transfer through the lumbopelvic region may be related to low back and pelvic pain. Indeed, altered motor control of the pelvic floor has been described in patients with pelvic pain.

Methods: In 18 embalmed specimens an incremental moment was applied to the sacroiliac joints to induce rotation of the innominate bones in the sagittal plane. After assessment of the relationship between rotation angle and moment, either two or six springs were applied to the pelvis. Two springs simulated tension in (at random) the left and right coccygeus, iliococcygeus or pubococcygeus muscles separately. The six springs simulated tension in all these pelvic floor muscles together. During the simulated tension the measurements were repeated.

Results: In females, simulated tension in the three pelvic floor muscles together stiffened the sacroiliac joints with 8.5% (p = 0.045), whereas a decrease of stiffness (16.1%) occurred when tension was simulated in the iliococcygeus muscles separately (p = 0.004). In males no significant changes occurred. In both sexes a backward rotation of the sacrum occurred due to simulated tension in the coccygeus (p=0.0), pubococcygeus (p=0.0) and in all three muscles together (p=0.0). The sacroiliac joints of female specimens were more mobile in comparison to male specimens (p= 0.014).

Conclusions: In females, pelvic floor muscles have the capability to increase stiffness of the pelvic ring and hence stabilise the pelvic ring. In addition, these muscles can generate a backward rotation of the sacrum in both sexes. Either way, pelvic floor muscles can play a role in human locomotion and posture.

Relevance

Stabilisation of the pelvis due to increased tension in the pelvic floor muscles is important in case of impairment of pelvic stability, especially in pelvic pain patients. Increased activity of these pelvic floor muscles might compensate for loss of pelvic stability by stiffening the pelvic ring and restoring proper load transfer through the lumbopelvic region.

Keywords

pelvic floor muscles, sacroiliac joint, biomechanics, mobility, force closure, urine incontinence, overactivity, pelvic pain, low back pain

Introduction

Pelvic floor muscles, in particular specific parts of the levator ani muscles, have the capability to constrict the lower end of the rectum and the urethra and in addition to form a muscular diaphragm supporting the pelvic viscera[1,2,3]. Furthermore, together with the coccygeus muscles, the levator ani muscles form a muscular diaphragm opposing the downwards thrust due to increased intra-abdominal pressure (IAP) [2]. A recent study[4] shows that increase of pelvic floor activity even precedes increase of IAP, indicating that pelvic floor muscle activity is not a simple response to elevated IAP. Actually, the pelvic floor muscles are capable of generating and controlling IAP[5,6]. This concept also holds for other muscles surrounding the abdominal cavity, like the transversus abdominis, the internal oblique muscles and the diaphragm[5,6]. Activity of these muscles can lead to increased IAP[5,6], whereas increased IAP is related to increased spinal stiffness[7,8,9] and lumbar spine stability[10]. In this way pelvic floor muscles indirectly contributes to lumbar spine stability.

Stability can be interpreted in many ways. For the definition of stability we refer to the definition of clinical stability of the spine by the American Academy of Orthopaedic Surgeons[11]: "Stability is the ability of the spine under physiologic loads to limit patterns of displacement so as not to damage or irritate the spinal cord or nerve root and in addition to prevent incapacitating deformity or pain due to structural changes". This definition also relates to pelvic stability. Muscles contribute to stability by controlling the relative positions of the joint, limiting patterns of displacement and providing safe load transfer. This contribution can be generated by a coordinated cocontraction of muscles surrounding the joint.

Being part of the muscular system surrounding the sacroiliac (SI) joints, certain pelvic floor muscles can contribute to SI joint stability. Snijders et al.[12,13] introduce the pelvic floor muscles in a model on adding stability to the pelvic ring by force closure. Force closure refers to increase of SI joint stiffness and hence stability due to compressive forces on the joint surfaces. Force closure depends on the contribution of muscles in two ways: a) muscles can generate a direct compressive force on the SI joint increasing stiffness and b) muscles can change the position of the joint leading to increased tension in the ligamentous structures[12,13]. Force closure depends, in addition, on the size and texture of the contact area of the SI joint surfaces. A larger contact area of the surfaces implies greater resistance against movement. The resistance against movement is enlarged by the presence of ridges and grooves[14] and a rough coarse texture[15]. The overall sum of compressive forces (by ligamentous structures, muscles and gravity) and the size of the contact area of the joint surfaces determine the force closure of the SI joint.

Low back and pelvic pain disorders can be related to hampered load transfer through the lumbopelvic region due to impairment of force closure and insufficient pelvic stability.[12,16,17]. In these patients enhancement of force closure of the SI joints can be relevant for increased pelvic stability. Theoretically, several muscles have the capability to increase force closure, e.g. the oblique and transversus abdominis muscles, the piriformis muscles and coccygeus muscles[12,13]. In vivo, however, increased force closure of the SI joint has exclusively been demonstrated during contraction of the transverse abdominal muscles[18].

In the present study we focus on the role of the pelvic floor on pelvic stability. For several reasons these muscles are of interest: a) since the pelvic floor muscles, and especially the coccygeus muscle, cross the SI joints these muscles might produce compressive forces to the pelvis[12,13], b) altered motor control patterns of the pelvic floor muscles have been reported in subjects with a clinical diagnosis of SI joint pain[19,20] and c) voiding dysfunctions have been demonstrated in a group of patients with SI joint pain[19,20,21]. In addition, we focussed on the capability of pelvic floor muscles to generate movement in the SI joint. Regarding the topography of the pelvic floor muscles we expect these muscles to counternutate the sacrum (backward rotation of the sacrum moving the caudal part of the sacrum forward).

Methods

To test SI joint stiffness different moments of force were applied to the SI joint and the amount of rotation was measured in the sagittal plane. Increase of SI joint stiffness due to simulated tension in the pelvic floor muscles was considered to be evidence of the stabilising role of these muscles. The relation between SI joint rotation and load showed an S-curve (See Figure 1, thin S-curve). An increase of stiffness of the SI joint was expected to result in a less steep S-curve (See Figure 1, thick S-curve). The slopes of the linear regression lines of these S-curves were considered as a measure for the stiffness of the SI joints (dotted lines in Figure 1). Pelvic floor muscles are considered to contribute to the stabilisation of the SI-joints if simulation of force in these muscles led to a significant decrease of the slope of this regression line.

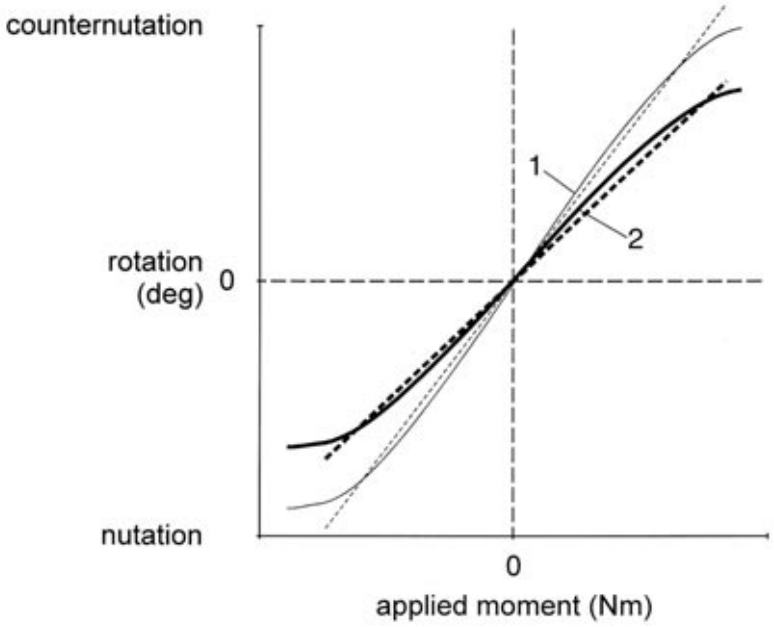

Figure 1. The solid thin S-curve(1) represents the expected relation between the amount of rotation in the SI joint and the applied moment, without springs applied to the pelvis. The solid thick S-curve(2) represents the expected change in S-curve with springs applied. The dotted thin line represents the slope without springs, the dotted thick line the slope after applying springs.

To test whether pelvic floor muscles were able to generate movement in the SI joint, the position of the innominates with respect to the fixed sacrum was measured before and after fixing the springs that simulate muscle forces. Forward rotation of the cranial part of the iliac bones, with respect to the sacrum, in the sagittal plane was considered to be evidence for the pelvic floor muscles to generate counternutation of the sacrum.

The following set-up was used: In 18 embalmed specimens (9 female and 9 male; average age 77 years, SD ± 14 years), consisting of pelvis, L4 and L5, with all ligaments intact, the moment-rotation relationships in the SI joints were studied. The sacrum was secured in a custom made rig[22]. A metal plate was screwed to each of the innominates (Figure 2, A). To enable the application of a moment to the iliac bones in the sagittal plane, each plate was connected to a steel axle. To allow three-dimensional translations of the iliac bones, the axle contained two universal joints (Figure 2, B) and a prismatic sliding joint (Figure 2,C). The torque on each axle (left and right) was realised with a string around a pulley (Figure 2,D), fixed at the end of the axle. Tension in the string was applied bilaterally with a custom made traction device, equipped with a control system. The moment applied to the iliac bone was measured with two torque transducers, one at each pulley (Figure 2,E).

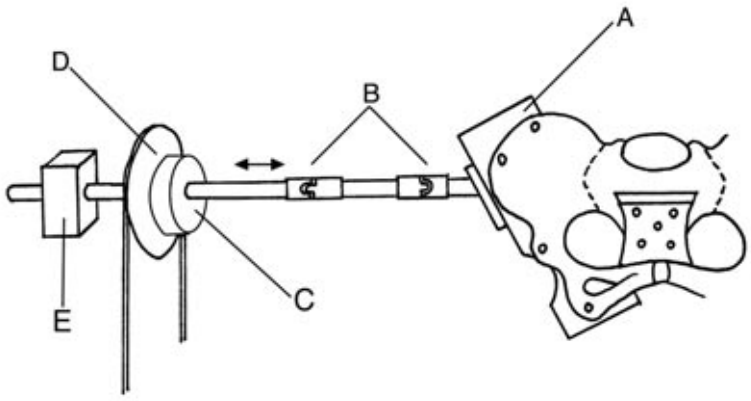

Figure 2. Fixation of the iliac bone to the pulley.
A: plate fixed to the iliac bone, B: axle with two universal joints, C: torque transducer, D: pulley, E: prismatic sliding joint.

In order to measure the position of the bones, twelve light reflecting markers were fixed on three screws, four on each screw. These screws were placed on the left iliac crest, the right iliac crest and the base of the sacrum. The markers were illuminated by an infrared light source mounted on two CCD video cameras (HCS Vision Technology MX5, Vision Dynamics ltd., Hampstead, England). The video images of these markers were digitised by a computer that was equiped with a frame grabber (VCS-II, Vision Dynamics ltd., Hampstead, England). The image coordinates from the cameras were combined to three-dimensional spatial coordinates using Direct Linear Transformation[23]. With custom made software we calculated the amount of rotation in the sagittal, frontal and transversal plane.

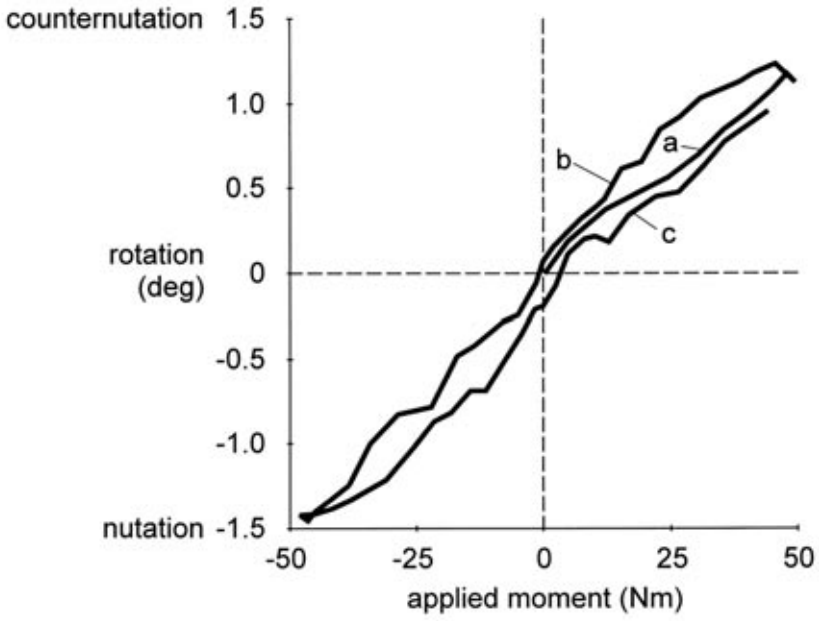

Figure 3. Example of a load deformation curve. The loading protocol was as follows. Trajectory a: start at zero, incremental loading to maximal counternutation; trajectory b: unloading to zero and loading to maximal nutation; trajectory c: unloading to zero and loading to maximal counternutation.

During each test an incremental moment was applied to the SI joints. Each load increment of three NM was applied slowly in five seconds. The angular movements due to each load step were registered after five seconds. The relation between the applied moment and the measured counternutation and nutation was displayed in a load deformation curve (Figure 3). Firstly, the moment was applied up to maximal counternutation (trajectory a in Figure 3). Next, the load was released, so that the iliac bones returned to their neutral position and then increased to maximal nutation (trajectory b in Figure 3), directly followed by the same procedure (release to neutral position and increase of load) to maximal counternutation (trajectory c in Figure 3). Maximal counternutation and nutation were reached when visually no or negligible additional counternutation or nutation occurred during three incremental load steps.

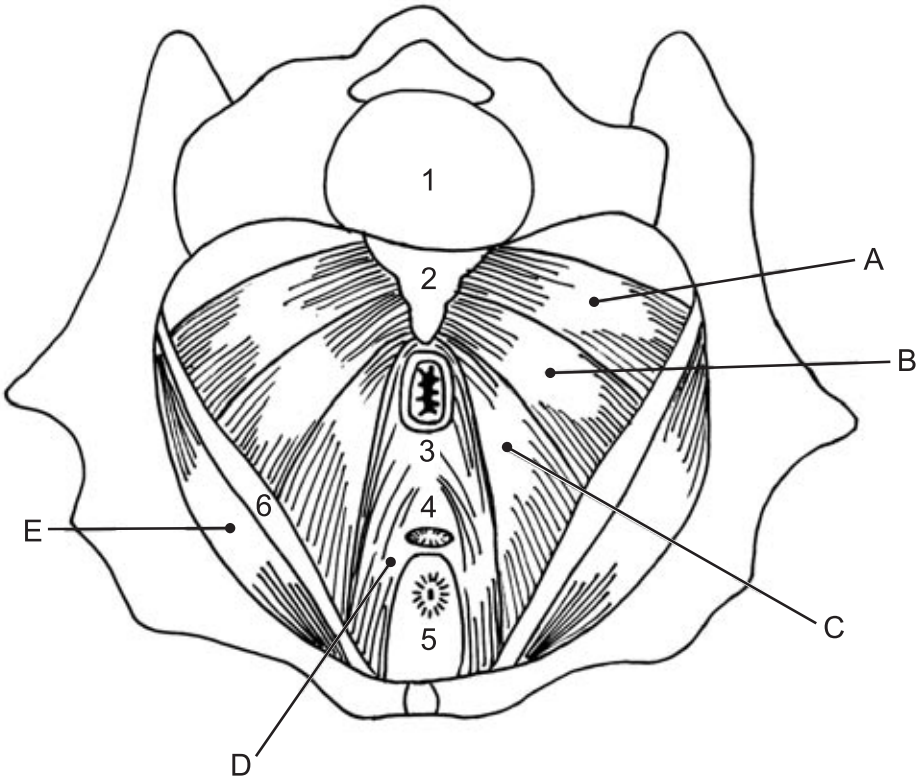

Figure 4. Schematic drawing of a cranial view of the pelvic floor consisting of A. coccygeus, B. iliococcygeus, C. pubococcygeus and D. puborectalis muscles. 1. sacrum, 2. coccyx, 3, anus, 4. vagina, 5. urethra, 6. tendinous arch of the levator ani muscle, E. obturatorius internus muscle.

