Laxity Measurements of the Sacroiliac Joints in Women with Pregnancy-Related Pelvic Pain

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Laxiteitsmetingen in de sacro-iliacale gewrichten
bij vrouwen met
zwangerschap-gerelateerde bekkenpijn

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Contents

Voor Joost en mijn ouders

Chapter 1

General introduction and aims of this thesis

1. Features of pregnancy-related pelvic pain

1.1 Introduction

Although in the prime of life and embarking on an exciting period of pregnancy and childbirth, unfortunately many women will be facing a difficult time. The unpleasant truth is that many pregnant women suffer from pelvic pain at some stage of their pregnancy. In about one-third of these women the severity of the pain is such that it impedes their normal activities. Although in most cases pelvic pain resolves after childbirth, some women continue to have problems after delivery; in some cases pelvic pain may even lead to disability. Due to inherent difficulties related to classification, terminology and lack of 'objective' criteria, pregnancy-related pelvic pain (PRPP) is frequently considered to be a 'non-disease'. The purpose of this chapter is therefore, to describe and evaluate the features of PRPP.

1.2 History

There is a general impression that PRPP has increased during the last decades, but as early as 1870 Snelling wrote that "relaxation of the pelvic articulations becomes apparent suddenly after parturition, or gradually during pregnancy, permitting a degree of mobility which effectual hinders locomotion and gives rise to the most distressing and alarming sensations".[67]

The softening process in the symphysis and the sacroiliac joints (SIJs) during pregnancy were of relatively great interest in the 19th century and several studies showed that the pelvic joints undergo characteristic changes that are physiological in pregnancy. The clinical side of the problem was less well represented. The observations of Abramson *et al.* in 1934 and Genell in 1949 were exceptional, because they elucidated essential clinical aspects of PRPP. [1, 22]

Abramson's group described the symptoms of 33 women with pelvic instability and made a distinction between symptoms related to the pubic joint alone, to the SIJs alone or to a combination of both. The pubic symptoms were pain in the symphyseal region with radiation to the inner side of the thighs, pain provocation by changing position, sensation of movement of the bones and difficulty in normal locomotion. The sacroiliac symptoms consisted of backache and localised pain in one or both SIJs. Frequently noted were a waddling gait, a positive Trendelenburg's sign (when the patient stands on one leg there is inability to hold the pelvis in the horizontal plane and the opposite buttock drops) and tenderness on the pelvic joints. In their study they used the width of the pubic symphysis as an index of relaxation of the pelvic joints but they found no correlation between the amount of relaxation of the joints and the severity of the symptoms. [1]

Genell's investigation, which was based on a series of 97 women, accurately described the clinical symptoms and signs of PRPP. He introduced the term "pelvic insufficiency" which was characterised by difficulties in performing various movements (turning over in bed, walking up and down stairs, and rising from deep

chairs), pain and tenderness of the pelvic joints, a positive Trendelenburg's sign and impairment of locomotion function (waddling gait). [22]
Farbrot described a correlation between pregnancy-related low back pain and the inclination of the sacrum. Measurements of the static sacral angle showed that pregnant women with an angle of over 55° developed pain, while pregnant women with an angle of 55° or less remained free. He indicated that pregnancy-related low back pain might be reduced or relieved by maintaining the tone of the abdominal musculature during and after pregnancy. [18]
Berezin concluded in 1954 that the symptoms (pain and difficulty in walking) were to a certain extent due to impaired stability of the pubic symphysis and SIJs, but that the instability varied widely with the severity of the symptoms and that pelvic insufficiency could not be defined as a condition in which the instability has exceeded a certain limit. [7]
In a follow-up of 137 patients with chronic pelvic relaxation Walde observed that secondary back pain was common in women with an unstable pelvis. [69]

1.3 Nomenclature

Different terms such as 'sacroiliac joint (SIJ) dysfunction', [6] 'symptom-giving pelvic girdle relaxation', [15, 34] 'pelvic insufficiency', [22] 'posterior pelvic pain', [46, 57] 'pelvic girdle syndrome', [3] and 'peripartum pelvic pain' [43] have been suggested as identifying labels.
The diagnosis of 'SIJ dysfunction' was made if there was pain at provocation testing and/or a disturbed motion of the SIJ at functional testing. [6]
The term 'symptom-giving pelvic girdle relaxation' was introduced by the Norwegian nomenclature committee to describe the ligament relaxation that causes considerable pain and/or pelvic instability (so that daily function is impaired). [15, 34]
'Pelvic joint syndrome' describes a similar condition in relation to one or more of the pelvic joints only outside pregnancy and puerperium. [15]
'Pelvic insufficiency' is a condition arising in the latter half of pregnancy which manifests itself as a deficient firmness in the pelvic joints causing the production of secondary muscular reactions in the form of contractions. [22]
Östgaard *et al.* have shown that for a successful treatment of back pain during pregnancy it is crucial to distinguish posterior pelvic pain from the lumbar back pain. [57] Women with 'posterior pelvic pain' experience time- and weight-bearing related pain in the gluteal area distal and lateral to the L5-S1 region for the first time during a pregnancy. They have pain-free intervals, a free range of motion in the spine, pain when turning in bed and finally a positive result on the posterior pelvic pain provocation test. Mens *et al.* defined 'posterior pelvic pain' as pain in the posterior part of the pelvis that started during pregnancy or within 3 weeks after delivery, without any indication for a specific disease to explain the disorder. [46]

To be classified, as 'pelvic girdle syndrome' patients must have daily pain in all three pelvic joints, confirmed with positive pain provoked by the tests from the equivalent joints. [3]
'Peripartum pelvic pain' can be described as pain in the pelvic region (with or without irradiation) that started during pregnancy or within the first 3 weeks after delivery and for which no clear diagnosis is available to explain the symptoms. [43]
Furthermore, several studies use derivations of the above-mentioned terms and do not define their patient groups clearly. The difficulties inherent to classification, diagnosis and treatment are partly due to the various terms which describe a heterogeneous, not to say miscellaneous, group of patients. [27]

1.4 Prevalence

Studies from various parts of the world have reported nine-month prevalence rates of PRPP ranging between 25% and 60%. [6, 9, 19, 27, 30, 40, 50, 53, 67] In 6-15% the pain during pregnancy is considered to be severe, interfering with daily life activities. [6, 9, 19, 27, 40] Although PRPP usually disappears gradually after delivery, a small percentage (2-9%) has persistent pelvic pain more than 6 months after childbirth. [4, 30, 34, 54] In women with previous PRPP the recurrence rate in subsequent pregnancies is estimated to be 41-71%. [54, 59] In retrospective studies, 10-28% of women with chronic low back pain refers the onset of back pain to the pregnancy. [67]

Differences in prevalence may be explained in part by the different population samples and whether the studies were prospective or retrospective. [34, 67] In addition, social acceptance of PRPP and differences in the possibility of receiving sickness benefits may also play a part. [34]

1.5 Signs and symptoms of PRPP

Pregnancy-related pelvic pain is characterised by pain from the posterior pelvis and/or from the pubic symphysis with or without radiation to the groins, thighs, buttocks and/or os coccygis, and may occur simultaneously with low back pain. [19, 22, 30, 42, 58]

In a study by Hansen et al. 227 women with PRPP described the pain most often as shooting pain, but a feeling of oppression, a sharp twinge or a dull pain were also frequently reported. [25] Unfortunately, because the pain frequently changes its location and severity (sometimes even disappears), the patient may become confused and uncertain. PRPP causes considerable disability in performing daily activities, in particular turning in bed, walking, lifting, standing, climbing stairs, forward bending, getting up from a chair sitting, sexual intercourse and straddle of the legs. [19, 23, 25, 30, 43, 53]

Many women experience pain at the beginning of an activity but generally can do what they used to do, only for a shorter period of time. [58] If they overdo certain activities the pain will be worse the following day. [23, 58] According to both Hansen *et al.* and Kristiansson *et al.*, the restriction in daily activities is related to the intensity of pain; [25, 30] increasing pain increases these difficulties. Frequently mentioned are an increase of pain just before menstruation, with a full bladder, and when withholding evacuation. [23, 43, 54]
A typical feature is the so-called 'waddling gait'. [16, 22, 23, 43] During walking the body leans over to the leg where the body weight is on. There is no decreased range of motion in the spine. [58] On the contrary, these women can often easily reach the floor with straight knees. [58]

1.6 Factors associated with PRPP

Several studies show that low back pain before pregnancy and during previous pregnancy are two factors strongly associated with an increased risk to develop PRPP. [6, 11, 26, 34, 40, 42, 43, 50, 52] The number of prior pregnancies has been proposed as a risk factor, but the results are conflicting. [6, 19, 40, 42, 50, 52, 67] Being multiparous does not increase the risk of getting PRPP, [34] but more back pain-related disability for a longer period is found in parous women with PRPP compared to nulliparous women with PRPP. [19, 52] Higher incidences of PRPP have been found in women who are exposed to more strenuous physical work such as repetitive lifting, twisting and bending. [6, 50, 52] Other factors associated with PRPP were lack of exercise, uncomfortable working conditions and back pain in relation to menstruation. [34, 40, 43, 52, 54] The use of oral contraceptives, height, weight, weight gain of the mother and the weight of the baby were, in most studies, not found to be risk factors in PRPP. [19, 40, 42, 50, 51]

1.7 Pathophysiology

1.7.1 Hormonal influence of relaxin

In 1926 it was already known that a hormone (later known as relaxin) was responsible for promotion of ligament relaxation in guinea pigs; [28] however, knowledge on the role of relaxin in humans is still limited. The primary source of circulating relaxin is considered to be the corpus luteum, but may also be produced by the decidua and the basal plate of the placenta. [39] Relaxin is believed to promote cervical ripening at the onset of parturition and to remodel pelvic connective tissue, leading to greater mobility of pelvic joints and widening of the symphysis pubis. [38] The circulating levels of relaxin rise during early pregnancy, then decline during weeks 14-22 and are relatively constant from week 24 of gestation onwards. [5, 31, 33, 61] MacLennan *et al.* were the first to show a highly significant increase of serum relaxin in pregnant women suffering from severe pelvic pain and excessive joint laxity, compared to a control group of normal pregnancies. [36, 37] It has been

suggested that the increased levels of relaxin in blood could be the cause of PRPP. [36, 37, 39] However, they used porcine relaxin antibody, which has only 50% homology in amino acid sequence with human relaxin. [10] Kristiansson *et al.* also found an association between relaxin concentration and pain in the pelvic area, but there was no relationship to pain intensity or degree of disability. [31] More recent studies, [2, 24, 60, 63] based on human relaxin antibody, showed no correlation at all between relaxin serum levels and severity of symptoms of PRPP. Bjorklund *et al.* carried the analysis one step further by adding degree of symphyseal distention. Serum relaxin levels were not associated with disabling pelvic pain or with the degree of symphyseal distention. [10] It is also possible that pelvic pain might relate to the number of relaxin receptors in the connective tissue of the pelvic joints and other sites, but this could not be assessed with the technology used at the time of their research. [39]

1.7.2 Postural changes associated with pregnancy

Changes in posture due to the increased weight during pregnancy are necessary to maintain balance and may be of significance in the production of PRPP. [17, 19] However, the nature of these changes is still not clearly understood and therefore the relationship between the changed posture and the development of PRPP is also unclear.

During pregnancy the additional abdominal weight increases the flexion moment acting on the spine and hip joints. [47, 55] By shifting the weight of the upper body backwards or by increasing the activity of the trunk and hip extensors, an increased extension moment is created to maintain balance. [19, 47, 55] Furthermore, lengthening of abdominal muscles due to growth of the uterus may reduce the ability of these muscles to maintain good posture. [20] In either case an enlarged lumbar lordosis is adopted.

However, other factors may have the opposite effect on posture. To maintain balance the women can also reduce the flexion moment by decreasing the activity of the iliopsoas muscle. A reduction of the iliopsoas activity results in a flattened lumbar spine. [47, 64] Furthermore, the abdominal muscles can be stretched to such an extent that they can serve as a tight cord pulling their origin at the symphysis pubis upwards, therefore rotating the pelvis posteriorly and causing the lumbar spine to flatten. [47]

Although several studies have shown different postural behaviours during pregnancy, there are few data on the relationship between these behaviours and the development of PRPP. Bullock *et al.* found significant changes in posture during months 5-9 of pregnancy but no significant relationship between back pain and posture in the thoracic, lumbar, and pelvic area during pregnancy. [12] Moore *et al.* found a significant relation between the anterior position of the line of gravity and the degree of PRPP at 34-42 weeks, although the position of the line of gravity did

not change significantly during pregnancy. [47] Furthermore, a large increase in lordosis between 16-24 and 25-33 weeks of pregnancy was associated with a large increase in pain. [47] Östgaard *et al.* found that large sagital and transverse abdominal diameters were only weakly correlated with PRPP. [55] They conclude that a naturally large lumbar lordosis was a risk factor for the development of PRPP, although the lumbar lordosis did not change significantly from the 12th to the 36th week. [55] Franklin *et al.* found an increased lumbar lordosis as women progressed from the first to the last trimester of pregnancy, but this was not related to back pain. [21]

1.7.3 Connective tissue microtrauma

A third possible explanation of pain in the sacroiliac region is connective tissue microtrauma due to exertion of the trunk extensor muscle forces to balance the anterior flexion moment caused by the growing uterus. [55]

1.7.4 Conclusion

None of the reviewed variables adequately explained why certain individuals complain of PRPP whereas others do not. PRPP can not be explained solely by laxity of collagen tissue induced by relaxin or by postural changes due to increased weight. [55] The fact that PRPP often starts when the weight gain by the mother and fetus is insignificant and that the incidence of PRPP does not parallel the weight gain, does not support the theory of postural changes. [12, 19, 51] It is possible that the pathophysiology of pain varies in each trimester. [19] The secretion of relaxin may contribute to pain in the first trimester, whereas weight gain and postural changes cause pain later on. Thus, it appears that several underlying mechanisms, operating singly or simultaneously, may cause PRPP. [19]

1.8 Diagnostic procedures

1.8.1 History

The patient history is perhaps the most useful tool for diagnosing PRPP. Patients should be asked to describe the exact location of the pain, pain onset, daily pattern of pain, pain-provoking activities, and changes in ability to perform daily tasks. Questions on obstetric history, previous back and pelvic problems, social background, sport history and working conditions are also important.

1.8.2 Mobility tests

Assessment of the position and mobility of the pelvic joints by palpation is frequently used to get information on the hyper- or hypomobility of these joints. Several studies have shown that assessment of mobility or position of the pelvic joints by palpation is difficult to perform in an objective manner and that

reproducibility is generally low. [3, 32, 35, 62, 71] Therefore, the use of mobility tests has been dissuaded.

1.8.3 Load transfer test

The active straight leg raise (ASLR) test is a well-documented, reliable, sensitive and specific diagnostic test to assess PRPP. [44, 46] The ASLR test is performed in supine position with straight legs and feet 20 cm apart. The subject has to raise the legs, one after the other, 20 cm above the examination table without bending the knee. The test is considered positive when the woman is unable to raise her leg or when pelvic pain is felt during hip flexion. When there is instability due to a disturbed load transfer from trunk to legs the test is easier to perform with application of a pelvic belt.

1.8.4 Hip abduction and adduction strength test

Testing hip abduction and adduction weakness allows to confirm the diagnosis in case of doubt, and also increases the level of objectivity *(Mens thesis)*. Both strengths can be measured (in newton) with a handheld dynamometer (Microfet®, Hoggan Health Industries Inc., Draper, Utah, USA) in supine position. The test is executed with the feet placed on the couch, and the knees placed at a 90 degrees angle. When measuring abduction strength, the examiner places the dynamometer with his right hand against the lateral aspect of the left knee and holds the right knee by means of his left hand placed against the lateral aspect of the right knee. The patient is asked to spread the legs during 5-7 seconds as forcefully as possible; the examiner holds the knees in position. After 5-7 seconds rest the measurement is repeated two times. When the score of the last measurement is the highest, an extra measurement will be performed, etc. The highest value of all measurements will be used for analysis. In the same position, the device is placed against the medial aspect of the right knee to measure adduction strength. The patient is asked to squeeze the device (and the right hand of the examiner) between the knees. A hip abduction strength of 196 newton and a adduction strength of 129 newton were chosen as cut-off levels to differentiate between patients with PRPP and healthy subjects.

1.8.5 Pain provocation tests

Tests that stress the structure in an attempt to reproduce the patient's symptoms (pain provocation tests) were shown to have a better reliability and reproducibility than mobility tests. [3, 32, 35, 62, 71] Several tests have been described.

- *Posterior pelvic pain provocation (PPPP) test (or the thigh thrust test)* [56]

The PPPP test is performed with the subject in supine position. The examiner gently presses the vertically positioned femur in the direction of the examination

table. The test is considered positive when the subject feels an increase of pain in the gluteal area on the side that was tested.

- *Patrick's fabere test* [3]

Patrick's fabere test is performed in supine position. One leg is flexed, abducted, and rotated laterally out so that the heel rests on the opposite kneecap. In a positive test, the patient experiences pain in the pubic symphysis and/or the SIJs. If the test results in pain on the medial side of the knee and femur or in the inguinal region, this indicates that the hip joint is affected.

- *Menell's test* [3]

Menell's test is performed in supine position. One leg, moved into 30° abduction and 10° flexion in the hip joints, is first pushed into, then pulled out from the pelvis, causing sagittal movement. In a positive test, the patient experiences pain in the pubic symphysis and/or the SIJs.

- *Trendelenburg test* [3]

The standing woman turns her back to the examiner and, standing on one leg, flexes the other at 90° (hip and knee). The test is considered positive for the stance leg if the hip is descending on the flexed side. In a positive test, the patient can experience pain in the pubic symphysis and/or the SIJs.

1.8.6 Supplementary examination

Imaging techniques like X-rays, computerised tomography or magnetic resonance imaging are useful for the diagnosis of impairments causing secondary SIJ instability, such as tumours or cysts. [13] The assessment of (abnormal) mobility in the pelvic joints requires an adequate visualisation and measurement technique. The method mostly used, devised by Chamberlain in 1930, measured vertical mobility in the symphysis pubis by radiographic anterioposterior projection with the patient alternating standing on one leg and the other. [44] Sturesson *et al.* used roentgen stereophotogrammetry with insertion of tantalum balls to examine movements of the SIJs. [66] Since radiography is not suited for repeated examinations during pregnancy, new measurement techniques have been developed. Snijders proposed a non-invasive vibration technique to assess SIJ laxity, which resulted in the introduction of the method of Doppler imaging of vibrations. [13, 14] An ultrasonographic technique for measuring the width of the symphysis pubis seems to allow for at least the same precision as Chamberlain's roentgenological method. [8, 9]

1.8.7 Differential diagnosis

Other disorders may also be associated with posture-dependent pain in the low back and pelvic region. In order to exclude disorders such as spinal-root compression, bursitis trochanterica, tendinitis adductor longus, difference in the

length of the lower extremities, psychological pain and possible involvement of the hip joints, differential diagnostic tests can be made.

1.9 Interventions for preventing and treating PRPP

1.9.1 Treatment of pregnant women with pelvic and/or low back pain

Mantle *et al.* [41] evaluated the prophylactic influence of back care classes offered early in pregnancy. Both treatment (n=85) and control (n=90) groups were offered the normal antenatal classes late in pregnancy, and the treatment group was also offered two one-hour sessions with ergonomic advice adapted to pregnancy. They concluded that back care advice early in pregnancy resulted in less troublesome or less severe backache later in pregnancy.

Thomas *et al.* [68] compared a standard hospital pillow with a specially designed maternity cushion (Ozzlo pillow) for their effects on prevention and alleviation of PRPP at 36-37 weeks of gestation. Patients (n=92) were randomised to two groups sleeping alternately one week with one pillow which supports the abdomen while lying on the side and changing after one week. Use of the Ozzlo pillow led to a greater reduction in backache at night and day than use of an ordinary cushion or pillow.