To answer the question whether pelvic floor muscles have the capability to increase SI joint stiffness we focused on the coccygeus muscles (See A in Figure 4) and two separate parts of the levator ani: the iliococcygeus and pubococcygeus muscles (See resp. B and C in Figure 4). Tension in each muscle was simulated by applying the following springs on either side of the pelvis:

- two springs were attached bilaterally to two rings fixed on the fixation plate (on each side one) at the height of the coccyx (See 1 in Figure 5) and the pelvic surface of the ischial spine (see A in Figure 5), simulating tension in the coccygeus muscle,
- two springs were attached bilaterally between the rings on the fixation plate at the height of the coccyx and the pelvic surface of ischial bone (see B in Figure 5), simulating tension in the iliococcygeus muscle according to the working line of the central part of this muscle and

- two springs were attached between the rings on the fixation plate at the height of the coccyx and the dorsal side of the pubic bones (see C in Figure 5), simulating tension in those fibres of the pubococcygeus muscle deriving from the pubic bones and inserting on the coccyx and sacrum.

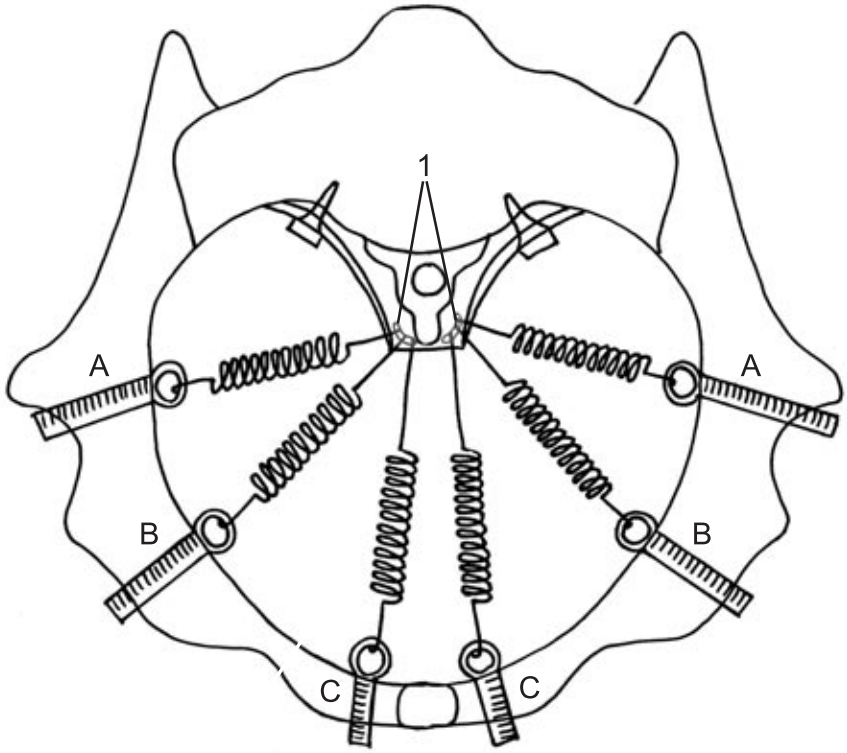

Figure 5. Schematic drawing of the localisation of the springs simulating: A. coccygeus , B. iliococcygeus, C. pubococcygeus muscles. 1.Two rings attached to the fixation plate.

The load of each spring was calibrated to be 50 N. On each specimen five subsequent tests were performed:

test 1. no intervention, followed subsequently by
test 2. with two springs attached to the pelvis, simulating either the left and right coccygeus, iliococcygeus or pubococcygeus muscles,
test 3. with two springs attached (left and right side), simulating one of the two remaining muscles not tested yet,
test 4. with two springs attached (left and right side), simulating the not tested muscle,
test 5. with six springs attached, simulating all three pelvic floor muscles.

Test 2, 3, 4 and 5 were performed in random order. Each test started with the registration of the position of the SI joint without external moment and without simulated muscle force. This was defined as the neutral position. Then, the springs were fixed to the pelvis while no moment of force was applied. The change in position of the innominates was measured. Subsequently, the incremental moment of force was applied, resulting in a load deformation curve.

To compare the data of all five load deformation curves of each specimen, we used an equal load range for data analysis (Figure 5). To determine an equal load range around the same neutral position for all curves we corrected for the initial displacement caused by the application of springs. For this purpose, the joint displacements and moments in experiments with simulated muscle force were calculated with respect to the neutral position as registered without spring forces and external moment.

For data analysis the first loading trajectory of each loading curve from neutral position to maximal counternutation was discarded. Furthermore, to avoid disturbance of data analysis due to the hysteresis loop, both ends of the load range were not used for data analysis (thin lines in Figure 6). Data analysis was performed on the remaining two trajectories of each load deformation curve: 1. the trajectory between maximal counternutation and maximal nutation and 2. the trajectory between maximal nutation and maximal counternutation (see bold trajectories in Figure 6). For both trajectories one mean slope was calculated by linear regression. A decrease in slope was considered to reflect increased SI joint stiffness.

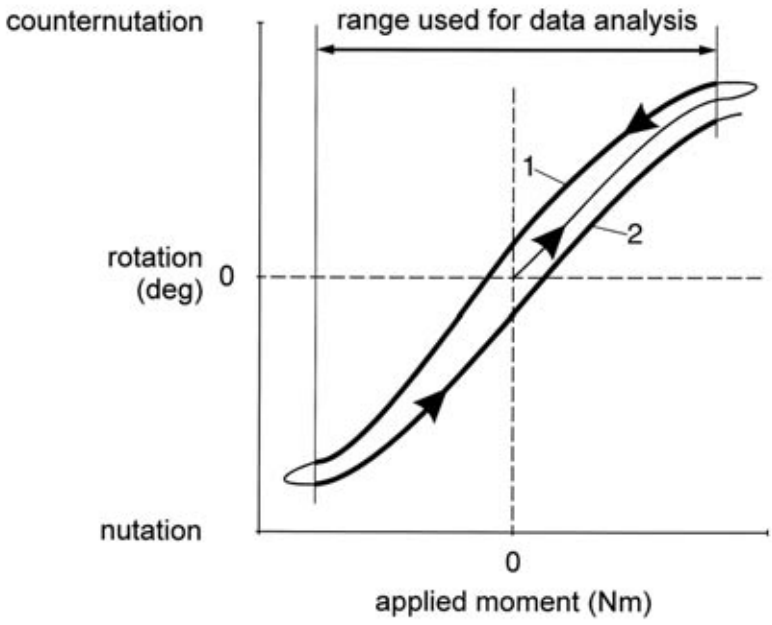

Figure 6. A schematic load deformation curve with the load range used for data analysis. The thin lines are trajectories not used for data analysis. The trajectories 1 and 2 (thick lines) are used for the calculation of a single slope.

To assess whether the pelvic floor muscles have the capability to counternutate the sacrum, we compared the position measured directly after application of the different springs with the neutral position (no springs attached and no moment of force applied to the pelvis). We used the paired samples t-test to analyse these data for significance. A mixed model ANOVA (proc mixed of SAS, version 6.12) was used to test whether the changes in slope by intervention were significant. The dependent variable slope was analysed after natural logarithmic (ln) transformation, due to positively skewed distribution of the slopes. The explanatory factors were: gender (female, male), side (left, right), type (four levels: the pubococcygeus, the iliococcygeus, the coccygeus muscle and the three muscles combined), and a side-specific baseline measurement of the (ln) slope as continuous covariate. The side by type and gender by type interactions were tested. No structure was imposed upon the residual correlations. By using a one-way ANOVA the initial differences between baselines measurements and hence stiffness between male and female were tested.

Since three specimens were lost (broken fixation plate, ventral capsular tear and one specimen with an ankylosis of the SI joint), 15 specimens were available for data analysis.

Results

SI joint stiffness tested by the one-way ANOVA of the baseline measurements showed a steeper slope (p= 0.014) in female pelvises in comparison to male pelvises, respectively 0.13 (± 0.08) and 0.06 (± 0.06). In female pelvises, the slope of the regression line of the S-curve decreased (p = 0.045) by 8.5% due to simulated tension in the pelvic floor muscles acting as a group (6 springs attached). In male pelvises there were no changes (p = 0.39, see Table 1).

In female pelvises an increase (p = 0.004) of the slope of the S-curve of 16.1 % occurred during simulated tension in exclusively the iliococcygeus muscles. No changes occurred in males. In neither of the sexes a change occurred during simulated tension in the pubococcygeus or coccygeus muscles (p >0.05). The percentual changes in geometric mean slopes and 95% confidence per sex and type are shown in Table 1. The mixed model ANOVA showed an interaction of gender by type (p = 0.0017). No interaction of side by type occurred.

For both sexes the T- test showed a counternutation in the SI joint when tension was simulated in the coccygeus muscles (p= 0.0), the pubococcygeus muscles (p= 0.0) and all three pelvic floor muscles combined (p= 0.0) (See Table 2). This in contrast to simulated tension in the iliococcygeus muscle (p> 0.05).

Discussion

In this study we have analysed the capability of pelvic floor muscles to stiffen the SI joint as well as the capability of these muscles to generate movement between the innominates and the sacrum. Firstly, we will discuss the effect of the pelvic floor muscles as a group on stiffness of the SI joints and the interaction of gender. Secondly, we will discuss the effect of the iliococcygeus, coccygeus and pubococcygeus muscles separately. Thirdly, we will discuss the generation of counternutation of the sacrum by pelvic floor muscles as well as clinical consequences of this finding. Finally, we will discuss the clinical relevance of increased tension in pelvic floor muscles.

Effect of pelvic floor muscles as a group on force closure of the SI joint

In females, we demonstrated a significant decrease of the slope of the S-curve by simulated tension in the pelvic floor muscles as a group. We regard this decrease as an increase of SI joint stiffness. This increase of SI joint stiffness can be considered as proof of the capability of the pelvic floor muscles to stabilise the SI joints, at least in the female. These results are in agreement with the model of force closure of the SI joint, adding stability to the pelvic ring by compressive force[12,13]. Pelvic floor muscles can contribute to force closure exclusively if ligaments at the opposite side of the SI joints avoid gapping of the joints, like the hinge in a nutcracker, when tension in the pelvic muscles is increased[12,13]. Since the pelvic floor muscles act on the innominates caudal to the SI joints, increased tension can be expected in ligaments situated cranially to the SI joint, e.g. the cranial short sacroiliac ligaments and the iliolumbar ligaments[24]. In line with this expectation, an in vitro study showed the capability of the iliolumbar ligaments to restrict SI joint mobility[22].

As stated in the introduction, one in vivo study demonstrated an increase of SI joint stiffness by contraction of the transverse abdominal muscle[18]. However, the outcome of that study may well be influenced by simultaneous pelvic floor contraction, since Sapsford et al.[3] demonstrated co-contraction of pelvic floor and transverse abdominal muscles. Unfortunately, Richardson et al.[18] did not test pelvic floor activity with EMG during their stiffness measurements of the SI joint.

In contrast with the female pelvises, no stiffening was observed when tension was simulated in the three pelvic floor muscles in men. This can be due to gender differences in SI joint mobility since in the present study female SI joints were twice as mobile as male SI joints.

Effect of separate pelvic floor muscles on force closure of the SI joint

A decrease of slope and hence an increase of SI joint stiffness was expected by simulating tension in the pelvic floor muscles separately. However, no significant effect was seen. In females, even a significant decrease of SI joint stiffness occurred during simulated tension in the iliococcygeus muscles. So the question remains why could we not demonstrate a stiffening effect of the pubococcygeus and coccygeus muscles and why does the opposite effect occur during simulated tension in the iliococcygeus muscles in female?

There are two possible explanations: a) these muscles are not capable of generating compressive forces and b) the compressive force of these muscles and increased tension in the ligaments surrounding the SI joints is counteracted by an alteration of position of the SI joint, due to fixation of the springs. As stated in the introduction a smaller contact implies less resistance against movement. This latter explanation could account for the decrease in stiffness during simulated tension in the iliococcygeus muscles. In the relatively mobile female SI joints, the springs may have led to such a small contact area between the joint surfaces that resistance against movement was nil, resulting in decreased joint stiffness.

Generation of counternutation of the sacrum

Simulated tension in either the coccygeus, the pubococcygeus or the pelvic floor muscles as a group generated significant counternutation of the sacrum. This indicates that pelvic floor muscles can influence posture and locomotion. By coordinated cocontraction with muscles nutating the sacrum (forward rotation of the sacrum moving the caudal part of the sacrum backward), the pelvic floor muscles can stabilise the SI joints. Muscles inserting on the sacrum, capable of extending the lower lumbar vertebrae and respectively nutating the sacrum are the deeper lumbar muscles of the erector spinae, the multifidus[2,13]. Parts of these multifidus muscles arise from the back of the sacrum and insert in the lumbar region on the mamillary processes of L4 and L5[2]. The multifidus muscles are known as local segmental stabilizers of the lumbar spine[25,26]. Hides et al.[25] demonstrated a decrease of cross sectional area and the presence of fat in the multifidus muscle at L5 in low back pain patients, ipsilateral to the side of complaints. They speculate that this loss of muscle fibres and increase of fat is due to inhibition of the ? and ? motor neurons[25,26]. A deficient inhibition of the multifidus muscle, and hence not optimal co-contraction of multifidus and pelvic floor muscles, might lead to a continuous counternutated position of the sacrum. Clinically this is interesting since counternutation of the sacrum leads to increased tension in the long dorsal sacroiliac ligament, as demonstrated by an in vitro study[27]. It is possible that sustained tension in the pelvic floor muscles can lead to pain in these ligaments and their periostal attachments. Indeed, pain within the boundaries of this ligament has been demonstrated in 21% of a population low back pain patients[28]; it has also been reported in patients with peripartum pelvic pain[29,30].

C*linical relevance of increased tension in pelvic floor muscles*

The stabilising effect of pelvic floor muscles in females can be relevant in case of decreased pelvic stability, especially in patients with pregnancy related low back and pelvic pain[12,16,17]. Increased tension in the pelvic floor, by a higher level of activity of these muscles can compensate for this decreased pelvic stability, increasing stiffness of the SI joints. However, such a sustained contraction can alter the timing and motor control of these muscles. Indeed, Avery et al.[20] reported an altered motor control of pelvic floor muscles in subjects with clinical diagnosis of SI joint pain. In addition, O´Sullivan[19] et al. showed, in patients with SI joint pain, increased pelvic floor descent during low load tasks compared with pain free subjects, also suggesting a change in motor control of the pelvic floor muscles. Sustained contraction of the pelvic floor muscles may well be related to voiding dysfunction, as reported in subjects with SI joint pain[19,20].

Finally, Pool-Goudzwaard et al.[21] demonstrated frequent occurrence of idiopathic coccygodynia in pelvic pain patients. This also might be caused by sustained contraction of the pelvic floor muscles, pulling the coccyx ventrally. This is in line with two studies[31,32] showing in patients with idiopathic coccygodynia an increased angle between the first and last segment of the coccyx.

In vivo measurements are necessary to test whether patients with low back and pelvic pain show sustained contraction of the pelvic floor muscles, possibly resulting in voiding dysfunctions and coccygodynia.

Conclusions

Increase of tension in pelvic floor muscles, viz. the combination of pubococcygeus, iliococcygeus and coccygeus muscles, stiffens and hence stabilises the female SI joint. Such an effect of the pelvic floor muscles could not be demonstrated in male specimens. Possibly this is related to their significantly less mobile SI joints. Most pelvic floor muscles had, in addition, the capability to counternutate the sacrum; this can be antagonized by the multifidus muscles.