Östgaard *et al.* [57] investigated a back school education and training program. The control group A (n=145) had no interventions, treatment group B (n=93) was offered a back school education and training program (two 45-min classes before the 20th week of pregnancy about simple anatomy, posture physiology, lifting and working technique, muscle and relaxation training, together with a written summary), and treatment group C (n=124) was offered the same program as group B, but the education was individual and for a longer period (five times 30 min). Furthermore, an individual training program was designed and tape-recorded for each participant with a recommendation to exercise at home three times a week. In addition half of the women in groups B and C were given a pelvic belt. The authors concluded that back school education in combination with a training program can reduce sick leave and pain only in women suffering from low back pain, and that the treatment was not able to prevent back or pelvic pain. A pelvic belt reduced pain at walking in the majority of women with back and pelvic pain, but did not reduce overall pain intensity and sick leave. [57]

Dumas *et al.* [17] investigated the value of exercise classes in the prevention and treatment of PRPP by improving posture. Pregnant volunteers participated in the treatment group (n=27, 78% with moderate or severe PRPP) in one-hour sessions consisting of warm-up, aerobics, callisthenics and relaxation exercises, three classes per week during pregnancy. The control group (n=38, 81% with moderate or severe PRPP) remained sedentary. The authors concluded that exercises classes did not prevent or reduce PRPP during pregnancy and after childbirth.

Noren *et al.* [49] investigated the impact of an individual-based treatment on pregnant women's sick leave. The women were examined and classified according to their symptoms. The treatment group (n=54; 9 with lumbar back pain, 25 with posterior pelvic pain, and 20 with combined pain) was offered individual exercise, information, ergonomic advice and a pelvic belt. The control group (n=81) received no treatment. The authors concluded that an accessible, individual physiotherapy program based on information and ergonomic advice was effective in reducing sick leave during pregnancy.

Nilsson-Wikmar *et al.* [48] compared three different treatment programs in pregnant women with pelvic pain. Group 1 (n=40) was provided a non-elastic belt and received information about their condition. The other two groups received the same as group 1, but group 2 (n=41) also had a home training and stretching program, and group 3 (n=37) also had medical training therapy using special training equipment to improve strength and posture. No significant differences were found between the three groups with respect to pain intensity and functional activities at baseline, at week 38 of gestation or at three months postpartum. The authors concluded that the non-elastic belt and information about the condition seems to be important regarding reduction of pain intensity and the ability to accomplish the different functional activities.

Kihlstrand *et al.* [29] investigated whether water-gymnastics during pregnancy may reduce the intensity of low back pain and the number of days on sick leave. The 129 women in the treatment group participated in water-gymnastics in hot water one-hour weekly (physical training lasted 30 min followed by 30 min of relaxation, all in water and to music adjusted to the different exercises and to relaxation) during the second half of pregnancy. The 129 pregnant women in the control group had no treatment. The results showed that at week 31 and from weeks 33-38, significantly fewer women in the treatment group suffered from pain. Significantly more women in the control group were on sick leave because of back/low back pain at some period during pregnancy. There were no observed negative side-effects of water-gymnastics.

Wedenberg *et al.* [70] compared the effects of acupuncture with physiotherapy in pregnant women with LBP. The treatment group (n=28) had ten 30 min individual acupuncture sessions during one month. The control group (n=18) had ten physiotherapy sessions lasting 50 min spread over 6-8 weeks, mainly group treatment (with information, ADL instruction, individualised exercises and water-gymnastics) and optional treatment (e.g. belts, warmth, massage, and soft-tissue mobilisation) was offered. Improvements in pain and disability were observed in both groups with results being significantly better in the acupuncture group than in the control group. However, these results need to be treated with caution because they may demonstrate a benefit of individual treatment over group treatment rather

than any true effect of acupuncture. Furthermore, the study examined only very short-term effects of treatment.

1.9.2 Postpartum treatment of women with persistent pelvic pain

Mens *et al.* [45] evaluated the effect of training of the diagonal trunk muscles in women with persistent pelvic pain 6 weeks to 6 months after delivery. All participants were given a 30-min videotape which contained information about the possible cause of pelvic pain, prognosis, therapeutic possibilities, ergonomic advice, how to behave if activities caused pain, the use of a non-elastic pelvic belt, and exercises according to the specific group. The last part of the videotape differed, depending on group assignment. The treatment group (n=16) received instructions on training the diagonal trunk muscles. Control group 1 (n=14) received instructions on light exercises of the longitudinal trunk muscles; control group 2 (n=14) instructions to gradually increase activities of daily living and to refrain from exercises. The treatment period lasted eight weeks and no individual training or instructions were given. The exercises were based on the current opinions in sport training that heavy exercises are necessary to gain muscle strength and endurance. The results showed no differences between the groups in pain, fatigue, Nottingham Health Profile, PPPP test, radiographic examination and global impression of improvement on a three point Likert scale. The authors concluded that training of the diagonal trunk muscle systems, without individual coaching, as done in this study, was not more effective than low graded training of the longitudinal trunk muscle systems or no exercises.

Stuge *et al.* [65] evaluated whether a specific stabilising exercise program reduced the women's pain, function and quality of life after the treatment period. Group 1 (n=40) received mainly an exercise program. The program was based on specific training of m. transversus abdominis with co-activation of the lumbar multifidus, training of m. gluteus maximus, m. erector spinae and the oblique abdominal muscles. Activation of the mentioned muscles was also incorporated into static postures and functional tasks in daily life, together with ergonomic advice. When needed, mobilisation was executed and self-mobilisation instructions. The women had to exercise for 30-60 min three days a week and the exercise period lasted for 20 weeks. Individual guidance by the physiotherapist and adjustments of the exercise program was performed once a week or every second week. Exercising was performed mainly at home. Group 2 (n=41) received different physiotherapy treatment modalities (ergonomics, massage, mobilisation, manual therapy, electrotherapy) as recommended by the physiotherapist, based on an individual examination. Stabilising exercises were not instructed. Type and amount of therapy were registered. The women received treatment approximately once a week or when needed. The main outcome measures registered were pain and functional status. Preliminary results indicated that a specific stabilising exercise treatment

program, when integrated functionally, was effective in reducing pain and improving functional status in women with PRPP after pregnancy.

1.9.3 Conclusions

Due to the small number of well-conducted randomised controlled trials in this area, no substantiated conclusions can be drawn. Some precautions related to clinical implications should be addressed. The results of the reviewed studies show that giving information about PRPP in combination with ergonomic advice and a pelvic belt is beneficial regarding reduction of pain and the ability to accomplish different functional activities. [41, 48, 49, 57] An Ozzlo pillow supporting the abdomen at night late in pregnancy seems to reduce back pain during day and night. [68] It seems highly likely that water gymnastics during the last half of pregnancy can reduce pain and sick leave during the last trimester. [29] It is not clear whether acupuncture or physiotherapy has any real benefit for back pain in pregnancy. There is some measurable reduction in pain with both methods. However, that acupuncture led to a greater reduction in pain may be a reflection of the personal care given by the acupuncturist compared with group therapy delivered by the physiotherapist. [70] Most of the investigated exercises showed no additional value in the treatment of PRPP during pregnancy or during the first 6 months after childbirth. [17, 45, 57] Preliminary results of the study by Stuge *et al.* [65] indicate that a specific stabilising exercise treatment program, when integrated functionally, is effective in reducing pain and improving functional status in women with PRPP after pregnancy.

2. Aims of the study

The review of the origin, the diagnosis and treatment of pregnancy-related pelvic pain led to the conclusion that laxity of the SIJs may play a central role in the understanding of this syndrome. The department of Biomedical Physics and Technology and the department of Rehabilitation have studied the biomechanical properties of the pelvic joints, in particular the SIJs for many years. Because no instrumented method was available, Snijders proposed a new vibration method for the in vivo assessment of SIJ laxity. This resulted in the method of Doppler imaging of vibrations (DIV), which runs as a continuous thread throughout this thesis. [13, 14]

Chapter 2 describes the intra- and inter-tester reliability indexes of DIV in SIJ laxity measurements performed by several testers, including one experienced tester as well as inexperienced testers. The contribution of various sources of measurement error associated with the measurement design is also addressed.

Chapter 3 presents the pregnancy part of a longitudinal study on 163 subjects with and without PRPP. This study was designed to investigate the association between PRPP and SIJ laxity at 36 weeks of pregnancy.

Chapter 4 describes the postpartum part of the study presented in chapter 3. The aims of this study were to describe the association between PRPP and SIJ laxity 8 weeks after childbirth and to determine to what extent asymmetric laxity of the SIJs during pregnancy has predictive power with regard to postpartum PRPP.
Chapter 5 presents a study designed to establish the influence of a pelvic belt on SIJ laxity. The belt was tested at two positions (low: at the level of the pubic symphysis, and high: just below the anterior superior iliac spines) and at two tensions (50 and 100 N) in ten healthy subjects.
Finally, the study in chapter 6 investigates the influence of a pelvic belt at low and high position on SIJ laxity and its effect on the active straight leg raise (ASLR) test in 25 women with PRPP.

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Chapter 2

Reliabilty of sacroiliac joint laxity measurement with Doppler imaging of vibrations

Abstract

We developed a noninvasive technique, referred to as Doppler imaging of vibrations (DIV), to measure laxity of the sacroiliac joint (SIJ). The purpose of this study was to examine the reliability of SIJ laxity measurements. A total of 10 healthy women (mean 29.9 ± 6 years old) participated in the study. At both sides, SIJ laxity was measured with DIV in threshold units (TU). Reliability and measurement error were assessed from repeated measurements by five testers on two occasions as well as by one experienced tester. Intraclass correlation coefficients ranged from 0.53 to 0.80 for all five testers, and from 0.75 to 0.89 for the one experienced tester. Only changes larger than 1.94 to 3.60 TU (any tester) or 1.45 to 2.38 TU (experienced tester) could be confidently detected. DIV is a reliable technique for SIJ laxity measurements in healthy subjects, when performed by an experienced tester.

Introduction

In the last two decades, the sacroiliac joint (SIJ) has received considerable attention as a potential source of low back and pelvic pain. [7] From this perspective, it is relevant to determine the mechanical properties of the SIJs, particularly the assessment of hyper- and hypomobility or laxity. The interest in the mechanics of the SIJ reinforces the need for a reliable measurement to test SIJ laxity. Previous studies have shown that existing clinical tests to assess SIJ laxity (such as the Gillet test measuring SIJ mobility by palpation) do not have the sufficient objectivity and reproducibility. [7] Sturesson *et al.* used a x-ray stereophotogrammetry technique, where tantalum markers were inserted into the sacrum and ilium and displacement on x-ray photographs was measured. [11] In different physiologic exercises, they found rotations up to 4° and translations up to 1.5 mm in the SIJ. Disadvantages of this technique are the invasive application of markers and the use of x-rays.