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8 Relation between low back and pelvic pain, pelvic floor activity and pelvic floor disorders

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Abstract

Objective: To assess the association between pregnancy related low back and pelvic pain (PLBP) and pelvic floor disorders complaints (PFDC).

Methods: A multi centre cross-sectional descriptive study was performed by 17 physical therapists. The study comprised 66 patients (20 with the referral PLBP, 46 with PFDC) and 11 healthy volunteers, all female. Each subject underwent physical assessment, intravaginal palpation and electromyographic (EMG) measurement. In addition, each subject filled in a special designed form including the Dutch translation of the Urogenital Distress Inventory completed with questions about defecation, pregnancy, delivery and sexual complaints. A division was made in four groups: A. healthy controls (n=11), B. patients meeting the strict criteria of PLBP (n=18), C. patients with PLBP not meeting the strict criteria (n=10) and D. a rest group with PFDC (n=38) not meeting the criteria of group B and C.

Statistical analysis: Differences in the presence of pelvic floor disorder related symptoms between groups B and C as compared to one another and to healthy controls were tested using exact odds ratio tests in cross tables. Confounding and effect modification (interaction) by age and vaginal delivery were examined through stratification. The level of activity in the pelvic floor muscles in groups A, B and C, measured with EMG and intravaginal palpation, was tested with an independent samples T-test for significant differences. Interaction and confounding by age and vaginal delivery were tested using linear regression. The Mann Whitney test was used to test differences in voluntary contraction measured with intravaginal palpation scored on a grading scale.

Results: In 52% of all patients a combination of PFDC and LBP and/or pelvic pain was present. Of these subjects 82% stated that the complaints started with LBP and/or pelvic pain *prior* to PFDC. Symptoms of PFDC occurred significantly more in the PLBP group than in the healthy control group. This was especially the case for the women with a negative active straight leg raise test (group C). In comparison to women with a positive test (group B) significantly more stress incontinence and sexual complaints were present in group C. In both PLBP groups (B and C) increased activity of the pelvic floor muscles could be demonstrated, as illustrated by a significantly higher rest tone, shorter endurance time and a paradoxical pushing reflex. After adjustment for the confounding effect of age no significant differences could be demonstrated between the PLBP groups and the healthy control group. No significant modifying effect of age and vaginal delivery was present on the differences in occurrence of stress incontinence and sexual complaints between group B and group C.

Conclusions: Adjustment for age is a necessity in testing associations between PFDC and PLBP, since age is an important confounding variable. Because of the apparent associations between PFDC and PLBP patients, clinicians assessing and treating such patients should focus on both PFDC and PLBP. Clinicians should be aware that certain PLBP patients are characterized by increased activity of the pelvic floor muscles as a mechanism to compensate for compromised pelvic stability. In these patients relaxation and motor control exercises of the pelvic floor muscles could be effective.

Keywords

pelvic floor muscles, pelvic diaphragm, pelvic floor dysfunction, urine incontinence, pelvic pain, overactivity, sacroiliac joint

Introduction

Low back and pelvic pain are common among pregnant women[1,2,3]. At least 50% of pregnant women have back pain to some extent[2,3]. Regression of low back pain and pelvic pain after delivery may be slow and incomplete[1,4]. A randomised controlled follow-up study in women with back pain during pregnancy reported the presence of low back pain 6 years later in 16% of the study population[4]. Several terms have been used to describe low back and/or pelvic pain related to pregnancy (posterior pelvic pain[5,6], sacroiliac joint dysfunction[7], pelvic girdle relaxation[8]) but we prefer the term Pregnancy related Low Back and Pelvic pain (PLBP). PLBP manifests itself as backache and tenderness around the pelvic joints, frequently extending to other parts of the pelvis, the upper legs and exceptionally the lower legs; it is influenced by a variety of postures and movement[9].

It has been hypothesised that PLBP is related to deficient pelvic stability[3,5,7,10,11]. In this study we define stability as the ability of a joint to bear physical loading without uncontrolled displacements so as not to damage structures and to prevent incapacitating deformity or pain due to structural changes. This conforms the definition of clinical stability produced by the committee for the spine of the American Academy of Orthopaedic Surgeons[12]. The hypothesis on deficient pelvic stability in PLBP patients is supported by the demonstration of asymmetric laxity of the sacroiliac (SI) joints in a group of patients characterised by severe pain and disability complaints[13].

Deficient pelvic stability could be compensated for by increased tension in muscles capable to stabilise the pelvic ring[14,15]. Since a recent in vitro study[15] demonstrated the capacity of pelvic floor muscles to stabilise the pelvic ring, we assume that certain PLBP patients use a higher level of activity (overactivity) in these muscles to compensate for deficient pelvic stability. In line with this assumption two studies[7,16] showed, in comparison to healthy subjects, altered motor control of pelvic floor muscles in PLBP patients during a low load task like an active straight leg raise. This altered motor control was normalized immediately after fixing a belt around the pelvis[7]. Often PLBP patients report release of pain when wearing a pelvic belt[3,5,17] and indeed a belt around the pelvis resulted in reduced SI joint mobility and increased SI joint stiffness as demonstrated respectively in vitro[18] and in vivo[19].

Overactivity of the pelvic floor muscles as a mechanism to compensate for deficient pelvic stability has, however, a drawback. It could influence the appropriate activity patterns of these muscles during essential voluntary and reflex motor manoeuvres. A direct impact can be expected on a) the endurance of these muscles (endurance will decrease), b) the reflexes of these muscles (continuously increased activity will diminishes reflex time and quality of the response) and c) a longer relaxation time of these muscles (muscle will not relax). These alterations in motor control might lead to pelvic floor disorders complaints (PFDC) as voiding dysfunction, incontinence of urine, constipation and sexual problems[20,21]. This is in line with studies on patients with SI joint pain and/or PLBP showing frequent occurrence of impaired bladder control and voiding dysfunction[7,16] as well as coccygodynia[20]. It has been hypothesized that coccygodynia finds an origin in overactivity of the pelvic floor muscles, pulling the coccyx ventrally[15]. However, accurate data on the associations between PLBP and PFDC as well as coccygodynia are lacking. In this study the associations have been tested between PLBP and PFDC such as voiding dysfunction, urinary incontinence, constipation, sexual problems, discomfort/ pain and coccygodynia. Also the association between PLBP and vulvar vestibulitis have been tested since White et al[22] demonstrated an overactivity and loss of motor control of pelvic floor muscles in patients with vulvar vestibulitis.

An association between urinary incontinence, voiding dysfunctions, sexual complaints and PLBP might well be influenced by age because of the negative relationship between strength of voluntary pelvic muscle contractions and increase of age, in women[23]. Interaction of age can be due to a decrease of estrogens (in the menopause) leading to atrophy of the

mucous membranes of the genital tract and to loss of control of the pelvic floor muscles[24]. So, in older women an increased occurrence of urinary incontinence and voiding dysfunctions can be expected. This decline in function of the pelvic floor muscles, however, might have a positive effect on those sexual complaints related to overactivity of the pelvic floor muscles. Therefore, interaction of age on the above mentioned associations has been assessed. Interaction of vaginal delivery on these associations has also been tested since a linear relationship exists between number of vaginal births and weaker voluntary contractions of the pelvic floor muscles[25]. Due to vaginal delivery, both muscular and neurological injuries have been reported directly affecting urethral function[24,25]. Stress urinary incontinence has been reported in 21% of a study population after vaginal delivery[26].

The interaction of vaginal delivery on the occurrence of coccygodynia has also been tested, since, during childbirth, the pelvic floor is exposed to direct compression from the foetus as well as to downwards pressure from the maternal expulsive efforts[25]. This might lead to an unstable and painful coccyx as well as to increased occurrence of discomfort and pain.

To get informed on the activity level of pelvic floor muscles in PLBP patients we assess the rest tone, strength, endurance, relaxation time and the quality of the reflexes of these muscles in comparison to healthy controls.

Methods

A multi centre (18) cross-sectional descriptive study was performed by 17 physical therapists in the Netherlands. For this purpose physical therapists were randomly chosen from the membership records of the Dutch Association of Pelvic Physical Therapists (NVFB) all specialised in assessing and treating patients with PFDC and PLBP. Originally 25 physical therapists agreed to co-operate in the study but 8 physiotherapists did not participate because of illness, work stress, no time and absence of patients willing to participate. Every physical therapist recruited women for this study, both patients as healthy volunteers, after giving information about the methodology and the importance of this study. All women signed an informed consent form. Approval was obtained from the Medical Ethical Committee of the Erasmus Medical Center Rotterdam.

Study sample

The study comprised healthy volunteers and patients with either the referral PLBP or PFDC by the general physician. The inclusion criteria were: female, age between 30 to 50 years, at least 12 weeks postpartum. Healthy volunteers with low back or pelvic pain and/or PFDC were excluded. Regardless of the referral of the general physician, the subjects were divided into four groups: A. healthy controls, B. patients meeting the strict criteria of PLBP (see below), C. patients with PLBP complaints not meeting the strict criteria of PLBP and D. a group with PFDC not meeting the criteria of group B and C. The strict criteria to appoint a patient to group B were the following: onset of low back and pelvic pain during pregnancy or delivery, a positive SI joint provocation test (Posterior Pelvic Pain test, PPP)[27] and a positive Active Straight Leg Raise test (ASLR) [3,5]. The PPP test was positive when pain was elicited in the dorsal pelvic region ipsilateral to the side of provocation[27]. The PPP test is a reliable, sensitive and specific pain provocation test of the SI joint to assess PLBP[27]. The ASLR test was positive if a subject, lying supine, was unable to raise a straight leg 5 cm from the couch or when this was accompanied by the experience of a profound heaviness of the leg. Reliability, sensitivity and specificity of the ASLR test are high[2,6]. Group C consisted of patients with the onset of low back and pelvic pain during pregnancy or delivery, a positive PPP test but a negative ASLR test. So, both group B and group C consisted of PLBP patients, with the only difference that the patients in group C scored negative on the ASLR test. Group D consisted of patients with the referral PFDC, not meeting the criteria of group B and C.

Physical assessment

Every subject underwent a physical assessment including inspection during standing, examination of active movements of the spine for pain provocation, the PPP test and the ASLR test. Attention was paid to diminishing or evenabsence of diaphragmatic motion during this last test, in line with the study of O'Sullivan et al[7]. The examiner documentated all findings on a special designed form. Data of the physical examination were used to create the nominal variables ASLR, PPP and low back and pelvic pain. A subject scored positive on the variable LBP and/or pelvic pain exclusively if in addition to the presence of low back and pelvic pain, the pain could also be provoked during movements of the spine or daily activities. The scores on these variables were used to create groups B, C and D.

Inspection and palpation

All subjects underwent an inspection of the vagina and perineum, using a cotton tipped applicator focussing on seven different signs: vulvar dryness, swelling, hyper- or hypoaesthesia, erythema and pain or burning. If three of these seven signs were present the subject was diagnosed as a possible vulvar vestibulitis, as proposed by White et al[22] and Friedrich[28]; this was used as a nominal variable. An intravaginal palpation was performed in all subjects, using a palpation protocol, with the subject lying supine on a bench with the back rest at 40º, knees bend and both feet on the table. The maximal voluntary force (Pmax) was assessed two times and scored on a 6-point Oxford grading scale using the validated PERFECT scheme of Laycock[29,30]. Intravaginal palpation, using the validated PERFECT scheme of Laycock[29,30], shows an inter-tester agreement of 58%, an intra-tester agreement of 71% and a test-retest agreement of 69%[29]. The inter-tester reliability of the P50% showed a Pearson product moment correlation (Pr) of 0.64, while the intra-tester reliability showed a Pr of 0.67[30]. Using Laycock's PERFECT scheme, also the endurance of pelvic floor contraction at 50% (P50%) of the maximum voluntary force was assessed (in seconds)[29,30]. All findings were documented by the examiner on a special designed form. The Pmax score was used as an ordinal variable. P50% was used as an interval variable.

Questionnaires

All subjects received a self administered questionnaire. Socio-demographic data were collected including age. Also data were collected on history and current status of low back and pelvic pain and/or pelvic floor complaints, the onset of complaints, location of pain (if present), experienced disability during daily activities. In addition all subjects filled in a Dutch translation of the Urogenital Distress Inventory (UDI)[31,32] completed with questions about obstetric history, defecation and sexual complaints. The additional questions are based on the advise of the ' Dutch Pelvic Floor Society' and are used by obstetricians and surgeons in several medical centres in The Netherlands. The Dutch translation of the UDI identified five domains: discomfort/pain, urinary incontinence, overactive bladder, genital prolaps and obstructive micturation. The Dutch translation of the UDI shows an adequate internal consistency, content-, criterion- and construct validity[32]. Data collected from all questionnaires were used to create nominal variables on the presence of:

a) discomfort/pain in the pelvic floor region,
b) urinary incontinence viz. stress incontinence and urge incontinence,
c) voiding dysfunction viz. urgency, frequency,
d) obstructive micturation,
e) constipation,
f) sexual complaints,
g) Caesarean section/ vaginal delivery
h) coccygodynia.

EMG measurement

All subjects underwent an intravaginal EMG measurement using a 2 canals vaginal sensor and a computerised EMG analysis (Myomed 932, Enraf Nonius Delft) following a specially designed protocol. The myomed EMG measurement is tested as a reliable method to register pelvic floor contraction[30,33]. The Pearson correlation coefficient (Pr) on the inter tester reliability of the myomed EMG measurement was 0.69, on the intra tester reliability 0.65, the test – retest agreement showed a Pr of 0.86[30]. The surface electrodes of the vaginal sensor detect gross EMG signals that correlate 0.99% with data produced by invasive fine wire stainless steel electrodes[33]. The subject was situated in the same position as during vaginal palpation. The vaginal sensor was inserted so that myographic activity of the pelvic floor muscles could be registered and tested. The following measurements were repeated two times, with 10 seconds between each separate test: rest tone in mV, maximum voluntary contraction (MVC) in mV, contraction during pushing and coughing in mV, endurance at 50% of the MVC in seconds and time necessary for relaxation after the endurance test in seconds, all registered on a special designed form.

Statistical analysis

Differences in the presence of PFDC between groups B and C compared to one another and to healthy controls in cross tables were analyzed through exact odds ratio tests using the statistical package Egret for Windows (version 2.04). The presence of the following PFDC complaints was tested: discomfort/pain, stress and urge incontinence, urgency, frequency, obstructive micturation, constipation, sexual complaints, vulvar vestibulitis and in addition coccygodynia. We examined interaction and confounding by age (young 30-39/ old 40-50) and vaginal delivery (Caesarean section yes/no) on the differences in the presence of urinary incontinence, voiding dysfunction and sexual complaints between groups A, B and C, using stratification. In addition, using the same method of analysis, the interaction of vaginal delivery on the association between coccygodynia and the presence of discomfort and pain was assessed. Using the common odds ratio test, stratum specific odds ratios were tested for significant differences.

The following variables concerning the level of activity in the pelvic floor muscles in group B and C with respect to the healthy control group (A) were tested for significant differences, using an independent samples T-test in SPSS 10.0: rest tone, MVC, relaxation time, sneezing and coughing and endurance at P50% measured by palpation and EMG. Interaction of the same variables, age and vaginal delivery, was tested using linear regression (SPSS 10.0). The Mann Whitney test (SPSS 10.0 for windows) was used to test differences in voluntary contraction measured with intravaginal palpation scored on a grading scale.

Results

The study comprised originally 81 subjects. Four subjects were excluded from data analysis since they did not meet the inclusion criteria (nulliparous and age). Data analysis was performed on 77 subjects, concerning 20 patients with the referral PLBP, 46 patients with the referral PFDC and 11 healthy subjects. Of all patients (n=66), 18 subjects met the strict criteria of group B. Of these 18 subjects, 10 were referred with the diagnosis PLBP and 8 with the referral PFDC (See Table 1). Each patient with a positive ASLR test (group B) showed absence of diaphragmatic motion during the test. Of the remaining PLBP patients 10 met the criteria of group C. Every patient in group C was referred with the diagnosis PLBP. The remaining patients (n=38), all with the primary referral PFDC complaints, were classified in group D (See Table 1).