In the Departments of Rehabilitation Medicine and Biomedical Physics and Technology (Erasmus University Rotterdam), we developed a noninvasive technique to measure SIJ laxity using low-intensity vibrations and colour Doppler imaging. This technique, further referred to as Doppler imaging of vibrations (DIV), produces laxity values of the SIJ. [2, 3] To exclude the influence of muscle tension, SIJ measurements are performed in a stationary, neutral and unloaded posture to measure the amount of passive laxity. By using very small amplitudes of the vibrations, far below the physiologic range of joint motion, the measured amount of laxity focuses on the centre of the normal range of motion, indicated as the neutral zone. [8]

The DIV technique was validated based on measurements performed on a metal and plastic pelvis model and on embalmed human pelves. [1, 2] The first *in vivo* study was performed on healthy subjects to assess the intratester reliability for an experienced tester, which was demonstrated to be high. [3] In our study on pelvic pain during pregnancy, we demonstrated that SIJ laxity left to right differences, rather than the laxity of the individual SIJs, were significantly different between pregnant women with moderate to severe pelvic pain and pregnant controls with absent or mild pain. [6]

Although the intratester reliability of the SIJ laxity measurements has already been examined, sources of measurement error associated with different aspects of the measurement protocol have not been adequately identified. [5, 11] Knowledge of these error sources, as well as their relative contributions to the total measurement error, are important for optimising the reliability of a given measurement protocol. [9, 11]

Additionally, the intertester reliability of the SIJ laxity measurements has not been established and insight is required concerning the number of testers, the number of testing occasions and repetitions needed to establish an acceptable level of reliability. For the interpretation of measurement results of individual subjects,

the standard error of measurement (SEM) and the smallest detectable difference (SDD) can be calculated. These reliability indices provide an indication of the absolute reliability of the measurement as opposed to the relative reliability provided by the intraclass correlation coefficient (ICC). Thus, for the tester measuring an individual subject, the SEM and SDD may be considered a more practical measure of reliability.

The first aim of this study was to determine intra- and intertester reliability indices of DIV in SIJ laxity measurements performed by several testers, including one experienced tester as well as inexperienced testers. The second aim was to estimate the contribution of various sources of measurement error associated with the measurement design.

Material and methods

Study group

A total of 10 healthy volunteers (mean age 29.6 ± SD 6.0 years; mean height 169.6 ± 4.4 cm; mean body weight 59.5 ± 5.2 kg) were recruited for this study. All subjects were women without any pelvic and/or low back pain for at least 1 year. Of the 10 women, 5 had one or two children; 2 of them had recently given birth to a child. The characteristics of the subjects of the present study were similar to the characteristics of patients who would typically be evaluated with DIV, except for the existence of pelvic and/or low back pain. [6] All women gave their informed consent to participate in the study.

Assessment of the laxity of the sacroiliac joints

SIJ laxity was measured with DIV, as described in our previous studies. [2, 3, 6] During a measurement, each subject was lying on a mattress in the prone position with relaxed muscles. Vibrations (frequency 200 Hz, amplitude not exceeding 0.05 mm and excitation power 1.4 W) were applied unilaterally to the anterior superior iliac spine (Figure 1). Vibrations were generated by a Derritron VP3 vibrator and driven by a TA120 power amplifier (both Derritron Electronics, Hastings, UK). The vibrations propagate in the pelvis through the ilium to the SIJ. The intensity of the vibrations was measured across the ipsilateral SIJ with colour Doppler imaging (Quantum Angio Dynograph 1, Philips Ultrasound Inc. 1987, Santa Ana, USA). The colour processing in our measurement instrument is based on FFT. At the dorsal side, the transducer was positioned across the sacroiliac region and the intensity of vibrations was measured successively on both sides of the SIJ. In a stiff joint, there is a small or imperceptible difference in vibration amplitude between the sides. The vibrations at both sides of the joint are picked up by the colour Doppler imaging transducer. The intensity of the vibration of the ilium and sacrum appears simultaneously on the monitor at high threshold values (dimension power

dB). Using the threshold button on the control panel of the colour Doppler imaging apparatus allows measurements by comparing the vibration amplitude of the ilium and of the sacrum as follows. At first, a threshold level is read from the monitor at which the colour of the vibrating sacrum disappears and changes to grey scale. Next, a second threshold level is found for the ilium. The difference in threshold levels is expressed in threshold units (TU, dimension dB). Because the threshold levels as measured by DIV are directly related to the vibration amplitude of the bone, a small or absent difference between the threshold levels of the sacrum and ilium is accepted as an indication of a stiff joint (low laxity < 2 TU). A large difference between the threshold levels of the sacrum and ilium is an indication of a loose joint (high laxity > 5 TU). The measurements were performed with unloaded SIJ, so laxity values found are representative for the neutral zone.

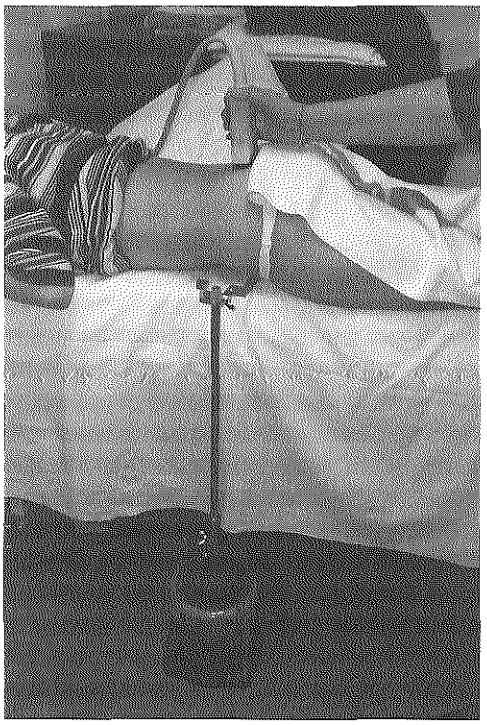

Figure 1. Experimental setup showing the vibrations propagate in the ilium up to the sacroiliac area. At the dorsal side, the vibrations of the ilium and the adjacent sacrum are picked up by a colour Doppler imaging transducer which covers both sides of the sacroiliac joint.

Procedure for assessment of reliability

After being instructed and trained, five testers (A, B, C, D and E) performed the measurements. Testers A and B were both physiotherapists and researchers, tester C was a medical doctor and researcher, tester D a medical student, and tester E a technician. Only tester A was experienced, having 3 years experience with this

method: all others were inexperienced. To assess the repeatability within and between testers on a single occasion, each tester carried out two repeated measurements (repetitions), first on the left SIJ and then on the right SIJ. To ensure a "blinded" procedure, measurement outcomes (threshold values) were masked and a second tester was present to read and record the data. Between assessments of one of the SIJs, the subject was requested to remain on the mattress without changing the position to minimise the influence of posture change on the repeated measurement outcomes. Tester A (3 years experience) placed all subjects in the correct position and was the first to perform a measurement. The order of the remaining four testers was randomised for each joint. To assess reliability over different occasions, another two repeated measurements were performed 3 days later at the same time of the day, under the same standardised conditions and using the same measurement procedure. The assumption was that, in this sample population, the laxity of the SIJs would not change within 3 days.

In this study, the object of measurement is the joint ($n_j = 20$) and the measurement factors are occasion ($n_o = 2$), repetition ($n_r = 2$), and tester ($n_t = 5$). Each joint was measured under all measurement conditions, resulting in a completely crossed four-way joint-occasion-repetition-tester (*jort*) design.

Data processing and analysis

Data were analysed using the generalisability theory. The generalisability theory distinguishes between a reliability study (also referred to as a generalisability, G, study) and future application of the measurements by a tester, indicated as decision, D studies. [11] A G study analysis was conducted on the laxity values of 20 sacroiliac joints of 10 subjects with a total number of 40 measurements for each subject. Analysis of variance (ANOVA) was performed with a statistical package for the social sciences (SPSS) 9.0 program, using the MINQUE (minimum norm quadratic unbiased estimation) method, to determine the multiple sources of measurement error, which were calculated as the percentage of the total variance. Variance components were calculated for all main effects for joint (*j*), occasion (*o*), repetition (*r*), and tester (*t*), all two-, and three-way interactions, towards the residual term. According to the approach of Cronbach *et al.*, [5] relatively small negative estimates of variance components were set to zero.

For the hypothetical D studies, all estimated variance components from the G studies, excluding the variance of interest, contributed to the absolute error variance. For the intertester reliability, testers were considered random in the D study and the factor joint (*j*) refers to the variance of interest. [9] The decision-maker can generalise to measurements of any tester in a large universe of testers who could apply DIV. [9, 11] For the intratester reliability, the factor tester is fixed and the factors of occasion and repetition random. In this design, the factor joint (*j*) and the joint-tester (*jt*) interaction component refers to the variance of interest. The

measurements of a tester will not be compared with those of any other tester, but are compared over occasions and repetitions. To study the influence of error reduction by increasing the number of measurement conditions and using mean scores as the measurement result, different possible measurement designs were considered: a single score, 1, 3 or 5 repetitions; 1 or 2 occasions, and 1 or 2 testers. In all but the first design, measurement results were mean scores.

A second G study was restricted to the measurements of the experienced tester (tester A). All variance components were estimated for a joint-occasion-repetition (*jor*) design. In the corresponding D studies, the focus is on comparing tester A measurements of a joint over occasions and repetitions (intratester reliability).

Reliability indices

Intraclass correlation coefficients (ICC) were calculated as the variance of interest divided by the total variance. [11] From the error variance, the standard error of measurement (SEM) was calculated as its square root. Based on the SEM, the smallest detectable difference (SDD) was calculated as 1.96 x $\sqrt{2}$ x SEM. [9] Clinically, this implies that, during evaluation of therapeutic interventions, the improvement in an outcome variable has to be equal to or exceed the SDD to be 95% sure of an effect of the intervention in an individual "joint".

In patients with pregnancy-related pelvic pain, the absolute difference between left and right SIJ laxity is of particular clinical interest. [4, 6] With the smallest detectable *side* difference (SD*s*D), we want to assess the minimal value of the left-right difference of SIJ laxity that can be interpreted as a real difference between left and right SIJ laxity. For the comparison between left and right SIJ laxity, the natural variance between left and right has to be taken into account. Therefore, the factor joint has been split up into the factors women (*w*) and side (*s*). The SD*s*D at the 0.05 level was calculated as SDD + [1.96 x $\sqrt{2}$ x $\sqrt{}$(women x side variance)].

Results

Sources of measurement error

The SIJ laxity values ranged from 0.0 to 5.8 TU. The results of the G study, presented in Table 1, include the estimates of variance components for all factors and interactions as well as the variance expressed as the percentage of the total variation for SIJ laxity values assessed from two-repeated measurements on two occasions by five testers in 20 joints.

As shown in Table 1, variation attributed to differences between occasions (*o*) and repetitions (*r*) was negligible. Clinically, this means that the measurement results were not systematically different between occasions and repetitions. The

main effect for tester (*t*) was very small. The rather large joint-occasion component shows that 6% of the variation was due to differences between occasions within a joint. The joint-occasion-tester interaction (13%), as a source of variation, shows that some joints have higher SIJ laxity values during a specific combination of occasion and tester, whereas other joints have lower values for the same combination. The four-way interaction term was confounded with residual error and, therefore, is not interpretable. The value of this component was relatively large (23.8%).

Table 1. Estimated variance components and variance expressed as the percentage of the total variation for sacroiliac joint laxity values.

Source of Variation	Variance Component	Percentage of Variation (%)
Joint (*j*)	1.89	52.94
Occasion (*o*)	0.00 *	0.00
Repetition (*r*)	0.00 *	0.00
Tester (*t*)	0.09	2.52
Jo	0.21	5.88
Jr	0.04	1.12
Jt	0.03	0.84
Or	0.00	0.00
Ot	0.00 *	0.00
Rt	0.00 *	0.00
Jor	0.00 *	0.00
Jot	0.46	12.89
Jrt	0.00 *	0.00
Ort	0.00 *	0.00
Residual	0.85	23.81
Total	3.57	100.00

* Negative estimates are replaced by zero. Values from two repeated measurements on two occasions by five testers in 20 joints.

Table 2 presents the estimated variance components and percentages of variance for tester A who had three years of experience with the method, in contrast to the other inexperienced testers. Table 2 shows that the variance between occasions and repetitions was negligible, implying that the mean laxity values over joints were not systematically different from one occasion to another and from one repetition to another. The largest parts of the error variance were attributed to the interaction

between joint and occasion (13.4%), and the three-way interaction term confounded with residual error (8.4%).

Table 2. Variance components and variance expressed as the percentage of the total variation for sacroiliac joint laxity values for an experienced tester.

Source of Variation	Variance Component	Percentage of Variation (%)
Joint (*j*)	2.25	75.25
Occasion (*o*)	0.00 *	0.00
Repetition (*r*)	0.00 *	0.00
Jo	0.40	13.38
Jr	0.09	3.01
Or	0.00 *	0.00
Residual	0.25	8.36
Total	2.99	100.00

* Negative estimates are replaced by zero. Values from two repeated measurements at both sides on two occasions in 20 joints.

Reliability indices

The ICC for both intra- and intertester reliability for the hypothetical D studies are given in Table 3. All ICCs were smaller than 0.80, except the design with three repeated measurements on two occasions with a fixed tester (*i.e.*, the same tester on each occasion) (0.80).

For the interpretation of measurement results of individual subjects, the SEM, SDD and SD*s*D inform us about the amount of measurement error that should be taken into account. SEMs for intratester values range from 1.25 to 0.70 TU and for intertester values from 1.30 to 0.78 TU (Table 3). The SDDs show that, in hypothetical applications of the measurement on healthy female SIJs assessed by the same tester, only changes larger than 3.47 TU (one repetition), 2.73 TU (three repetitions), 2.55 TU (five repetitions), or 1.94 TU (two occasions and three repetitions) can be interpreted as real changes in SIJ laxity. The intertester values ranged from 3.60 to 2.17 TU.

Table 3. Intra- and intertester reliability indices of sacroiliac joint laxity measurements.

Design	Measurement result	Number of measurement conditions *o*	*r*	*t*	ICC	SEM (TU)	SDD (TU)	SD*s*D (TU)
Intratester								
1	Single value	1	1	1	0.56	1.25	3.47	5.26
2	Mean value	1	3	1	0.68	0.98	2.73	4.52
3	Mean value	1	5	1	0.70	0.92	2.55	4.34
4	Mean value	2	3	1	0.80	0.70	1.94	3.73
Intertester								
1	Single value	1	1	1	0.53	1.30	3.60	5.39
2	Mean value	1	3	1	0.63	1.04	2.90	4.69
3	Mean value	1	5	1	0.66	0.99	2.73	4.52
4	Mean value	1	3	2	0.74	0.81	2.25	4.04
5	Mean value	2	3	1	0.75	0.78	2.17	3.96

Measurement conditions: *o* = occasion, *r* = repetition and *t* = tester. Reliability indices: ICC = intraclass correlation coefficient; SEM = estimate of standard error of measurement; SDD = smallest detectable difference = 1.96 x √2 x SEM (α = .05); SD*s*D = smallest detectable *side* difference = SDD + [1.96 x √2 x √(women x side variance)].

For the comparison between left and right SIJ laxity, the SD*s*D was calculated. The SD*s*D for intratester values ranges from 5.26 to 3.73 TU and for intertester values from 5.39 to 3.96 TU. This implies that, for individual subjects assessed by the same tester, only differences between left and right SIJ larger than 5 TU (one and three repetition) or 4 TU (five repetitions or two occasions and three repetitions) can be interpreted as real differences in laxity.

For the intratester reliability for testers A, B, C, D and E, the ICCs (SEMs) were 0.75 (0.86), 0.31 (1.53), 0.68 (1.23), 0.21 (2.43) and 0.65 (1.12), respectively, for a single measurement. Because the testers with little experience showed irregular results, further analysis was focused on the intratester reliability for an experienced tester (tester A) for five possible applications of the DIV on individual joints (Table 4). Compared with the intratester ICC for a fixed tester in Table 3, estimated intratester ICCs with an experienced tester were considerably higher; in four of the five designs ICCs were greater than 0.80. This indicates that the SIJ laxity measurements are more reliable when done by an experienced tester than by another fixed tester.

SEMs ranged from 0.86 to 0.52 TU, and the SDDs from 2.38 to 1.45 TU. The SD*s*Ds show that, in hypothetical applications of the measurement on healthy

women SIJs by an experienced tester, only differences larger than 3 TU (one, three or five repetitions, or two occasions) or 2 TU (two occasions and three repetitions) can be interpreted as real differences between the left and right SIJ laxity.

Table 4. Intratester reliability of sacroiliac joint laxity measurements for an experienced tester.

Design	Measurement result	Number of measurement conditions		ICC	SEM (TU)	SDD (TU)	SD*s*D (TU)
		o	*r*				
1	Single value	1	1	0.75	0.86	2.38	3.21
2	Mean value	1	3	0.81	0.72	1.99	2.82
3	Mean value	1	5	0.83	0.69	1.90	2.73
4	Mean value	2	1	0.84	0.64	1.78	2.61
5	Mean value	2	3	0.89	0.52	1.45	2.28

Measurement conditions: *o* = occasion, and *r* = repetition. Reliability indices: ICC = intraclass correlation coefficient; SEM = estimate of standard error of measurement; SDD = smallest detectable difference = 1.96 x $\sqrt{2}$ x SEM (α = .05); SD*s*D = smallest detectable *side* difference = SDD + (1.96 x $\sqrt{2}$ x $\sqrt{}$(women x side variance)).

Discussion

Sources of measurement error

The main purpose of this study was to assess the reliability of SIJ laxity measurements under different conditions, including multiple testers, occasions, and repetitions. The approach of the generalisability theory for assessing reliability provides a practical tool, because important sources of measurement error can be determined and accounted for. [11]

For the intertester reliability, this study has shown that 47% of the total variance was attributed to measurement error. One of the main sources of this error is associated with differences in the assessment of joints among occasions and testers (*i.e.*, joint-occasion-tester variability) (13%). In other words, some joints show higher SIJ laxity values during a specific combination of occasion and tester, whereas other joints show lower values for the same combination. Variability in the assessment of joints among occasions (6%) is another substantial source of error. The percent of total variance accounted for by the occasion effect was negligible. This implies that measurements on different occasions were consistent when averaged across joints, testers and repetitions, but there were notable differences among the occasions across different joints. Possible explanations for the variability in a joint measurement on different occasions concern the position of

the subjects or the performance of the measurements. Reduction of this variation can be achieved by better standardisation of the measurement protocol.

The present data show that testers were reasonably consistent in their measurements when averaged across both occasions and repetitions; there were only small differences (1%) in the total variance, in that some testers measured some joints differently from other testers. More specific training and longer experience with the DIV method may decrease these sources of measurement error even further.

The repetition effect plus interaction terms with repetition did not substantially contribute to the total variance (<2%). These findings indicate that measurements remained consistent over the repetitions, which were performed in quick succession, by one tester within one occasion. The percentage of total variance attributable to the residual error was 24%, suggesting that a substantial portion of the variance remained unexplained by this design. This part of the variation cannot be influenced because it cannot be attributed to the known sources.

For the intra-tester reliability of an experienced tester, only 25% of the total variance was attributed to measurement error. The results from the G study (Table 2) indicate that variance between occasions was an important source of measurement error. It was not the general trend (*o*) that was most distinct, but rather an interaction with joints (*jo*). The residual error accounted for only 8% of the total variance. Clinically, this finding indicates that the measurement results of an experienced tester are less subject to unknown systematic and random variation than that of a random tester.

Reliability indices for the five testers

The results of the D study provide information on the number of repetitions or occasions that are required to reach the desired level of reliability in the assessment of a subject's SIJ laxity.[10] Reliability indices were calculated for mean values over different numbers of testers, occasions and repetitions.

The inter- and intratester reliability for a SIJ laxity measurement was moderate. For a single measurement, the ICCs for intra- and intertester reliability were 0.56 and 0.53, respectively (Table 3). To obtain an acceptable level of reliability (ICC $\geq$ 0.8), a fixed tester would have to perform at least three repetitions on two occasions. In clinical practice, however, it is too time-consuming to measure on two occasions.