Table 1: *Classification in subgroups*

Referral	n		Group	n	Age
Healthy control	11	11	A	11	42.6 ± 5.7
		10	C	10	35.0 ± 5.7
PLBP	20				
		10	B	18	37.2 ± 7.2
		8			
PFDC	46	38	D	38	40.0 ± 7.4

In 52% of all patients (n=66) a combination of PFDC, LBP and/or pelvic pain was present. Of these subjects 82% (n= 33) stated that the complaints started with LBP and/or pelvic pain *prior* to PFDC. LBP and/or pelvic pain was also present in 60 % (n = 23) of group D (patients with PFDC not meeting the criteria of PLBP) . In 86% (n=20) of these PFDC patients LBP started *prior* to their complaints.

Differences in PFDC between the groups (Table 2)

The exact cross table analysis showed significant crude differences between groups B and A (healthy controls) concerning the presence of urge incontinence (Odds Ratio (OR) > 1.4), discomfort/pain (OR = 19.2) and coccygodynia (OR >1.4). No significant differences were demonstrated concerning the presence of frequency, urgency, stress incontinence, obstructive micturation, constipation, sexual complaints and vulvar vestibulitis.

Differences between group C and A were demonstrated concerning the presence of urgency (OR = 9.1), stress incontinence (OR >4.4), urge incontinence (OR > 1.3), discomfort/ pain (OR = 14.8), coccygodynia (OR >1.3) and sexual complaints (OR = 45.8). No significant differences were demonstrated for the presence of frequency, obstructive micturation, constipation and vulvar vestibulitis.

Significant differences between group C and B were demonstrated concerning the presence of stress incontinence (OR >2.4) and sexual complaints (OR 12.8). No other significant differences were demonstrated.

Stratification by age (See Table 3)

No significant differences in the presence of all tested PFDC between group B and group C on one hand and group A on the other were demonstrated after adjustment for age except for sexual complaints in the younger stratum in group C. Although in the younger stratum the OR of group C relative to group A was significant for sexual complaints (OR >1.2), the adjusted OR across both age-strata nor the common odds ratio test reached significance.

A significant OR in group C relative to group B was found for stress incontinence in the younger age group (OR > 1.6) as well as overall across both age-strata (OR >2.0), adjusted for age. No significant effect modification could be demonstrated. No significant differences in the presence of all other tested PFDC between group B and C were demonstrated after adjustment for age except for sexual complaints in the younger stratum. Although in the younger stratum the OR of group C relative to group B was significant for sexual complaints (OR > 1.1), the adjusted OR across both age strata nor the common odds ratio test reached significance.

***Table 2**. Crude differences in the presence of PFDC between groups A (n=11), B (n=18) and C (n=11) expressed by means of OR's*

PFDC	B versus A				C versus A				C versus B			
	OR	CI 95%	P	S	OR	CI 95%	P	S	OR	CI 95%	P	S
Frequency	4.8	0.7 – 58.5	0.14		6.0	0.7 – 88.5	0.12		1.0	0.2 – 5.2	1.00	
Urgency	5.3	0.7 – 64.2	0.10		9.1	1.0 – 140.5	0.05	*	1.8	0.3 – 14.6	0.74	
Stress incontinence	2.8	0.4 – 33.8	0.45		> 4.4	4.4 – inf	0.00	*	>2.4	inf – 0.0	0.00	*
Urge incontinence	> 1.4	1.4 – inf	0.02	*	> 1.3	1.3 – inf	0.02	*	1.2	0.2 – 7.7	1.00	
Obstructive micturation	4.3	0.6 – 51.7	0.18		6.1	0.7 – 88.5	0.13		1.5	0.2 – 9.8	0.92	
Discomfort/pain	19.2	2.4 – 274.9	0.00	*	14.8	1.5 – 265.1	0.01	*	1.9	0.3 – 24.6	0.77	
Coccygodynia	> 1.4	1.4 – inf	0.02	*	> 1.3	1.3 – inf	0.02	*	1.2	0.2 – 7.7	1.00	
Constipation	4.0	0.7 – 31.6	0.16		2.5	0.3 – 24.5	0.53		2.0	0.4 – 9.5	0.49	
Sexual complaints	4.8	0.5 – 257.6	0.29		45.8	2.8 – 3527.7	0.00	*	12.8	1.3 – 674.7	0.02	*
Vulvar vestibulitis	> 0.6	0.6 – inf	0.15		1.2	0.0 – 107.8	1.00		inf	inf – inf	0.15	

* P < 0.05
OR = Odds Ratio
CI 95% = Confidence Interval of 95%
P = P-value
S = Significance
inf = Infinite

***Table 3**. Differences in the presence of PFDC between groups A,B and C stratified by age group expressed through age group specific odds ratio's and adjusted odds ratio's*

PFDC		B versus A					C versus A					C versus B				
		OR	CI 95%	P	S	CT	OR	CI 95%	P	S	CT	OR	CI 95%	P	S	CT
Frequency	adj	2.7	0.2 – 38.8	0.56		0.4	4.0	0.2 – 274.9	0.58		1.0	0.9	0.2 – 5.5	1.00		1.0
	young	>0.2	0.2 – inf	0.32			>0.2	0.2 – inf	0.36			1.0	0.1 – 9.9	1.00		
	old	0.8	0.0 – 22.6	1.00			>0.0	0.0 – 156.0	1.00			0.9	0.0 – 22.6	1.00		
Urgency	adj	3.6	0.4 – 48.7	0.35		0.5	5.2	0.2 – 340.5	0.42		0.5	1.2	0.1 – 10.8	0.95		1.0
	young	>0.2	0.2 – inf	0.33			>0.3	0.3 – inf	0.32			1.7	0.2 – 24.4	1.00		
	old	1.6	0.1 – 32.5	1.00			>0.0	0.0 – 156.0	1.00			>0.0	0.0 – 97.5	1.00		
Stress	adj	1.8	0.2 – 26.5	0.87		1.0	>0.8	0.8 – inf	0.07		?	>2.0	2.0 – inf	0.00	*	?
Inc.	young	0.7	0.0 – 67.2	1.00			>0.1	0.1 – inf	0.36			>1.6	1.6 – inf	0.01	*	
	old	3.6	0.1 – 264.8	0.60			>0.8	0.8 – inf	0.40			>0.0	0.0 – inf	0.85		
Urge	adj	3.6	0.4 – 48.7	0.33		0.5	5.2	0.2 – 340.5	0.42		0.5	0.8	0.1 – 5.7	1.00		1.0
Inc.	young	>0.3	0.3 – inf	0.33			>0.3	0.3 – inf	0.21			0.9	0.1 – 7.2	1.00		
	old	1.6	0.1 – 32.5	1.00			>0.0	0.0 – 156.0	1.00			>0.0	0.0 – 234.0	1.00		
Sexual	adj	3.1	0.2 – 177.5	0.65		1.0	14.0	0.5 – 981.4	0.11		0.3	9.8	0.9 – 539.6	0.07		0.4
Compl.	young	>0.1	0.3 – inf	0.61			>1.2	1.2 – inf	0.03	*		>1.1	1.1 – inf	0.03	*	
	old	1.2	0.0 – 109.7	1.00			>0.0	0.0 – 273.0	1.00			>0.0	0.0 – 234.0	1.00		

* P < 0.05
OR = Odds Ratio
CI 95% = Confidence Interval of 95%
P = P- value
S = Significance
CT = Common odds ratio test (p-value)
adj = overall adjusted odds
inf = infinite
Inc. = Incontinence
Compl. = Complaints
? = no outcome

Stratification by vaginal delivery (See Table 4)

Confounding and modifying effects of vaginal delivery (no Caesarean section) on the differences of group B and group C relative to healthy controls (group A) could not be analysed since no subject in the healthy control group had a Caesarean section.

After adjustment for vaginal delivery the overall OR's of stress incontinence and sexual complaints in group C relative to group B remained significant (OR>1.2 and OR = 12.2, respectively). Although in the stratum vaginal delivery the OR of group C relatively to group B was significant for stress incontinence (OR > 1.2), the common odds ratio test did not reached significance. No significant effect modifications by vaginal delivery could be demonstrated for any PFDC.

Table 4. *Differences in the presence of PFDC between group C (n=11) and B (n=18) adjusted for vaginal delivery noted in overall adjusted and stratum specific odds.*

PFDC		C versus B				
		OR	CI 95%	P	S	CT
Frequency	adjusted	1.2	0.2 – 8.2	1.00		1.00
	Vag del	1.2	0.1 – 11.4	1.00		
	CS	1.4	0.0 – 156.5	1.00		
Urgency	adjusted	1.9	0.2 – 15.4	0.69		1.00
	Vag del	1.4	0.3 – 13.1	1.00		
	CS	>0.0	0.0 – inf	0.95		
Stress incontinence	adjusted	>1.2	1.2 – inf	0.03	*	?
	Vag del	>1.2	1.3 – inf	0.03	*	
	CS	inf	inf – inf	1.00		
Urge incontinence	adjusted	1.4	0.2 – 9.6	0.98		0.41
	Vag del	2.1	0.4 – 19.6	0.67		
	CS	0.3	0.0 – 39.1	1.00		
Sexual complaints	adjusted	12.2	1.4 – 645.5	0.02	*	1.00
	Vag del	9.9	0.8 – 566.2	0.07		
	CS	>0.1	0.1 – inf	0.57		
Coccygodynia	adjusted	1.1	0.3 – 7.1	1.00		1.00
	Vag del	0.8	0.1 – 7.0	1.00		
	CS	3.1	0.0 – 391.0	1.00		
Discomfort/ pain	adjusted	0.9	0.0 – 13.8	1.00		?
	Vag del	0.9	0.0 – 13.8	1.00		
	CS	inf	inf – inf	1.00		

* P < 0.05
OR = Odds Ratio
CI 95% = Confidence Interval of 95%
P = P- value
S = Significance
CT = Common odds ratio test (p-value)
Vag del = Vaginal delivery
CS = Caesarean Section
inf = infinite
? = no outcome

Differences in EMG recordings between the subgroups (Table 5)

The variables rest tone, MVC, endurance at 50% of MVC, relaxation time, pushing and coughing measured with EMG were analysed after natural logarithmic (ln) transformation, due to positively skewed distribution of the variables. Geometric means and 95% confidence limits of their ratios relatively to healthy controls are obtained from back transforming the results for the log-transformed variables. The independent samples T-test demonstrated a significantly shorter endurance contraction time of the pelvic floor at 50% of the MVC in group B and C (33.4 sec and 17.8 sec, respectively) relative to healthy controls (54.0 sec). During pushing both group B (9.1 mV) and C (10.4 mV) showed a significantly higher mV output than healthy controls (3.0 mV). The mV output during pushing in group B and C tended to increase with regard to the rest tone (in group B from 5.6 to 9.1 mV and group C from 7.2 to 10.4 mV), instead of a decrease as shown in group A (4.8 to 3.0 mV). No significant differences could be demonstrated between the three subgroups with respect to the rest tone, MVC, relaxation time and coughing.

Linear regression demonstrated a linear correlation between endurance in seconds and age (Beta -7.4, p=0.01, Rsq 0.8): the older females in group C showed significantly less endurance time. In addition, a linear correlation was demonstrated between endurance and vaginal delivery (Beta -7.4,p = 0.01, Rsq 0.7): the females with vaginal delivery showed less endurance time.

Table 5 *Comparison of EMG measurements in groups B (n=18) and C (n=10) with healthy controls A (n=11) after back-transformation to geometric means and to 95 % confidence limits of their ratios relatively to group A as reference for the log transformed variables*

EMG measurement	Group	GMean	P	S	95% CI
Rest tone	A	4.8			
(in mV)	B	5.6	0.27		0.58 to 2.35
	C	7.2	0.10		0.76 to 2.95
MVC	A	21.9			
(in mV)	B	20.8	0.88		0.45 to 1.97
	C	20.0	0.81		0.45 to 1.83
Relaxation time	A	3.8			
(in sec)	B	5.1	0.30		0.74 to 2.32
	C	6.6	0.15		0.79 to 3.74
Endurance time at 50% MVC	A	54.0			
(in sec)	B	33.4	0.04	*	0.40 to 0.95
	C	17.8	0.00	*	0.19 to 0.55
Coughing	A	26.6			
(in mV)	B	20.5	0.34		0.45 to 1.32
	C	20.9	0.49		0.37 to 1.63
Pushing	A	3.0			
(in mV)	B	9.1	0.00	*	1.62 to 5.81
	C	10.4	0.00	*	1.77 to 6.88

* P < 0.05

GMean = Geometric mean
CI 95% = Confidence Interval of 95%
P = P-value
S = Significance
sec = seconds

Differences in palpation between subgroups

The exact Mann-Whitney test showed a significantly higher rest tone (P ? 0.05) of the pelvic floor muscles measured by palpation in group B and group C in comparison to healthy controls. No differences could be demonstrated between both group B and C and healthy controls concerning the maximum voluntary force.

The independent samples T-test showed a significant difference (P = 0.03) between group C and group A concerning endurance at 50% MVC measured by palpation (resp. 8 versus 17 sec). No significant difference could be demonstrated between group B and healthy controls (resp. 15 versus 17 sec).

Discussion

This study demonstrates the frequent occurrence of PFDC in PLBP patients, especially urgency, urge incontinence, stress incontinence, discomfort/pain, sexual complaints relative to healthy controls, if not adjusted for age. The findings of this study are in line with former studies reporting loss of bladder control, voiding dysfunction (especially stress incontinence) and coccygodynia in PLBP patients[20] and patients with SI joint pain[7,16]. In contrast with O'Sullivan et al[7] we could not demonstrate an increased occurrence of urinary frequency.

Relation between PFDC and the motor control of pelvic floor muscles

Furthermore, the present study demonstrates an increased activity level of the pelvic floor muscles in all PLBP patients relative to healthy subjects, illustrated by a significantly higher rest tone and shorter endurance time measured with intravaginal palpation and EMG. PLBP patients can use this continuously elevated activity level of pelvic floor muscles in order to stabilise the SI joints and generate augmentation of pelvic stability. We assume that a relation is present between the demonstrated occurrence of PFDC and an increased level of activity in the pelvic floor muscles.

Due to the increased activity of the pelvic floor muscles the activity patterns of these muscles during voluntary and reflex motor manoeuvres can be influenced. For instance, to reinforce closure of the urethra and to maintain continence an appropriate activity pattern of a part of the pelvic floor muscles (the pubococcygeus and puborectalis muscles) is needed[24]. According to Loenen and Vierhout[34], the levator ani muscles contribute to 1/3-1/2 of the urethral closure pressure. Relaxation of the above mentioned pelvic floor muscles is needed for voiding[24]. If prior to the onset of voiding the activity level of the pelvic floor muscles is not adequately reduced, this can lead to voiding dysfunction[24]. In addition, continuously elevated activity in the pelvic floor muscles might hamper the coordinated and timely response as well as the effect of reinforcement of closure pressure during a sudden rise of intra-abdominal pressure as in coughing of sneezing, resulting in stress incontinence of urine[24,35,36]. Indeed, the present study shows a change in the coordinated response to a rise of intra-abdominal pressure demonstrated by a significantly different and paradoxical pushing mechanism in PLBP patients relative to healthy controls, measured with EMG. In healthy subjects the pelvic floor muscles relax during pushing as demonstrated by a drop of the mean rest tone. In contrast, both PLBP groups show a contraction of these muscles during this manoeuvre. The contraction is strongest in the PLBP group with the highest level of activity of the pelvic floor muscles: group C. The present study supports the assumption that PFDC and a higher level of activity of the pelvic floor muscles are related since both voiding dysfunctions and stress incontinence can be demonstrated in patients with a higher level of activity of the pelvic floor muscles.