When interpreting laxity values of an individual woman, it is important to also consider the SEMs. Ideally, we would like to have large ICCs (*i.e.*, close to 1.0) with low SEMs, which would indicate that the measurements are consistent and there is minimal variability across the testers. The SEMs for SIJ laxity measurements of a fixed tester (Table 3) were large; the largest SEM (assessed for

a single measurement by one tester on one occasion and one repetition) is 1.25 TU, which was 20% of the measurement range in healthy subjects. This indicates that laxity values of subsequent measurements of a joint may vary considerably and only differences larger than 3.47 TU between consecutive measurements should be interpreted as true changes in a woman's SIJ laxity.

Reliability indices for an experienced tester

Compared with the above, measurements performed by an experienced tester were more reliable and include less measurement error. At least three repeated measurements on one occasion would be required to obtain ICCs above 0.80. Increasing the number of occasions on which an experienced tester performed measurements would have some positive influence on the ICC. The SEM values for intratester applications of SIJ laxity measurements of an experienced tester did not exceed 0.86 TU, which was 14% of the measurement range. The results indicate that specific training and experience of a tester are important requirements for reliable SIJ laxity measurements.

Buyruk *et al.* [3] conducted a study on SIJ laxity in healthy subjects with three repeated measurements on three occasions by one experienced tester. Using their data from 14 healthy women, we performed an analysis similar to that of the present study. This resulted in an ICC of 0.93 and a SEM of 0.83 TU for a single measurement. Although the ICC of the experienced tester in the current study (0.75) is somewhat lower than that obtained from the data of Buyruk and colleagues, the SEM is comparable (0.86), despite the fact that the tester in our study was "blinded" to the measurement outcomes, whereas the tester in the latter study was not. The lower ICC can be explained by the fact that the variance between subjects in the study of Buyruk and colleagues is larger than in the present study. However, for assessing reliability with respect to changes in individual subjects, it is not the magnitude of the between-patient variance that is relevant, but the error variance and associated SEM. [9] The SEMs of the comparable studies are of the same magnitude.

From the SDD, a tester knows what differences need to be measured to conclude that a different measurement result reflects a real change rather than measurement error. If the mean of three repetitions on one occasion performed by the experienced tester is used, a change in SIJ laxity between two measurements is significant when changes are larger than 1.99 TU. For clinical settings in which only one tester is available, but a subject can be measured on two occasions (during which time no treatment effect is expected), the SDD for the mean score over three repetitions (design 5; Table 4) is 1.45 TU.

To compare the laxity of the left and right SIJs, the SD*s*D was calculated. In a previous study it was postulated that a difference between left and right SIJ laxity is an important feature for pregnancy-related pelvic pain. [4, 6] From the SD*s*D

of the design with three repeated measurements on two sides for an experienced tester, it can be concluded that we are 95% certain that a difference larger than 2.8 TU is above the 95th percentile of the difference between left and right SIJ laxity of healthy women. Thus, a woman with a difference between left and right SIJ laxity ≥ 3 TU is not within the normal range of difference between left and right SIJ laxity.

Conclusions

To obtain SIJ laxity measurements that are reliable, a minimum of three repetitions is recommended during one test occasion by an experienced tester. Some variation between occasions might be inevitable, despite strict standardisation of the measurements. In addition to natural variation in SIJ laxity, this may result from the positioning of the subject or the performance of the measurements. The results from this study indicate that specific training and experience of a tester are necessary for reliable SIJ laxity measurements.

The DIV method is a promising test from both clinical and research viewpoints. The device is noninvasive and suitable for repeated measurements even during pregnancy. It might present a means for the early diagnosis of pregnancy-related pelvic pain and for monitoring SIJ laxity response to therapy. It remains to be determined, however, if these recommendations hold true for different patient groups.

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Chapter 3

Pelvic pain during pregnancy is associated with asymmetric laxity of the sacroiliac joints

Abstract

Objective. The aim of this study was to investigate the association between pregnancy-related pelvic pain (PRPP) and sacroiliac joint (SIJ) laxity. ***Methods.*** A cross-sectional analysis was performed in a group of 163 women, 73 with moderate or severe (PRPP+) and 90 with no or mild (PRPP-) PRPP at 36 weeks of pregnancy. SIJ laxity was measured by means of Doppler imaging of vibrations in threshold units (TU). Pain, clinical signs and disability were assessed with visual analog scale (VAS), posterior pelvic pain provocation (PPPP) test, active straight leg raise (ASLR) test, and Quebec back pain disability scale (QBPDS), respectively. ***Results.*** Mean SIJ laxity in the PRPP+ group was not significantly different from the PRPP- group (3.0 *versus* 3.4 TU). The mean left-right difference, however, was significantly higher in the PRPP+ group (2.2 TU) than in the PRPP- group (0.9 TU). In the PRPP- group, only 4% had asymmetric laxity of the SIJs in contrast to 37% of the PRPP+ group. Between the PRPP+ subjects with asymmetric and symmetric laxity of the SIJs significant differences were found with respect to mean VAS for pain (7.9 *versus* 7.0), positive PPPP test (59% *versus* 35%), positive ASLR test (85 *versus* 41%) and mean QBPDS score (61 *versus* 50). ***Conclusions.*** Increased SIJ laxity is not associated with PRPP. In fact, pregnant women with moderate or severe pelvic pain have the same laxity in the SIJs as pregnant women with no or mild pain. However, a clear relation between asymmetric laxity of the SIJs and PRPP is found.

Introduction

Every other pregnant woman reports pain in the pelvic region, ranging in intensity from mild to severe pain. [1] Pregnancy-related pelvic pain (PRPP) includes pain from the posterior pelvis and/or from the pubic symphysis. The pain starts during pregnancy and often disappears soon after childbirth. [2] In 10-15% of the cases the pain becomes chronic, that is persisting for more than three months after childbirth. [2]

PRPP may be caused by several factors related to changes that occur naturally during pregnancy. Change in the center of gravity, secondary to weight gain, can create a strain on weight-bearing structures in the body and is likely to be more problematic if superimposed on pre-existing problems, including muscle weakness. Pregnancy-related hormones create general laxity of collagenous tissue. It is supposed that this laxity in the symphysis pubis and the sacroiliac joints (SIJs) is a preparation for delivery. [3-6] The laxity is generally more pronounced in multiparous women than during the first pregnancy [7, 8] and is commonly cited as an underlying cause of pelvic pain during pregnancy. [6, 9] It is impossible to establish the relationship between laxity of the SIJs and pain intensity during pregnancy because, until recently, assessment of laxity in the SIJs was impossible to perform in an objective manner during pregnancy. [10-12]

We previously demonstrated that sacroiliac joint (SIJ) laxity can be objectively quantified *in vivo* by Doppler imaging of vibrations (DIV). [13, 14] This non-invasive technique using dynamic excitation is suited for repeated examinations during pregnancy. The reproducibility of the technique has been shown to be very high. [13] The aim of the present study was to investigate the association between PRPP and SIJ laxity during pregnancy.

Material and methods

A total of 163 pregnant women at a gestational age of 31 to 40 weeks were included in the study. The main exclusion criterion was the presence of low back and/or pelvic pain before pregnancy. Also excluded were subjects with either pain in the lumbar spine only, pain radiating to below the knee, known congenital anomalies of the spine, known rheumatologic disease affecting the locomotion system or twin pregnancy. The subjects were recruited from the obstetric outpatient clinic of the University Hospital Rotterdam and gave their informed consent to participate. The study was approved by the hospital's medical ethics committee. For each subject, the questionnaire, tests and measurements were completed on the same day.

Subjects completed a questionnaire that included questions on general and obstetric history, age, body weight, height, sports activity prior to pregnancy, and

previous and present PRPP. A pain drawing was used to indicate the location(s) of the pain.

SIJ laxity was measured with DIV, as described in our previous studies. [13, 14] During a measurement the subject was lying in prone position with relaxed muscles on a mattress with a cut-away at the level of the uterus to avoid pressure. Vibrations of 200 Hz were applied unilaterally to the anterior superior iliac spine. The intensity of the vibrations was measured across the ipsilateral SIJ with color Doppler imaging (Quantum Angio Dynograph 1, Philips Ultrasound Inc., Santa Ana, California, USA). The transducer was positioned across the sacroiliac region and the intensity of vibrations was measured successively on both sides of the SIJ. When a SIJ is stiff, there is a small or absent difference in vibration amplitude between both sides of the SIJ, and the intensity of the vibrations is slightly lower or the same at the sacrum than at the ilium. Since the vibration amplitude is directly related to the threshold units (TU) of the bone as measured by DIV, a small or absent difference between the threshold units of the sacrum and ilium is accepted as an indication of a stiff joint (low laxity < 2 TU). [13] A large difference between the threshold units of the sacrum and ilium is an indication of a loose SIJ (high laxity > 5 TU). [13] We performed three consecutive SIJ laxity measurements without postural change and used the mean laxity value of each SIJ for further analysis. The absolute difference between left and right SIJ was calculated ($|\text{left-right}|$). Based on a previous study a difference of 3 TU or more was defined as asymmetric laxity of the SIJs. [14] One observer (LD) who has three years of experience in the DIV, collected the data and performed the SIJ laxity measurements as well as all pain provocation tests.

The posterior pelvic pain provocation (PPPP) test and the active straight leg raise (ASLR) test are well-documented, reliable, sensitive and specific diagnostic tests to assess PRPP. [15-18] The PPPP test was performed with the subject in supine position. [16] The vertically positioned femur was gently pressed by the examiner in the direction of the examination table. The test was considered positive when the subject felt an increase of pain in the gluteal area on the side that was tested. The ASLR test was performed in supine position with straight legs and feet 20 cm apart. [17, 18] The subject had to raise the legs, one after the other, 20 cm above the examination table without bending the knee. The test was considered positive when the subject was unable to raise the leg and/or when pain was increased during the test.