In PLBP patients with a continuously elevated activity level of pelvic floor muscles vaginistic complaints can be expected. In line with this expectation v.d Velde[21] demonstrated differences in contractions of these muscles between a group of patients with vaginistic complaints in combination with pelvic floor complaints and healthy controls. Indeed, the

present study demonstrates a significantly increased occurrence of sexual complaints as well as an increased level of activity of pelvic floor muscles in PLBP patients with respect to healthy subjects, if not adjusted for age.

In PLBP patients using a continuously elevated level of activity to compensate for loss of pelvic stability, also coccygodynia can be expected. An elevated activity level of the pelvic floor muscles may pull the coccyx ventrally. Indeed, in patients with idiopathic coccygodynia, an increased angle between the first and the last segment of the coccyx is demonstrated[37,38]. The present study confirms a more frequent presence of coccygodynia as well as elevated activity level of the pelvic floor muscles in PLBP patients.

White et al[22] demonstrated an overactivity and loss of motor control of pelvic floor muscles in patients with vulvar vestibulitis. We assumed that in PLBP patients with a continuously elevated activity level of pelvic floor muscles vulvar vestibulitis might be present. However, the present study does not confirm this assumption: no association could be demonstrated between vulvar vestibulitis and PLBP (neither group B nor C). Probably the demonstrated overactivity and loss of motor control of the pelvic floor muscles in patients with vulvar vestibulitis, demonstrated by White et al[22], is not comparable to the altered activity patterns in PLBP patients. Another reason why associations between vulvar vestibulitis and PLBP can not be demonstrated can be the small sample size of this study.

Differences between the PLBP groups

The present study shows significant differences between both PLBP groups: stress incontinence and sexual complaints occur more frequently in group C than in group B, also after adjustment for age and vaginal delivery. It has to be emphasized that the patients of group B and C differ exclusively in their score on the Active Straight Leg Raise (ASLR) test, viz. group B has a positive and group C a negative score. The ASLR test is advocated as a test for the quality of load transfer through the lumbopelvic region [3,5,7,16]. This load transfer is impaired when pelvic stability is compromised[2,4,6,7,8]. A strong correlation has been demonstrated between impairment of ASLR and an unilateral increase in pelvic mobility visualised by radiography[6]. So, in PLBP patients with a positive ASLR test load transfer through the lumbopelvic region is hampered, and pelvic stability as well. In PLBP patients with a negative ASLR test pelvic stability seems not to be compromised. On the other hand all these patients scored positively on the PPP test. We hypothesise that PLBP patients with a negative ASLR test are able to compensate for loss of pelvic stability successfully by increased activity of the pelvic floor muscles. This increased activity will generate augmentation of pelvic stability leading to a negative ASLR test, although the SI joint still can be painful (positive PPP test). Indeed, increased activity of the pelvic floor muscles relative to healthy subjects was especially manifest in PLBP patients with a negative ASLR test.

The more frequent occurrence of stress incontinence and sexual complaints in group C relative to group B is in line with the hypothesis that especially patients in group C are able to compensate compromised pelvic stability by increased activity of the pelvic floor muscles. We speculate that in patients with a positive ASLR test, different compensation strategies are present. O'Sullivan et al[7] demonstrated an altered motor control of the diaphragm and a descent of the pelvic floor during the ASLR test in PLBP patients (all with a positive ASLR test). This altered motor control of the diaphragm, viz diminished or even absent diaphragmatic motion, and descent of the pelvic floor can be the response to the generation of intra-abdominal pressure in order to splint the spine and pelvis[7]. In line with these findings, the present study shows an absence of diaphragmatic motion during the ASLR test in all PLBP patients with a positive score on the test. Still, the significant higher rest tone of the pelvic floor muscles in both PLBP groups as demonstrated in this study, seems to be in contrast with a descent of the pelvic floor during the ASLR test. Such an aberrant movement of the pelvic floor in PLBP patients during the ASLR test was also reported by Avery et al[12]. However, a descent of the pelvic floor during the ASLR test is not conclusive for the level of activity of these muscles.

Confounding of age

Results of the present study emphasize the importance of adjustment for age in testing associations between PFDC and PLBP relative to healthy controls, since age appears to be a confounding variable. After adjustment for age no differences could be demonstrated between both PLBP groups on one hand and the healthy controls on the other. No other study dealing with loss of bladder control, voiding dysfunction and coccygodynia in PLBP patients[20] and patients with SI joint pain[7,16] tested interaction of age. So, the results of these studies might well be distorted by interaction of age.

Confounding of age might well be due to the expected increased occurrence of voiding dysfunctions and urinary incontinence and decreased occurrence of sexual complaints in older women, due to loss of pelvic muscle control[24] and strength[23]. Indeed, in line with this expectation, the present study shows a shorter endurance time in older women in group C measured with EMG, relative to healthy women.

The present study shows a more frequent occurrence of stress incontinence and sexual complaints exclusively in the younger generation. This is in contrast with the expected effect of age on these symptoms. However, we have to be careful interpretating these data since the common odds ratio test reached no significance. The small sample size, especially after stratification, can be the reason why both strata do not differ significantly. Due to the small sample size the estimates of the odds can be unstable[39].

Interaction of vaginal delivery

Interaction of vaginal delivery/Caesarean section was expected since vaginal delivery weakens pelvic floor contractions affecting the continence mechanism[19], as demonstrated by the frequent occurrence of stress incontinence after vaginal delivery[26]. In line with this expectation the present study shows a decreased endurance in patients with a vaginal delivery, measured with EMG and intravaginal palpation; this in contrast with patients with a Caesarean section. In line with former studies[19,26], the present study shows a significantly increased occurrence of stress incontinence in subjects who had a vaginal delivery. However, we have to be careful interpretating the data since the common odds ratio test did not reach significance. Again the small sample size, especially after stratification, may be the reason why both strata do not differ significantly.

General conclusion

In PLBP patients often a combination of PLBP and PFDC occurs. This combination of both complaints is influenced by the age of a patient. Clinicians should be aware of this co-existence of complaints as well as the confounding effect of age. In assessment of PLBP patients the clinician should be aware of different compensation strategies for loss of pelvic stability. A negative ASLR test can be a sign of a successful compensation mechanism for compromised pelvic stability by continuously elevated activity of the pelvic floor muscles, effecting the motor control of these muscles and hence their role in the continence mechanism. So, based on this study, clinicians assessing and treating patients with PLBP should focus on PFDC as well.

Clinicians diagnosing and treating PFDC should distinguish between symptoms based on PFDC itself and symptoms related to an altered motor control of pelvic floor muscles due to changes in the locomotor system. Of all 38 PFDC patients, 60% experienced a combination of LBP and/or pelvic pain and PFDC. Of these latter subjects 86% stated that the LBP and/or pelvic pain complaints started *prior* to PFDC. On the basis of this study we assume that the primary cause of PFDC frequently must be sought in changes in the locomotor system. Clinicians treating patients with a dysfunctional pelvic floor due to changes in the locomotor system should integrate the treatment of LBP with the treatment of PFDC related symptoms. Negation of a possible cause of PFDC related symptoms in the locomotor system can diminish the effect of therapy.

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Literature

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8 Appendix: Influence of pelvic floor muscles on the continence mechanism

Introduction

To understand the relation between increased activity of the pelvic floor muscles on the continence mechanism, knowledge of the anatomy of the relevant structures is essential as well as knowledge of the physiology of the continence mechanism. This appendix focuses on the anatomy of the pelvic floor and the related organs. Furthermore, the role of pelvic floor muscles in the process of micturition and defecation is described. Since all subjects in the survey (chapter 8) were female, the description is limited to female pelvic organs and pelvic floor muscles. In literature, there are differences of opinion regarding the anatomy and physiology of the bladder neck and proximal urethra, the innervation of the urethral sphincters and pelvic floor muscles as well as the underlying pathology in urinary incontinence. This appendix is primarily based on traditional anatomic descriptive studies[1,2,3,4]. The description of pelvic floor action and the process of micturition and defecation is based on research performed in vivo[5-10,13,16-19].

Anatomy

The perineum overlies the pelvic aperture. Its boundaries are the pubic arch and the arcuate pubic ligament, the coccyx and on each side the ramus inferior of the os pubis, the ramus of the os ischium, the ischial tuberosity and the sacrotuberous ligament[1,2]. The perineum can be divided in two regions: the anal and the urogenital region[1,2,3]. The most important muscle of the anal region is the external anal sphincter[1,2,3]. Muscles of the urogenital region can be divided in two groups: the superficial urogenital and the deep perineal muscles[1,2,3]. The superficial urogenital muscle group consist of the transverse perineal superficiales, the bulbospongiosus and the ischiocavernosus muscles[1,2,3]. The deep perineal muscle group consists of the sphincter urethrae and the transverse perineal profundus muscles[1,2]. All these muscles of the anal and urogenital region form a relatively superficial muscular layer. The pelvic floor muscles forming a deeper, funnel shaped pelvic diaphragm, are the coccygeus muscles and the levator ani complex, including the pubovaginalis, the puborectalis, the pubococcygeus and iliococcygeus muscles[1,2,3,4,5]. These striated muscles, have the capacity to support the pelvic contents and to prevent prolapse through the pelvic outlet[1,3].

The muscle of the anal region

The external anal sphincter (See A in Figure 1) is a striated triple loop muscle system, surrounding the anal canal, consisting of deep, superficial and subcutaneous loops. According to Shafik[7], each loop has individual attachments, direction of muscle fibres and innervation. The deep loop consists of a thick annular band surrounding the upper part of the internal anal sphincter and fusing with the puborectalis muscle (E in Figure 1)[1,7]. The muscle bundles of the deep part of the external anal sphincter loop around the upper part of the rectal neck and are attached posteriorly to the anococcygeal ligament and fuse anteriorly with the superficial transverse perineal muscles[1,3,7]. This loop pulls the anorectal junction anteriorly, thus assisting in anal closure. The deep loop is innervated by the inferior rectal branch of the pudendal nerve (S2, S3)[3,7]. The superficial loop embraces the midportion of the rectal neck and is attached to the tip of the coccyx. After surrounding the lower part of the internal anal sphincter this loop inserts into the perineal body. It is innervated by the perineal branch of S4[7]. The subcutaneous loop lies horizontally below the lower borders of the internal anal sphincter and encloses the lower part of the anal canal. It lies beneath the skin and is supplied by the inferior rectal branch of the pudendal nerve[7]. The external anal sphincter is responsible for up to 30% of the anal closure pressure[3,8]. It maintains a low level of activity in sleep[3,8]. The external anal sphincter induces voluntary continence by twofold action: 1) preventing internal anal sphincter relaxation on detrusor contraction and 2) sealing the rectal neck by direct compression and neck kinking[7]. It contracts strongly when intra-abdominal pressure increases and with voluntary effort[3,8].

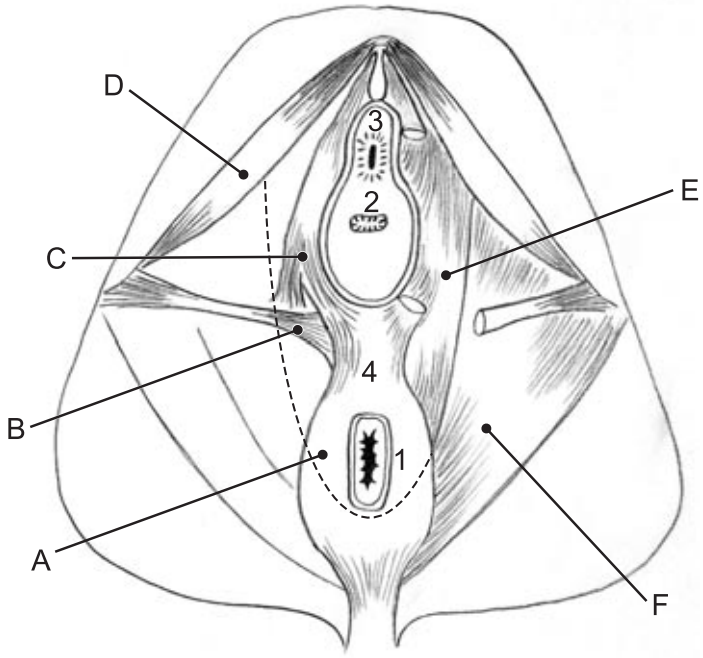

Figure 1. Perineal view of the muscles of the superficial layer and deep layer: Superficial: A.external anal sphincter, B. the transverse perineal superficialis, C. the bulbospongiosus and D. the ischiocavernosus. Deep: E. puborectalis and F. iliococcygeus as part of the levator ani muscle.1. anus, 2. vagina, 3. urethra, 4. perineal body. Adapted from Sapsford et al. 1998.

Muscles of the urogenital region

The external urethral sphincter (See S in Figure 2) is a striated voluntary muscle, surrounding the urethrae[1,2,3]. Its superior fibres form a horseshoe whose dorsal ends merge with the smooth muscle of the bladder neck. The inferior fibres encircle the membranous urethrae as far as the lower urethrae and vagina[1,2,3,4]. The external urethral sphincter intermingles posteriorly with connective tissue of the anterior vaginal wall[9] and converges with the perineal body[1,2]. It is considered to consist of three parts:

a) the rhabdosphincter (See 1 in Figure 2), a striated intramural sphincter, surrounding the urethra in its middle third, inserting into fibrous tissue,

b) the compressor urethrae (See 2 in Figure 2), blending with the rhabdosphincter muscle, arising from the ischiopubic rami to arch across the anterior surface of the urethra and

c) the sphincter urethrovaginalis (See 3 in Figure 2), blending with the compressor urethrae above. It passes posteriorly along the urethra and vagina and inserts into the perineal body and the opposite muscle, forming a sling[3,9].

The external urethral sphincter consists primarily of slowtwitch fibres (type 1)[10,11]. The three muscles act to compress, retract and elongate the urethra[3], especially if the bladder contains fluid. The external urethral sphincter may receive innervation from below via the pudendal nerve, a branch of the sacral plexus (S2-S4) and from the pelvic splanchic nerves above[1,3,9].

The deep transverse perineal muscles extend from the medial aspect of the ischial ramus to the perineal body and decussate with fibres of the contralateral counterpart. The deep transverse perineal muscles end in the perineal body dorsally of the external urethral sphincter[1,2,3,9].

The superficial transverse perineal muscles form a narrow muscular strip almost transversely across the superficial perineal space[1,2,3]. They are variable in development and sometimes absent[1]. They arise from the medial and anterior aspects of the ischial tuberosity and insert into the perineal body joining the muscle on the opposite side. The superficial muscles end in the perineal body ventrally of the external anal sphincter and dorsally of the bulbospongiosus muscles (See C in Figure 1).Simultaneous contraction of these muscles probably help to fix the perineal body although the precise function is not clear[1,3].

The bulbospongiosus muscles arise from the perineal body, where its fibres decussate with those of the external anal sphicter and contralateral fibres of transverse perineal muscles. The muscles pass ventrally on each side of the vagina and urethra and insert across the body of the clitoris(See D in Figure 1). These muscles close the orifice of the vagina[1,2,3,9].

The ischiocavernosous muscles arise from the medial aspect of the ischial tuberosity and the adjacent surface of the ischial ramus and cover the surface of the crus clitoridis (See E in Figure 1) inserting into an aponeurosis attached to the sides of the crus clitoridis[1]. The last two muscles act upon the erection of the clitoris by compression of the deep dorsal vein and are probably involved in the female sexual response[1,13].

All above mentioned muscles of the urogenital region are supplied by the perineal branch of the pudendal nerve[1,3].

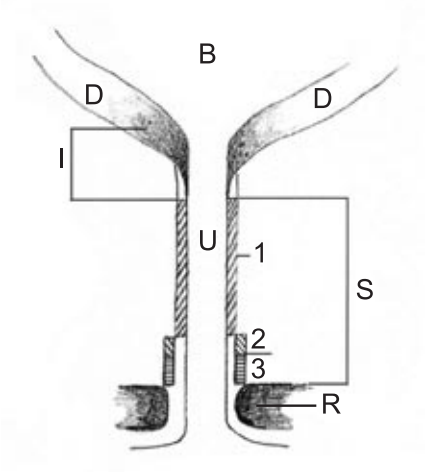

Figure 2. The relationships of the muscles in longitudinal section of the female urethra. The external urethral sphincter (S) consisting of 1. the rhabdosphincter, 2. the compressor urethrae and 3. the sphincter urethrovaginalis. R = region of bulbospongiosus muscle, B = bladder, D = detrusor muscle, I = internal urethral sphincter

The pelvic floor muscles

The levator ani complex (See Figure 3) forms the main part of the floor of the pelvic cavity and consists of the puborectalis, pubococcygeus (with a part coined the pubovaginalis) and the iliococcygeus muscles[1].

The puborectalis muscles (See A in Figure 3) is formed by fibres deriving from the pelvic surface of the pubis passing the urethra and vagina, looping around the anorectal junction, mingling with the muscle from the opposite side. Posteriorly its fibres are incorporated into the deep external anal sphincter and can be considered as one entity[4]. The subcutaneous part of the puborectalis muscle is connected to the coccyx by the anococcygeal ligament[1,3,4,7]. According to Shafik (1987) [7] the puborectalis muscle differs in morphology, innervation and function from the levator ani and should not be coined a part of the levator ani muscles. The puborectalis muscles reinforce the internal anal sphincter and help to create the anorectal angle. The puborectalis muscles receive innervation directly from the sacral roots (S3-S4) passing cranial to the pelvic floor[4].

The *pubococcygeus muscles* (See B in Figure 3) are funnel shaped, with a transverse portion, the levator plate (a) and a vertical portion, the suspensory sling (b)[13].

a) The levator plate stretches across the pelvis, arising from the pelvic surface of the pubic bone and the anterior part of the fascia over the obturator internus muscle (See 6 in Figure 3)[1,3]. Posteriorly the levator plate blends in a tendinous raphe (See 4 in Figure 3) also called the anorectal junction or ligament[3], inserts into the coccyx and is continuous with the ventral sacrococcygeal ligament[1,2,13]. The anterior boundary of the levator plate is the levator hiatus, an opening between the two pubococcygeus muscles[1,2,3,13]. The levator plate is connected to the pelvic organs by a facial condensation called the hiatal ligament[1,3,12]. It arises from the inner edge of the levator plate and splits fanwise into multiple septa to blend with the rectal and vesical neck as well as into the upper vaginal end[1,3,13]. Anteriorly the hiatal ligament forms the pubovesical ligament[3,13].

b) The suspensory sling forms together with the puborectalis muscle the levator tunnel: a muscular tube surrounding the intrahiatal organs (rectum, vagina and urethra)[13].

The most anterior medial fibres of the pubococcygeus muscles derive from the pelvic surface of the pubis lateral to the symphysis and sweep backwards across the sides of the vagina to reach the attachment on the perineal body. These muscle fibres constitute a sphincter muscle for the vagina and are coined *the pubovaginalis muscle* (See C in Figure 3) [1].

The iliococcygeus muscle (See D in Figure 3) arises from the fascia over the obturatorius internus muscle, the ischial spine and the posterior lateral part of the tendinous arch of the levator ani [1,2,3] and passes posteromedially to join the muscle on the other side. It unites posteriorly with fibres of the pubococcygeus muscle in the rectococcygeal raphe and inserts on the lateral margins of the coccyx[1,3]. In lower mammals the iliococcygeus is responsible for the side to side movements of the coccyx (wagging the tail in animals)[1,3]. There are differences in opinion regarding the innervation of the pelvic floor muscles[3]. It seems there is a considerable individual variation in the nerve supply[3]. The pubococcygeus and iliococcygeus muscles can be innervated directly by sacral roots of S3- S4 and by a branch arising from the inferior rectal nerve and/or pudendal nerve[1,2,3,].

The coccygeus muscle (See E in Figure 3) arises from the pelvic surface and tip of the ischial spine; they fuse with the sacrospinous ligament and inserts into the lateral margins of the upper coccyx and lower sacrum[1,2,3]. It may provide support for pelvic organs[3]. The coccygeus muscle is supplied by a branch from S4-S5 spinal nerve[1,3].

During contraction of the pelvic floor muscles, the levator ani and coccygeus, the apex of the sacrum[11], the coccyx, the anorectal junction, the vagina and the urethra are pulled anteriorly[1,3]. Furthermore, the most medial fibres act as compressors of the visceral canals[1,2,3]. The vagina and urethra can be lifted in a cranial direction during contraction[3]. Together with the abdominal muscles the pelvic floor muscles contract to raise the intra-abdominal pressure[1,3]. However, unlike the abdominal muscles, they are active in the inspiratory phase of quit respiration[1].

In an intravaginal EMG study the levator ani muscles exhibit tonic muscle activity[10]. In this muscle group a high proportion slowtwitch (type 1) fibres are present[3,9,10], mainly responsible for the maintenance of tone of the levator ani muscles. Approximately 30% of the pubococcygeus muscle fibres are fasttwitch fibres, activated during sudden increase of intra-abdominal pressure as in coughing, straining or sneezing. Fasttwitch fibres are not able to maintain muscle tone for a longer period[3,9,10]. Activities of daily live generate a higher level of activity in the pubococcygeus muscles compared to supine position[11].

The pelvic organs and related structures

The urinary bladder (See Figure 2), acting as a reservoir for fluid, varies in size according to the amount of fluid that it contains, as well as with the state of distension of the neighbouring viscera[1]. The bladder consists of a base, neck and apex[1]. The base is, in females, closely related to the anterior wall of the vagina[1,2]. The apex of the bladder, directed towards the cranial part of the pubic symphysis, is connected to the umbilicus by the median umbilical ligament. The bladder has a three layered wall, consisting of: a) the serous, peritoneal covering, b) the muscular stratum, consisting of the non-striated detrusor vesicae muscle[1,2,3] and c) the mucous membrane, continuous with the ureters above and urethra below [1,2,3]. The nerves supplying the bladder, forming the vesical plexus, consist of both sympathetic and parasympathetic components, each containing motor and sensory fibres[1]. The parasympathetic fibres (S2-S4) convey motor fibres to the detrusor muscle[1,2,3] whereas the sympathetic efferent fibres from T11-L2 inhibit this muscle. Normal filling and emptying of the bladder is controlled by the parasympathetic nervous system [1,2,3].

The female urethra (See Figure 2) begins at the internal urethral orifice of the bladder and runs anterio-caudally, ending at the external urethral orifice[1]. It passes between two sides of the levator ani but has no direct attachment to this muscle[3]. It lies against the anterior vaginal wall and the lower two-thirds are inseparable from it[3]. The urethral wall contains mucous, erectile and muscular layers[1,2,3,9]. The thin spongiose erectile layer contains a plexus of large veins intermixed with bundles of nonstriated muscle fibres[1,9]. The muscular layer consists of nonstriated muscles arranged in a thin circular layer, coined the internal urethral sphincter (See I in Fig.2) and a thick longitudinal layer[9]. So, in contrast with males, in females, the urethra is devoid of a thick well defined nonstriated muscle[1,2,3] However, the urethra is surrounded by the striated external urethral sphincter as described above[1,2,3,9].

The perineal body is a fibromuscular structure in the mid-point of the perineum, between the anus and the vagina[3]. It acts as a hub of the muscle complex and contributes to efficient functioning of those muscles. Furthermore it provides support for the anal canal. (See 4 in Figure 3)

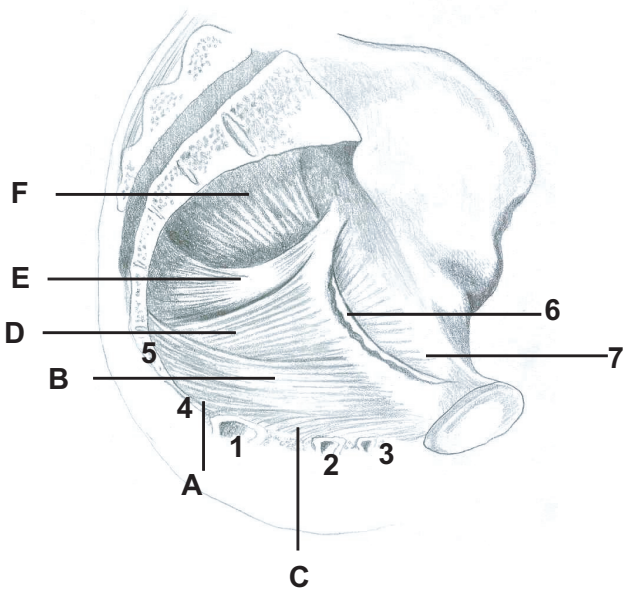

Figure 3. Pelvic view of the levator ani muscles consisting of A. the puborectalis, B. the pubococcygeus C. the pubovaginalis and D. iliococcygeus muscles forming the pelvic diaphragm with E. the coccygeus muscle. F. piriformis muscle 1. anal canal, 2. vagina, 3. urethra, 4. anococcygeal ligament, 5. coccyx, 6. tendinous arch of the levator ani, 7. fascia of the obturator internus.

Physiology

The process of defecation

At rest anal closure is maintained predominantly by the internal and external anal sphincters[1,3,7,8]. Before defecation, feces are stored in the sigmoid colon[4]. As stools enter the rectum, the internal anal sphincter relaxes by the anorectal inhibitory reflex to open the rectal neck[7,8]. However, opening of the rectal neck requires a relaxation of the external anal sphincter. Awareness of filling of the rectum is prerequisite for the response of the external anal sphincter to internal anal sphincter relaxation[3]. If it is not convenient to defecate, the external anal sphincter remains contracted, preventing relaxation of the internal anal sphincter and sealing the rectal neck by compression[7]. In addition, anal closure can be maintained by the puborectalis muscle[3,4,7]. Contraction of the puborectalis muscle narrows the anorectal angle and will lengthen the anal canal which is in favour of anal closure[4,7]. At time of defecation the pelvic floor muscles including the puborectalis muscle as well as the external anal sphincter relax, the intraabdominal pressure (IAP) is increased by contraction of diaphragm and abdominal muscles and the pelvic floor descends 1-2 cm[3,4,7,8]. In addition, the anorectal angle widens and the anal canal funnels and shortens[3,7,8]. As defecation proceeds the increased IAP compresses the rectum against the supporting levator plate[3,7]. At the end of defecation activity occurs in the pelvic floor muscles including the puborectalis muscle and the external anal sphincter, restoring normal position of the pelvic viscera and closure pressure[3,7,8].

The process of micturition

Maintenance of urinary continence is multifactorial, depending on muscle control: a detrusor muscle allowing the bladder to fill to a normal volume and adequate urethral closure function[3,9]. This muscle control involves both the peripheral and central nervous system as well as intact anatomical structures in and around the urethra[3,9].
The following factors (can) contribute to urinary continence:

a) the mucous layer of the urethra seals the urethra by its turgor and elasticity.
b) an adequate closure pressure by contraction of the external urethral sphincter. In addition, especially the pubovaginalis (as part of the pubococcygeus muscle) and puborectalis muscles contract, reinforcing closure of the urethra[9]. This closure pressure must be greater than the pressure of the bladder[14]. According to van Loenen[15], the levator ani muscles contributes to 1/3-1/2 of the urethral closure pressure. The urethral closure pressure measured during urodynamic studies as the difference between intravescical and intraurethral pressure have shown that increase in activity is present especially in the lower region of the urethra at the height of the compressor urethra and external urethral sphincter[16]. According to Vereecken et al.[8] in coughing and sneezing, additional closure pressure is reinforced by activity of the levator ani muscles (fasttwitch fibres), especially the pubococcygeus, resulting in closure pressure of the urethra with effort [3,8].
c) the anatomical position of the bladder neck[9]. Although still under discussion DeLancey [18] conceptualised the following system: contraction of the levator ani muscles moves the urethra ventrally compressing it against a 'precervical arch', a ligamentous structure fixing the urethra to the levator ani muscle. Such a precervical arch has been demonstrated by magnetic resonance by DeLancey[17] and Klutke et al.[5]. However, Kirschner et al.[18] could not identify this ligamentous structure arch or other ligaments fixing the urethra to the levator ani.

In order to initiate micturition, a fall of urethral resistance immediately precedes a rise in pressure within the lumen of the bladder. This may be due, at least in part, to contraction of the nonstriated ventral longitudinal muscle system located in the neck of the bladder and the wall of the urethra, coined the dilator urethrae by Dorscher et al.[15], causing urethral dilatation. Bernstein[9] states that relaxation of the levator ani muscles allows the urethra to move

posteriorly and inferiorly leading to a loss of the urethrovesical angle, allowing voiding[3,9]. Furthermore, according to DeLancey [18], the precervical arch pulls anteriorly to the urethra also facilitating its opening[7,18]. Immediately prior to the onset of micturition the tonus of the external urethral sphincter and puborectalis and pubococcygeus muscles is reduced[1,2,3,9]. Due to this relaxation the bladder neck descends and opens[1,3,17] The urine enters the urethra. The flow begins on relaxation of the external urethral sphincter[1,3]. At the onset of micturition, the bladder pressure rises usually due to detrusor muscle contraction in response to bladder wall stretch[3,9,17]. Urine flows until the bladder is empty or when a small residue remains[3]. The detrusor muscle then relaxes and the pelvic floor muscles regain their low level of activity[3,8,9].

Still a controversy exists about the role of the external urethral sphincter. However, most authors agree on the essential role of this muscle for micturation and the concept that for micturation relaxation of the pelvic floor muscles is a necessity[1,3,9,17].

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9 General Discussion

General Discussion

Evolution of the model of selfbracing

In science, theoretical models evolve. These arise from thoroughly testing, providing evidence of all components of the model and abandoning those parts proven not to be correct. This thesis contributes to the evolution of the model of selfbracing, a model on providing stability to the lumbopelvic region by force closure of the sacroiliac (SI) joints and the pelvis to secure proper load transfer through the region[1,2]. This relatively new model on selfbracing has been developed in the early nineties (See Chapter 2)[1,2]. In the early nineties, muscle action was considered to be essential for delivering compressive forces to the SI joints. This was also the starting point for assigning a compressive action to the thoracolumbar fascia, when stretched by the latissimus dorsi and gluteus maximus muscles (See Chapter 3)[3]. The translation of this model on selfbracing to treatment of patients with compromised lumbopelvic stability implied training of muscles capable of stretching the thoracolumbar fascia and/or muscles with the capacity to compress the SI joints directly[3]. The model resulted in a therapeutic mode of training oblique muscle "slings", using a rotation exercise program, involving the action of the hamstrings, the gluteus maximus, the latissimus dorsi, the internal and external obliques and the trapezius muscles (See chapter 2)[4]. These muscles were trained to improve strength and as a result increased compressive forces on the SI joints. However, a clinical study by Mens et al[5] showed that strengthening hamstrings and gluteus maximus muscles was counterproductive in patients with pregnancy related pelvic pain due to compromised pelvic stability. So, it is questionable whether compressive force on the SI joints will be increased by hamstrings and gluteus maximus muscle action. Currently, it also can be questioned whether stretching of the thoracolumbar fascia by the latissimus dorsi is able to compress the SI joints[5,6]. Bogduk et al[6] state that the magnitude of its compressive action is overstated considering the attachments and number of fascicles in the latissimus muscle able to brace the SI joints. So, compressive action of the thoracolumbar fascia on the SI joints by tensioning the latissimus dorsi appears to be trivial as well. Therefore, the model on selfbracing of the SI joints should be adjusted since evidence for compressive action by the latissimus dorsi, gluteus maximus muscles and hamstrings on the SI joints is lacking.