Severity of pain was measured by means of a visual analog scale (VAS) for the worst pain during the preceding week (VAS_{week}) with a range from 0 to 10, where 0 denoted no pain and 10 worst possible pain. [11, 19] Disability was measured with a modified Quebec back pain disability scale (QBPDS, range 0-100). [20] This scale was developed to measure the grade of disability in non-specific low back pain, but the scale appeared also suitable in patients with PRPP. [18]

Subjects were classified into two groups based on the VAS_{week} and the pain drawing. Subjects were assigned to the PRPP+ group when VAS_{week} was > 3 (moderate or severe pain) [21] and the pain was felt in (at least) the region of the SIJs and/or in the pubic symphysis region (n=73). Subjects with VAS_{week} = 0 (absent pain) or with $0 < VAS_{week} \leq 3$ (mild pain) [21] in the region of the SIJs and/or pubic symphysis region were assigned to the PRPP- group (n = 90).

Statistical evaluation. Statistical analysis involved the calculation of the means and standard deviations for each of the variables measured. Comparisons between two groups were carried out using Mann-Whitney's test and the Chi-square test. A Pearson Chi-square test was used to investigate the association between pelvic pain and asymmetric laxity of the SIJs. A p-value of < 0.05 was taken to represent statistical significance.

Results

Subjects

Of the 163 subjects who participated in the study, 73 had moderate or severe PRPP (PRPP+ group) and 90 had no or mild PRPP (PRPP- group). The mean gestational age at the time of testing was 36.2 ± 1.5 weeks. General and anthropometric data are listed in Table 1. The body weight during pregnancy, parity and the presence of pelvic pain during a previous pregnancy (in parous women) were significantly higher in the PRPP+ group than in the PRPP- group. PRPP started significantly earlier in the PRPP+ group compared with the PRPP- group (p = 0.04).

SIJ laxity

The distribution of mean SIJ laxity values and the left-right difference in the PRPP+ and PRPP- groups is shown in Figure 1A and B, respectively. Both stiff (< 2 TU) and loose (> 5 TU) joints were found in the PRPP+ and PRPP- groups. Although the mean SIJ laxity value of the PRPP+ group was lower than in the PRPP- group, this difference was not significant (p = 0.11): 3.0 ± 1.7 (s.d.) TU and 3.4 ± 1.8 TU, respectively. The mean left-right difference, however, was significantly higher in the PRPP+ group (2.2 ± 1.7 TU) than in the PRPP- group (0.9 ± 0.9 TU).

Asymmetric laxity of the SIJs

In the PRPP- group, only four of the 90 women had asymmetric laxity of the SIJs in contrast to 27 of the 73 women in the PRPP+ group (Table 2). The sensitivity of the asymmetric laxity measurement was 27/73 (37%). The sensitivity of the PPPP test and ASLR test in the same group was 44% and 58%, respectively. The specificity of the asymmetric laxity measurement was 86/90 (96%), which was in the same range as the PPPP and ASLR tests (93% and 97%, respectively).

Table 1. General and anthropometric data of subjects with moderate or severe (PRPP+) and no or mild (PRPP-) pregnancy-related pelvic pain

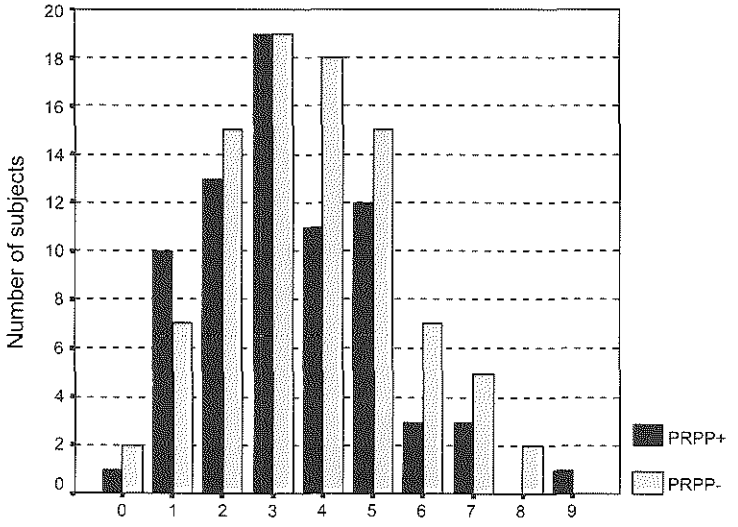
Groups	PRPP+ group	PRPP- group
	$n = 73$	$n = 90$
Age (years, mean ± s.d.)	29.7 ± 5.4	30.5 ± 5.6
Height (cm, mean ± s.d.)	165.1 ± 7.5	167.1 ± 7.0
Body weight prior to pregnancy (kg, mean ± s.d.)	69.0 ± 14.4	64.5 ± 11.9
Body weight at measurement (kg, mean ± s.d.)	81.3 ± 14.5	76.6 ± 12.3 *
Parity (mean ± s.d.)	1.1 ± 1.1	0.7 ± 0.9 *
nulliparous (%)	32.9%	48.9% *
parous (%)	67.1%	51.1%
Use of oral contraceptives (%)	94.5%	86.7%
Hormones to induce pregnancy (%)	16.4%	20.0%
Working (%)	57.5%	64.4%
Sports activity prior to pregnancy (%)	67.1%	58.9%
Pelvic pain during previous pregnancies (%)	53.1%	8.7% *
Reported onset pelvic pain (weeks, mean ± s.d.)	22.4 ± 7.5	26.8 ± 5.7 *

n = number of patients; * $p < 0.05$ compared with the PRPP+ group.

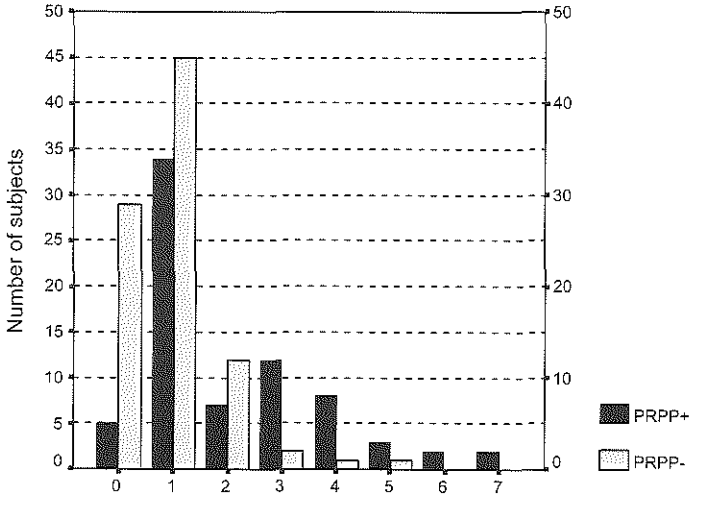
Table 2. Number of subjects (percentage) with positive test results with sensitivity and specificity of tests for pregnancy-related pelvic pain (PRPP) in the study population

	PRPP+ group $n = 73$	PRPP- group $n = 90$	Sensitivity (%)	Specificity (%)
Asymmetric laxity	27 (37.0%)	4 (4.4%)	37.0	95.6
PPPP test	32 (43.8%)	6 (6.7%)	43.8	93.3
ASLR test	42 (57.5%)	3 (3.3%)	57.5	96.7

Figure 1. Distribution of subjects with moderate or severe (PRPP+) and absent or mild (PRPP-) pregnancy-related pelvic pain in relation to their measured sacroiliac joint (SIJ) laxity value, expressed in threshold units (TU).



A. mean SIJ laxity value (TU)



B. difference between left and right SIJ laxity values (TU)

In Table 3 we present the clinical scores and tests in relation to asymmetric and symmetric laxity of the SIJs. Between the subjects with asymmetric and symmetric laxity of the SIJs significant differences ($p < 0.05$) were found with respect to VAS for pain, score on QBPDS, positive PPPP test, and positive ASLR test.

Table 3. Clinical scores and positive SIJ specific tests in relation to results of sacroiliac laxity measurements in patients with pregnancy-related pelvic pain

Clinical scores and SIJ specific tests	Laxity measurement	
	Symmetric $n = 46$	Asymmetric $n = 27$
Pain severity scored on VAS	7.0 ±1.7	7.9 ± 1.6*
QBPDS score	50.4 ±20.2	60.5 ±12.7*
PPPP test	16 (34.8%)	16 (59.3%)*
ASLR test	19 (41.3%)	23 (85.2%)*

Data are presented as means ± s.d. or number of patients (percentage) with positive test results; n = number of patients; * $p < 0.05$ compared with the symmetric group.

Discussion

Subjects

We studied the relation between pelvic pain during pregnancy and SIJ laxity, after excluding subjects with pain of other origin. Some studies have stressed the importance of differentiating between posterior pelvic pain and pain in the lumbar spine region, [7,12, 22, 23] or have reported a strong correlation between pain in the region of the SIJs and pain in the symphysis pubis. [2] Therefore, in the group with PRPP we included only subjects with pain in the region of the SIJs and/or symphysis pubis and excluded subjects with pain in the lumbar spine only.

Both subjects with pain and asymptomatic controls were randomly selected from the obstetric outpatient clinic of the University Hospital Rotterdam. Subjects with moderate or severe PRPP were characterized by high body weight during pregnancy, early onset of pain, and a history of pelvic pain in previous pregnancies, which is in agreement with previous data on subjects with PRPP. [11, 24, 25]

SIJ laxity

Increased joint laxity is a well-recognized phenomenon during pregnancy. [3, 4, 7, 8] Similar to these studies, the current study revealed an increased laxity of individual SIJs during pregnancy. In a previous study the mean SIJ laxity value of 45 healthy women with a mean age of 27.7 ± 4.9 years was 2.8 TU, [14] which was lower than the mean SIJ laxity value of pregnant women found in the present study. Increased laxity of the pelvic girdle during pregnancy has been described to correlate with PRPP. [3, 4, 6, 7, 9, 24] Abramson *et al.* demonstrated by X-ray that the severity of the symptoms corresponded in a general way to the amount of relaxation of the symphysis. [3] This relationship was by no means constant because some of the subjects with less than the average amount of separation had pelvic pain and several subjects with a high amount of separation had no complaints at all. Björklund *et al.* used ultrasonography for the assessment of symphyseal laxity and found a strong association between severe pelvic pain during pregnancy and an increased symphyseal distention. [24] In contrast to these reports, the results of the present study suggest no relation between increased SIJ laxity and pelvic pain during pregnancy. SIJ laxity in the group with moderate or severe PRPP was not different from the group with no or mild PRPP. In both groups a broad range of laxity values was found. Therefore, increased laxity is not necessarily an indication of pathology or the cause of complaints.