If indeed, strengthening of these muscles in order to compress and stabilize the SI joints is pointless, does this imply that rotation exercise programs are meaningless as a therapeutic mode in patients with compromised pelvic stability? According to Mooney et al[7] rotation exercise programs are effective for patients with SI joint pain due to compromised lumbopelvic stability because of the normalisation of the activity pattern of gluteus maximus and contralateral latissimus dorsi muscles[7]. So, training oblique slings can be useful in training patients with compromised lumbopelvic stability but for different purposes like normalisation of the muscle activity pattern[7] or stabilisation of the lumbar spine[8,9].

The only muscles shown to have a stiffening and hence stabilising effect on the SI joints are the transverse abdominal muscle and the pelvic floor muscles[10,11] (See chapter 7). So, a special therapeutic mode has been developed to train the transverse abdominal muscles, proven to be effective in patients with low back pain (LBP) and pelvic pain[12,13]. Therefore, treatment of patients with LBP and pelvic pain due to compromised lumbopelvic stability should include training of the transverse abdominal muscles. It can be questioned whether treatment also should include training of the pelvic floor muscles to compress and stabilise the SI joints. As a general rule, this seems not advisable since this study shows that increased tension of the pelvic floor muscles may lead to pelvic floor dysfunction related symptoms as stress urinary as well as sexual complaints[14]. This is opposite to the advise of Critchley[15] to facilitate pelvic floor contraction in order to increase activity of the transverse abdominal muscle.

Contribution of ligaments to the selfbracing mechanism

This study has made another contribution to the evolution of the selfbracing model by focussing on the role of ligaments. Theoretically, ligaments play an important role in the model of selfbracing by generating a compressive force on the SI joints when stretched due to certain positions of the joint. However, accurate data on the influence of several ligamentous structures surrounding the SI joint was lacking. The only biomechanical study focussing on ligamentous structures of the SI joint was an in vitro study showing increased tension in the sacrotuberous ligament during nutation of the sacrum (forward movement of the base of the sacrum with respect to the iliac bone)[16.17]. In this thesis we focussed on two other important ligaments surrounding the SI joint: the long dorsal sacroiliac and the iliolumbar ligament.

The long sacroiliac ligament was of special interest since pain within the boundaries of this ligament has been indicated in 21% of a population low back pain patients[18]; it has also been reported in patients with peripartum pelvic pain[19,20]. A biomechanical study by our Research group showed tensioning of this ligament during counternutation of the sacrum (backward movement of the base of the sacrum with respect to the iliac bone) (See Chapter 4)[21]. So, a contribution of this ligament to the selfbracing mechanism can be expected during counternutation of the sacrum. A sustained counternutated position of the sacrum might lead to strain and pain in this ligament (See Chapter 4)[21]. One cause for such a sustained counternutated position can be increased activity of the pelvic floor muscles since this study has demonstrated a counternutating effect of this muscle group on the sacrum (See Chapter 8)[14]. As shown in a group of LBP and pelvic pain patients, increased activity of the pelvic floor muscles is present. This may be a compensatory mechanism for loss of pelvic stability (See Chapter 8)[14]. Consequently, pain in the long dorsal sacroiliac ligament may be a sign of compromised pelvic stability.

The iliolumbar ligament is another important ligamentous structure with the capacity to contribute to the selfbracing mechanism (See Chapter 5 and 6) [22,23]. This ligament is of special interest since it might be a primary source of LBP[24,25,26]. Until now a direct biomechanical effect of the iliolumbar ligament on the SI joint has been ignored. This is surprising, since this study demonstrated the presence of a sacroiliac part of the iliolumbar ligament (See Chapter 5)[22]. The existence of a sacroiliac part connecting ilium and sacrum crossing the SI joints implies a role for the IL in the biomechanics of the SI joints. The biomechanical study on the IL demonstrated a restriction of SI mobility in the sagittal plane (See Chapter 6)[23]. The ventral band of the IL particularly contributes to this restriction of mobility. This is noteworthy since the ventral band derives from the iliac crest and inserts, not on the sacrum, but on the transverse process of L5. As a consequence, movement of L5 can restrict SI joint mobility by influencing the tension in the ventral band[27,28,29,30]. As a result, the kinematics of the SI joint and the lumbar zygapophysial joint of L5-S1 are coupled. Consequently, the model of selfbracing must be expanded to the lumbar region since selfbracing of the pelvis will directly influence L5-S1 and vice versa. Loss of stability somewhere in the kinematical chain will affect all structures involved. Hence, clinicians assessing patients with LBP and pelvic pain should not search for a singular structural diagnosis as a painful ligament. Painful ligaments can merely be a sign that changes have occurred somewhere in the kinematical chain instead of being a primary source of pain.

The integration of disciplines

The impact of the selfbracing mechanism as explanatory biomechanical model for LBP and pelvic pain does not remain within the boundaries of the pure physical domains of medicine. As shown by the present study a relation is present between LBP, pelvic pain and pelvic floor dysfunction related symptoms such as urinary incontinence, voiding dysfunctions as well as sexual complaints. Several experts can be involved in the assessment and treatment of these complaints e.g. gynaecologists, urologists, sexologists, orthopaedic surgeons, physical therapists. The selfbracing mechanism can expound the combination of these complaints. LBP and pelvic pain can be related to hampered load transfer through the

pelvic region due to compromised pelvic stability. To restore a proper load transfer patients can compensate loss of pelvic stability by increased activity of the pelvic floor muscles (Chapter 8)[14]. However, increased activity may affect the continence mechanism as well as sexual activity[31]. Hence, alterations in the locomotor system may lead to pelvic floor dysfunction related symptoms. The start of LBP and pelvic pain prior to the development of pelvic floor dysfunction complaints in 82% of a population (n=40) with a combination of both LBP/pelvic pain as pelvic floor complaints supports this assumption (See Chapter 8)[14].

So, as an explanatory model the selfbracing mechanism connects several domains in medicine and requires special caution by clinicians treating patients with both pelvic floor complaints, LBP and pelvic pain. Clinicians assessing these patients should distinguish between symptoms based on pelvic floor disorders itself and symptoms related to an altered motor control of pelvic floor muscles due to changes in the locomotor system. Hence, in assessment and treatment of patients with a combination of LBP/ pelvic pain and pelvic floor complaints attention must be paid to the quality of lumbopelvic stability. Also physicians with a pure physical scope should be aware of the co-existence of LBP and pelvic pain and pelvic floor dysfunction related symptoms; in treatment they should address these complaints as well.

Integration of the physical and psychosocial intervention

In today's treatment of patients with subacute and chronic LBP, as mentioned in the introduction of this thesis, the emphasis is on behavioral treatment. By operant conditioning the activity tolerance of the patient increases (graded activity). In addition, various kinds of physical exercises are used, to encourage health behaviour and to avert a disuse syndrome[32].

The present study provides biomechanical knowledge which can be implemented in treatment of LBP and pelvic pain patients. The goal of physical training can be the recovery of lumbopelvic stability in addition to the goal of encouraging health behaviour. So, in patients with LBP and pelvic pain due to compromised pelvic stability the first step in physical training can be training of the transverse abdominal muscles in order to increase lumbopelvic stability. In addition, the clinician should assess and, if present, treat possible pelvic floor dysfunction related symptoms. These treatment modalities can be used in behavioral treatment in patients with subacute and chronic LBP due to compromised lumbopelvic stability. In fact, they should be essential components as long as stability training of the lumbopelvic region and treatment of pelvic floor dysfunction complaints does not interfere with the increase of activity tolerance and the self motivation of a patient.

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Summary

Summary

To gain insight into the origin and (delay in) recovery of nonspecific Low Back Pain (LBP) this thesis focuses on anatomical and biomechanical aspects of the lumbopelvic region. This insight is relevant for clinicians assessing and treating patients with nonspecific LBP. The reason to focus on the lumbopelvic region derives from the concept that impairment of lumbopelvic stability, in particular that of the sacroiliac joints, results in deficient load transfer through this region. This may lead to pain disorders as nonspecific LBP. So, knowledge of the influence of lumbopelvic structures on the stability of the sacroiliac joints can be important for treatment of patients with LBP due to impairment of lumbopelvic stability.

In *Chapter 2* an anatomical, biomechanical model is introduced on selfbracing of the sacroiliac joints, providing stability to the lumbopelvic region. This model is based on the concept that under postural load specific ligament and muscle forces are necessary to intrinsically stabilise the pelvis. Since load transfer from spine to pelvis and lower extremities passes the sacroiliac joints, effective stabilisation of these joints is essential. Stabilisation of the sacroiliac joints can be provided in two ways. Firstly; by interlocking of the ridges and grooves on the joint surfaces (form closure); secondly, by compressive forces of structures like muscles and ligaments (force closure). Muscle weakness and insufficient tension of ligaments can lead to diminished compression, influencing load transfer negatively. Continuous strain of pelvic ligaments can be the result, leading to pain. For treatment purposes of these pain complaints stabilisation techniques followed by specific muscle strengthening procedures are indicated.

In *Chapter 3* the anatomical and biomechanical relations of the superficial and deep lamina of the posterior layer of the thoracolumbar fascia are described. Aim of the study of the thoracolumbar fascia has been to gain insight into the possible role of this structure in the load transfer between spine, pelvic, legs and arms. Firstly, an anatomical descriptive study has been performed since the caudal relations of the posterior layer of the thoracolumbar fascia had not been studied previously. Secondly, a biomechanical study has been performed by simulating the action of various muscles measuring the displacement in the posterior layer of the thoracolumbar fascia. Conclusions from this study are that muscles normally described as hip, pelvic, and leg muscles interact with so-called arm and spinal muscles via the thoracolumbar fascia, allowing effective load transfer between spine, pelvis, legs, and arms. It is speculated that a simultaneous contraction of muscles rotating the trunk can stabilise the lower lumbar spine and sacroiliac joints.

Chapter 4 focuses on the anatomy and biomechanics of the long dorsal sacroiliac ligaments. These ligaments are of special interest since in many patients with nonspecific low back pain or peripartum pelvic pain, pain is experienced in the region directly caudal to the posterior superior iliac spines. Here, the long dorsal sacroiliac ligaments are located. Data on the functional and clinical importance of these ligaments has been lacking. Conclusions from this study are that the long dorsal sacroiliac ligaments have close anatomical relations with the erector spinae muscles, the posterior layer of the thoracolumbar fascia, and a specific part of the sacrotuberous ligaments. Functionally, they are an important link between legs, spine, and arms. The ligaments are tensed when the sacrum is counternutated and slackened when nutated. Pain localized within the boundaries of the long dorsal sacroiliac ligaments could indicate among others a sustained counternutation of the sacrum. In diagnosing patients with nonspecific LBP, the long dorsal sacroiliac ligaments should not be neglected.

Chapter 5 and 6 focus on the iliolumbar ligaments. These ligaments have been described as the most important ligaments for stability of the lumbosacral junction and in addition, they may play an important role in stabilising the sacroiliac joints. Furthermore, these ligaments are considered to be an important source of chronic low back pain. Data on a functional relation between the iliolumbar ligaments and sacroiliac joint stability has been lacking. To gain insight into their presumed stabilising effect on the SI joints, an anatomical

descriptive study (Chapter 5) as well as a biomechanical study (Chapter 6) has been performed. Specific dissection shows the existence of a special part of the iliolumbar ligaments connecting the ilium and the sacrum, distinct from the ventral sacroiliac ligaments: a sacroiliac part. These sacroiliac parts of the iliolumbar ligaments pass between the cranial surface of the ala of the sacrum and the iliac tuberosity of the iliac crest. The sacroiliac parts of the iliolumbar ligaments are mainly orientated in the frontal plane, perpendicularly to the sacroiliac joints. The existence of the sacroiliac parts of the iliolumbar ligaments is in line with the assumption of the iliolumbar ligaments having a direct effect on the stability of the sacroiliac joints. A biomechanical study has been performed to test whether the iliolumbar ligaments are able to restrict sacroiliac joint mobility in embalmed specimens. The focus has been on three separate parts of the iliolumbar ligaments: a) the dorsal bands, connecting the tip of the transverse process of L5 with the iliac tuberosity at the medial part of the iliac crest, b) the ventral bands, connecting the ventrocaudal aspect of the transverse process of L5 with the iliac tuberosity of the iliac crest and c) the sacroiliac parts of the iliolumbar ligaments. Main conclusions of this study are: 1) the iliolumbar ligaments restrict sacroiliac joint sagittal mobility and 2), the ventral bands of the iliolumbar ligaments contribute most to this restriction.

In *Chapter 7* the focus is on the pelvic floor muscles. In the model of selfbracing pelvic floor muscles have the capacity to provide stability to the sacroiliac joints, a necessity for a proper load transfer through the lumbopelvic region. Hampered load transfer through the lumbopelvic region may be related to an altered motor control of these muscles. Indeed, altered motor control of the pelvic floor has been described in patients with pelvic pain. A biomechanical study in embalmed specimens has been performed to gain insight into the effect of tension in the pelvic floor muscles on stability of the pelvis. Conclusions of this study are that, in females, pelvic floor muscles have the capacity to increase stiffness of the pelvic ring and hence stabilise the pelvic ring. In addition, these muscles can generate a counternutation of the sacrum in both sexes. So, pelvic floor muscles can play a role in human locomotion and posture. The findings of this study resulted in the hypothesis that low back pain patients with impaired lumbopelvic stability may increase the activity level of the pelvic floor muscles continuously, in order to stabilise the sacroiliac joints. There is a drawback, this continuously increased activity level of the pelvic floor muscles can alter the motor control and the reflexes of these muscles. This may lead to urine incontinence and voiding dysfunctions.

In *Chapter 8* attention is paid to a multi-center patient survey. Aim of this cross-sectional study was to assess the associations between pregnancy related low back pain and pelvic floor disorder complaints. Furthermore, the activity level of the pelvic floor muscles in these low back pain patients relative to healthy controls has been/is tested. Results of the study show that in 52% of all patients participating in the study a combination was present of pelvic floor disorder on one hand and low back pain complaints on the other. Of the subjects with pelvic floor disorder complaints 86% stated that the complaints started with low back pain and/or pelvic pain *prior* to their pelvic floor complaints. Symptoms of pelvic floor disorders, such as incontinence of urine, voiding dysfunction and sexual complaints occurred significantly more in the low back pain group compared to healthy controls, if not adjusted for age. After adjustment of age no significant differences in the presence of all tested pelvic floor disorder complaints between patients with low back and pelvic pain on one hand and healthy controls on the other could be demonstrated. Especially stress incontinence and sexual complaints occurred more frequently in pregnancy related low back pain patients with a negative active straight leg raise test in comparison to women with a positive test. The active straight leg raise test is advocated as a test for the quality of load transfer through the lumbopelvic region. It is hypothesized that these women induce the symptoms by a continuously elevated activity level in their pelvic floor muscles in an effort to stabilise the pelvic ring. This increased activity of pelvic floor muscles was illustrated by a) a significantly higher rest tone, b) a shorter endurance time and c) a paradoxical pushing reflex in the low back pain patient group relative to the healthy controls. Conclusions of this study are that

clinicians should be aware of a co-existence of pelvic floor disorder complaints and low back and pelvic pain in patients. This co-existence of complaints is influenced by age of the patient. In assessing and treating patients with a combination of low back pain and pelvic floor disorders complaints the clinician should focus on *both* complaints. Furthermore, clinicians should be aware that certain pregnancy related low back pain and pelvic pain patients compensate for compromised pelvic stability by increased activity of the pelvic floor muscles possibly leading to pelvic floor disorder complaints. A negative score on the active straight leg raise test in patients with peripartum low back and pelvic pain can be an indication for this increased activity. In these patients relaxation and motor control exercises of the pelvic floor muscles could be effective.

The overall conclusions and implications of this study are discussed in *Chapter 9* of this study. This thesis focuses on the contribution of several ligaments and muscles to the stability of the sacroiliac joints, according to the model of selfbracing. This model can be very useful in assessment and treatment of low back pain and pelvic pain patients. Still, this anatomical and biomechanical model gives insight into only a part of the complexity of LBP. Clinicians should be aware that LBP and pelvic pain is a biopsychosocial problem.

amenvatting

Samenvatting

Om inzicht te krijgen in het ontstaan en herstel van lage rugklachten richt dit proefschrift zich op anatomische en biomechanische aspecten van lage rug en bekken. Dit inzicht is met name relevant voor clinici die patiënten met aspecifieke lage rugpijn onderzoeken en behandelen. De reden om de aandacht te vestigen op anatomische en biomechanische aspecten van lage rug en bekken ligt in het vermoeden dat verlies van stabiliteit in lage rug en bekken, met name van de sacroiliacale gewrichten, kan leiden tot verstoorde krachtsoverdracht in deze regio. Dit kan pijnklachten tot gevolg hebben zoals aspecifieke lage rugpijn. Kennis van de invloed van lage rug- en bekkenstructuren op de stabiliteit van de sacroiliacale gewrichten kan dus belangrijk zijn voor het behandelen van patiënten met aspecifieke lage rugpijn als gevolg van verstoorde stabiliteit van lage rug en bekken.

In *hoofdstuk 2* wordt een anatomisch, biomechanisch model geïntroduceerd: het 'selfbracing' mechanisme van de sacroiliacale gewrichten. Het model is gebaseerd op de visie dat tijdens belasting van het houdings- en bewegingsapparaat specifieke ligamenten en spieren nodig zijn om de stabiliteit van de sacroiliacale gewrichten te waarborgen. Deze stabiliteit is een vereiste voor een optimale krachtsoverdracht van lage rug naar bekken en onderste extremiteiten. Stabiliteit van de sacroiliacale gewrichten berust op twee principes: a) vormsluiting, door het passend sluiten van richels en groeven voorkomend op de gewrichtsoppervlakken en b) krachtsluiting, door compressie geleverd door spieren en ligamenten (kracht sluiting). Verminderde kracht in bepaalde spieren en niet optimale spanning in banden rondom het bekken kan deze compressie doen afnemen en de krachtsoverdracht negatief beïnvloeden. Verandering in belasting van structuren rondom het bekkengewricht kan hiervan het gevolg zijn hetgeen tot pijnklachten kan leiden. Bij behandeling van deze klachten zijn stabilisatietechnieken en specifieke spierversterkende oefeningen geïndiceerd.

In *hoofdstuk 3* wordt een anatomisch, biomechanisch onderzoek naar de bovenste en onderste lamina van de oppervlakkige laag van de fascia thoracolumbalis beschreven. Het doel van dit onderzoek was inzicht te krijgen in de rol die deze structuur zou kunnen spelen in de krachtsoverdracht tussen romp, bekken, benen en armen. Eerst heeft een anatomisch onderzoek plaats gevonden, daar de relatie tussen de oppervlakkige laag van de fascia thoracolumbalis en andere lager gelegen structuren nog niet bestudeerd was. Vervolgens heeft een biomechanisch onderzoek plaatsgevonden waarbij krachten van verscheidene spieren werden nagebootst en de verplaatsing in de fascia thoracolumbalis werd gemeten. Geconcludeerd wordt dat een nauwe relatie bestaat tussen enerzijds spieren die anatomisch beschreven als heup-, bekken-, en beenspieren en spieren behorend bij arm en romp anderzijds. Hierdoor kan effectieve krachtsoverdracht plaatsvinden tussen wervelkolom, bekken, armen en benen. Voorgesteld wordt dat met name het gelijktijdig contraheren van de grote bilspier en de contralaterale brede rugspier de lumbale wervelkolom en de sacroiliacale gewrichten stabiliseren.

Hoofdstuk 4 richt de aandacht op de anatomie en de biomechanica van de lange dorsale sacroiliacale banden. Deze banden zijn interessant daar menig patiënt met aspecifieke lage rugklachten en peripartum bekkenpijn, pijn ervaart direct onder één of beide spinae iliacae posteriores superiores: een aanhechtingspunt van deze banden. Gegevens over de functie en de klinische betekenis van deze banden zijn niet bekend. Conclusies van deze studie zijn dat de lange dorsale sacroiliacale banden een directe verbinding hebben met de musculi erector spinae, de oppervlakkige laag van de fascia thoracolumbalis en met een specifiek gedeelte van de sacrotuberale band. Functioneel gezien zijn de lange dorsale sacroiliacale banden een belangrijke schakel tussen benen, wervelkolom en armen. De banden komen op spanning tijdens achteroverkanteling (contranutatie) van het sacrum en ontspannen tijdens vooroverkanteling (nutatie) van het sacrum. Pijn in de regio van deze banden kan wijzen op een aanhoudende contranutatie van het sacrum. Tijdens het

onderzoek van patiënten met aspecifieke lage rugklachten mogen de lange dorsale sacroiliacale banden niet genegeerd worden.

Hoofdstuk 5 en 6 hebben de iliolumbale banden tot onderwerp. Deze banden worden in de literatuur beschouwd als structuren die de belangrijkste bijdrage leveren aan de stabiliteit van de lumbosacrale overgang. Daarnaast zouden deze banden een belangrijke rol kunnen spelen bij de stabiliteit van de sacroiliacale gewrichten. De iliolumbale banden worden beschreven als een belangrijke bron van chronische lage rugklachten. Gegevens over de functionele relatie tussen de iliolumbale banden en de sacroiliacale gewrichten zijn niet bekend. Om inzicht te verwerven in het mogelijk stabiliserend effect van deze banden op de sacroiliacale gewrichten is zowel een anatomisch (hoofdstuk 5) als een biomechanisch onderzoek (hoofdstuk 6) uitgevoerd. Specifieke dissectie toonde het bestaan aan van een speciaal onderdeel van de iliolumbale banden gelegen tussen ilium en sacrum: een sacroiliacaal gedeelte. Het sacroilicaal gedeelte van de iliolumbale banden is met name georiënteerd in het frontale vlak, loodrecht op de sacroiliacale gewrichten. Het bestaan van een sacroiliacaal gedeelte van de iliolumbale banden steunt de gedachte dat de iliolumbale banden een directe invloed hebben op het functioneren van de sacroiliacale gewrichten. Een biomechanisch in vitro onderzoek is uitgevoerd om na te gaan of de iliolumbale banden de beweeglijkheid van de sacroiliacale gewrichten kunnen beperken. Het onderzoek heeft zich toegespitst op drie onderdelen van de iliolumbale banden: a) de dorsale banden, welke het uiterste puntje van beide processus transversi van L5 verbinden met de tuber iliaca van de crista iliaca, b) de ventrale banden, welke het voorste en onderste gedeelte van de processus transversi van L5 verbinden met de tuber iliaca van de crista iliaca en c) het sacroiliacale gedeelte van de iliolumbale banden. Belangrijkste conclusies van deze studie zijn: 1) de iliolumbale banden verminderen de beweeglijkheid van de sacroiliacale gewrichten in het sagittale vlak en 2) de ventrale banden leveren hiertoe de grootste bijdrage.

In *hoofdstuk 7* wordt de aandacht gericht op de bekkenbodemspieren. In het 'selfbracing' model van de sacroiliacale gewrichten kunnen de bekkenbodemspieren de sacroiliacale gewrichten stabiliseren. Dit is noodzakelijk is voor een optimale krachtsoverdracht tussen lage rug en bekken. Een verstoorde krachtsoverdracht kan leiden tot een verandering in motoriek van deze spieren. Inderdaad is bij patiënten met lage rug- en bekkenpijn een verandering in de motoriek van bekkenbodemspieren aangetoond. Om inzicht te krijgen in het stabiliserend effect van de bekkenbodemspieren op de sacroiliacale gewrichten is een biomechanisch in vitro onderzoek uitgevoerd. Conclusies van deze studie zijn dat de bekkenbodemspieren de stijfheid van de vrouwelijke bekkengewrichten kunnen vergroten en de bekkenring kunnen stabiliseren. Daarnaast kunnen deze spieren, zowel bij mannen als bij vrouwen, het sacrum achterover doen kantelen. Bekkenbodemspieren zijn dus belangrijk voor het houdings- en bewegingsapparaat. De bevindingen van deze studie staven de gedachte dat patiënten met lage rug- en bekkenpijn met klachten op basis van verstoorde stabiliteit van de lage rug en bekken het verlies aan stabiliteit kunnen compenseren door de spieractiviteit van de bekkenbodemspieren langdurig te verhogen. Dit is niet zonder gevaar want door langdurig verhoogde spieractiviteit veranderen de motoriek en de reflexen van deze spieren. Dit zou kunnen leiden tot bekkenbodemklachten zoals incontinentie voor urine en plasproblemen.

In *hoofdstuk 8* wordt een patiëntenonderzoek beschreven, uitgevoerd bij diverse centra. Doel van deze cross-sectionele studie is het verband vast te stellen tussen zwangerschap gerelateerde lage rug- en bekkenpijn aan de ene hand en bekkenbodemklachten aan de andere. In deze studie wordt ook de spieractiviteit van de bekkenbodemspieren gemeten en vergeleken met gezonde individuen. De studie toont aan dat in 52% van de patiënten die deelnamen aan de studie een combinatie van zowel bekkenbodemklachten als lage rug- en bekkenpijn voorkomt. Daarnaast geeft 86% van de patiënten met bekkenbodemklachten aan dat hun huidige bekkenbodemklachten pas begonnen na pijnklachten in rug en/of bekken. Bekkenbodemklachten als gevolg van bekkenbodem disfunctie (zoals urine incontinentie, plasproblemen en problemen tijdens het vrijen) komen significant vaker voor in de groep patiënten met lage rug- en bekkenpijn dan bij

de controle groep. Deze uitkomst wordt sterk beïnvloed door leeftijd van de patiënt. Na het corrigeren voor leeftijd zijn er geen significante verschillen aantoonbaar in de aanwezigheid van bekkenbodemklachten tussen de gezonde populatie enerzijds en de patiënten met lage rug- en bekkenpijn anderzijds. Verder toont dit onderzoek aan dat stressincontinentie en klachten tijdens het vrijen met name voorkomen bij lage rug- en bekkenpijn patiënten die negatief scoren op de actieve beenheftest, ongeacht de leeftijd van de patiënt. De actieve beenheftest wordt beschouwd als een test voor de kwaliteit van krachtsoverdracht in de lage rug- en bekkenregio. Mogelijk ontwikkelen vrouwen met lage rug- en bekkenpijn bekkenbodemklachten als gevolg van langdurig verhoogde spieractiviteit van de bekkenbodemspieren in een poging de stabiliteit van de bekkenring te waarborgen. Aanwijzingen voor deze verhoogde spieractiviteit in deze patiëntengroep blijkt uit a) verhoging van de rusttonus van de bekkenbodemspieren, b) afname van het uithoudingsvermogen van deze spieren en c) een paradoxaal persreflex.

Conclusie van deze studie is dat clinici zich moeten realiseren dat bij patiënten een combinatie van lage rug- en bekkenpijn aan de ene hand en bekkenbodemklachten aan de andere kunnen voorkomen. Dit gezamenlijk voorkomen van beide klachten wordt beïnvloed door de leeftijd van de patiënt. Indien beide klachten gezamenlijk voorkomen zal de clinicus zich moeten richten op *beide* klachten. Daarnaast zouden clinici zich ervan bewust moeten zijn dat sommige patiënten met zwangerschapsgerelateerde lage rug- en bekkenpijn het verlies van stabiliteit van het sacroiliacale gewricht proberen te compenseren door een toename van activiteit van de bekkenbodemspieren, waardoor mogelijk bekkenbodemklachten kunnen ontstaan. Een negatieve score op de actieve beenheftest kan hiervoor een aanwijzing zijn. Ontspanningsoefeningen van de bekkenbodem en oefeningen gericht op controle van de motoriek kunnen voor deze patiënten zinvol zijn.

In *hoofdstuk 9* zijn de conclusies en implicaties van dit proefschrift samengevat en bediscussieerd. Dit proefschrift richt zich met name op de rol van verschillende structuren aan stabiliteit van het bekken. Hierbij is uitgegaan van het ‘selbracing’ model van de sacroiliacale gewrichten als achterliggend model. Uitkomsten van deze studie zullen met name bruikbaar zijn voor clinici die patiënten met lage rug- en bekkenpijn onderzoeken en behandelen. Toch is het zinvol stil te staan bij het gegeven dat het ‘selfbracing’ model slechts een beperkte bijdrage levert aan het begrip over het ontstaan en herstel van een complex probleem als lage rug- en bekkenklachten. Clinici dienen zich goed bewust te zijn dat lage rug- en bekkenklachten een biopsychosociaal probleem betreft.

Dankwoord

Dankwoord

In Nederland zijn we niet gewend een klopje op iemands schouder te geven. Vreemd eigenlijk want waardering van een medemens heeft iedereen juist zo nodig. Wellicht is dat ook de reden dat het dankwoord van alle hoofdstukken in een proefschrift vaak het allereerst wordt gelezen. Ik wil dan ook graag van deze gelegenheid gebruik maken om een ieder een flinke klop op de schouder te geven. Vele mensen hebben mij de afgelopen 10 jaar geholpen met het uitvoeren van alle onderzoeken en het schrijven van het proefschrift. Zeker als 'vrije onderzoeker' en 'parttime promovenda' ben ik afhankelijk geweest van de hulp en steun van velen.

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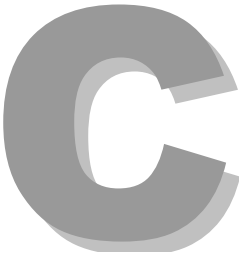

urriculum vitae

Curriculum Vitae

Annelies Pool was born in The Hague on September 17th 1965, the Netherlands. After attending HAVO at Christelijk lyceum Dr. W.A. Visser 't Hooft' in Leiden she graduated at the Academy of Physical Therapy in The Haque in 1987. In 1991 she finished the study for manipulative therapist at 'Stichting School voor Manuele Therapie' in Utrecht. Since 1987 she works as a physical therapist and later also as a manual therapist in the Medical Center Impact in Zoetermeer.

In 1992 she became a member of the Researchgroup Musculoskeletal System, founded by three departments, viz. the Department of Biomedical Physics and Technology under leadership of Prof. Dr. Ir. CJ Snijders, the Department of Rehabilitation Medicine under leadership of Prof. Dr. H. Stam and the Department of Anatomy represented by Dr. A. Vleeming and Dr. R. Stoeckart. In the auspices of the Department of Anatomy she performed studies on the thoracolumbar fascia and the long dorsal sacroiliac ligament. From 1996 till 2000 she worked at the 'Spine and Joint Centre' in Rotterdam, a rehabilitation center with special focus on peripartum pelvic pain patients. She was partly responsible for the development of therapy protocols and patient information folders. Meanwhile she started a PhD study at both the Department of Biomedical Physics and Technology and Department of Neuroscience under guidance of Prof. Dr. Ir. CJ Snijders and Dr. R. Stoeckart. This resulted in several studies on the iliolumbar ligament and the pelvic floor. To fill the gap between the education for physical therapist and an academic education she started to study Health Psychology at the Open University in Heerlen in 1999. In 2000 she became a BSc in Health Psychology and nowadays she is heading for her teaching practice and final thesis. In 2002 she started a patient survey in cooperation with Dr. M. Vierhout and M. Slieker of the Center of Pelvic Floor Reconstructive Surgery of the Erasmus Medical Center in Rotterdam. This resulted in an article on the association of pelvic floor disorders and pregnancy related low back and pelvic pain.

Currently she is working part time for the Department of Biomedical Physics and Technology in combination with her work as physical and manual therapist at the Medical Center Impact. She is lecturer at the 'Stichting School voor Manuele Therapie' in Utrecht, the Dutch Paramedic Institute and the Academy of Physical Therapy ' Hogeschool' in Leiden (Postgraduate courses). She is married with Jan Pool and mother of Lisanne and Jesper.

List of publications

List of publications

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