Of particular clinical interest is the left-right difference of SIJ laxity. During pregnancy this asymmetric laxity is significantly larger in the group with moderate or severe PRPP compared to the group with no or mild PRPP. This is a new finding which has not been reported in previous studies on PRPP and joint laxity. In the studies of Abramson and Björklund the severity of pain could not predict the degree of symphyseal distention in the individual case, indicating that mechanisms other than increased relaxation of pelvic ligaments must be involved. [3, 24] Asymmetric laxity of the SIJs seems to be more directly related to PRPP.

Clinical meaning of asymmetric laxity of the SIJs

The results of the present study demonstrate that our test for asymmetry of SIJ laxity can effectively measure disease severity in subjects with PRPP, because asymmetric laxity of the SIJs correlates well with severity scales and clinical tests for SIJ dysfunction. Subjects with pain and asymmetric laxity of the SIJs reported significantly more pain and experienced more disability than the subjects with pain but without asymmetric laxity. Furthermore, the PPPP and ASLR tests were more frequently positive in the subjects with PRPP and asymmetric laxity of the SIJs than in the subjects with PRPP and symmetric laxity. Therefore, testing for asymmetry of SIJ laxity does discriminate between less and more severe forms of PRPP.

Subjects with asymmetric laxity of the SIJs might form a risk group for chronic pain after delivery, because subjects with high pain intensity during pregnancy have a greater chance that the pain will persist after delivery than subjects with less severe problems. [19] Further studies are needed to follow-up subjects with PRPP after delivery, to determine to what extent measurements of SIJ laxity have predictive power with regard to chronic PRPP.

Conclusion

The results of the present study suggest that increased SIJ laxity is not associated with pelvic pain during pregnancy. In fact, pregnant women with moderate or severe pelvic pain have the same laxity in the SIJs as pregnant women with no or mild pain. However, asymmetric laxity of the SIJs is associated with moderate or severe PRPP in a subgroup of the patients and correlated well with severity scales and clinical tests for SIJ dysfunction.

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Chapter 4

The prognostic value of asymmetric laxity of the sacroiliac joints in pregnancy-related pelvic pain

Abstract

Study design. Prospective cohort study. ***Objective.*** To determine the prognostic value of asymmetric laxity of the sacroiliac joints (SIJs) during pregnancy on pregnancy-related pelvic pain (PRPP) postpartum. ***Summary of background data.*** In a previous study we observed a significant relation between asymmetric laxity of the SIJs and moderate to severe PRPP during pregnancy. ***Methods.*** A group of 123 women were prospectively questioned and examined, and SIJ laxity was measured by means of Doppler imaging of vibrations at 36 weeks gestation and at 8 weeks postpartum. A left to right difference in SIJ laxity $\geq$ 3 threshold units was considered to indicate asymmetric laxity of the SIJs. ***Results.*** In subjects with moderate to severe PRPP during pregnancy, SIJ asymmetric laxity was predictive of moderate to severe PRPP persisting into the postpartum period in 77% of the subjects. The sensitivity, specificity and positive predictive value of SIJ asymmetric laxity during pregnancy for PRPP persisting postpartum were 65%, 83% and 77%, respectively. Subjects with moderate to severe PRPP and asymmetric laxity of the SIJs during pregnancy have a threefold higher risk of moderate to severe PRPP postpartum than subjects with symmetric laxity. ***Conclusion.*** These data indicate that in women with moderate to severe complaints of pelvic pain during pregnancy, SIJ asymmetric laxity measured during pregnancy is predictive of the persistence of moderate to severe PRPP into the postpartum period.

Introduction

Pregnancy-related pelvic pain (PRPP) is a common clinical problem. The reported incidence in prospective studies, in which diagnosis was based on pain history and/or clinical examination, varies from 6% to 23%. [2, 17, 22] The pathophysiology of PRPP is not fully understood. Although an association between PRPP and increased pelvic girdle relaxation has been suggested, [1, 5, 13, 18] there is no evidence that the degree of symphyseal distention predicts the severity of the pain in pregnancy or postpartum in the individual case. [1, 5]

The association between PRPP and sacroiliac joint (SIJ) laxity has not been extensively studied, mainly because radiographic studies cannot be justified in pregnant women. It was previously demonstrated on cadavers, healthy subjects, and patients with chronic low back and pelvic pain that SIJ laxity can be objectively assessed by Doppler imaging of vibrations (DIV). [6-8] This technique allows for the quantification of SIJ laxity by comparing the intensity of vibrations between iliac and sacral bones. [8] This noninvasive technique permits repeated and safe measurements during pregnancy because low-energy vibrations (200 Hz) and ultrasound (color Doppler imaging) are used. To obtain SIJ laxity measurements that are reliable, a minimum of three repetitions is recommended during one test occasion by an experienced tester.[12]

A previous study on PRPP during pregnancy demonstrated that asymmetric laxity of the SIJs, rather than increased laxity of the individual SIJ, is associated with PRPP. [11] Pregnant women with moderate to severe pelvic pain have the same range of individual SIJ laxity values as pregnant women with absent or mild pain. [11] However, the difference between left and right SIJ laxity were significantly different between pregnant women with moderate to severe pelvic pain and pregnant controls with absent or mild pain. [11] The aim of the present study was to determine the prognostic value of asymmetric laxity of the SIJs during pregnancy on PRPP postpartum.

Material and methods

Subjects

In this prospective cohort study, subjects at 30 weeks gestation were recruited from the obstetric outpatient clinic of the University Hospital Rotterdam. The main exclusion criterion was the presence of low back and/or pelvic pain *before* pregnancy. Also excluded were subjects with pain radiating to below the knee, known congenital anomalies of the spine, known rheumatologic disease affecting the locomotion system, or twin pregnancy. Subjects completed a questionnaire that included questions on general and obstetric history, age, body weight, height, sports activity before pregnancy, and previous and present PRPP. A pain drawing was used to indicate the location(s) of pain. The study was approved by the

hospital's Ethical Committee, and written informed consent was obtained from each subject.

SIJ laxity measurement

At 36 weeks of pregnancy and 8 weeks postpartum SIJ laxity was measured with DIV as previously described. [6-8, 11] Briefly during a measurement, the subject was lying in prone position with relaxed muscles on a mattress with a cut-away at the level of the uterus to avoid pressure during pregnancy. Vibrations, with an amplitude not exceeding 0.05 mm and a frequency of 200 Hz, were applied unilaterally to the anterior superior iliac spine. We used color Doppler imaging (Quantum Angio Dynograph 1, Philips Ultrasound Inc., Santa Ana, CA) and placed the transducer across the ipsilateral SIJ to measure the intensity of the vibrations. When a SIJ is stiff, there is a small or absent difference in vibration amplitude between both sides of the SIJ, and the intensity of the vibrations is the same or only slightly lower at the sacrum than at the ilium. Because the vibration amplitude is directly related to the threshold units (TU) of the bone as measured by DIV, an absent or small difference (< 2 TU) between the sacrum and ilium is accepted as an indication of a stiff joint. [6, 7] A large difference in TU between the sacrum and ilium is an indication of a less stiff SIJ (high laxity > 5 TU). [6, 7] Three consecutive SIJ laxity measurements were performed on each side without postural change and the mean laxity value of each SIJ was used for further analysis. The absolute difference between left and right SIJ laxity [(L-R) difference] was calculated. As previously defined, a (L-R) difference of 3 TU or more was considered to indicate asymmetric laxity of the SIJs. [8, 11, 12] One observer (L.D.) performed all SIJ laxity measurements and all pain provocation tests.

Severity of pain and clinical tests

Severity of pain was measured by means of a visual analog scale for the worst pain during the preceding week (VAS_{week}) with a range from 0 (no pain) to 10 (worst possible pain). [15, 25] Disability was measured with a modified Quebec back pain disability scale (QBPDS, range 0-100). [14] This scale was originally developed to measure the degree of disability in nonspecific low back pain but has also been used for patients with PRPP.[19]

The posterior pelvic pain provocation (PPPP) test and the active straight leg raise (ASLR) test are well documented, reliable, sensitive, and specific diagnostic tests to assess PRPP. [16, 19, 20, 24] The PPPP test was performed with the subject in supine position. [16, 24] The examiner gently presses the vertically positioned femur in the direction of the examination table. The test is considered positive when the subject feels an increase of pain in the gluteal area on the side that was tested. The ASLR test was performed in supine position with straight legs and feet 20 cm apart. [19, 20] The subject is asked to raise the legs, one by one, to 20

cm above the examination table without bending the knee. The test is considered positive when the subject is unable to raise the leg and/or when pelvic pain increases markedly during the test.

Composition of groups

PRPP was defined as moderate to severe pelvic pain felt in the region of the SIJs and/or the pubic symphysis. For the analysis, subjects with pain classified as moderate to severe ($VAS_{week} > 3$) were compared with subjects with absent or mild pain ($VAS_{week} \leq 3$). [10] The subjects were divided into four subgroups (A - D) based on the intensity of their pain during pregnancy and postpartum (Table 1).

Table 1. Composition of subgroups of subjects classified according to intensity of pregnancy-related pelvic pain during pregnancy and postpartum.

Group	*n*	Pain during pregnancy (36 wks)	Pain postpartum (8 wks)
A	64	None or mild	None or mild
B	4	None or mild	Moderate to severe
C	29	Moderate to severe	None or mild
D	26	Moderate to severe	Moderate to severe

n = number of subjects

Statistical evaluation

The Kruskal-Wallis test was used for overall comparison of variables of the four subgroups. In case of a significant result ($p < 0.05$), the Mann-Whitney U-test was used to compare subgroups. The Wilcoxon signed rank test was used to analyze changes in SIJ laxity values between the measurements at 36 weeks of pregnancy and 8 weeks after childbirth. The χ^2 test was used for comparisons between groups of categorical variables. A *p*-value of < 0.05 was considered significant.

Results

Subjects

A total of 163 pregnant women at a mean ± SD gestational age of 36.3 ± 1.4 weeks were included in the study. Of these, 123 women also attended re-examination at 7.7 ± 1.9 weeks postpartum. The drop-out group (18 subjects with PRPP and 22 controls) did not differ from the remaining group except for a slightly younger age (27.5 ± 4.4 years *vs.*31.0 ± 5.6 years; $p < 0.05$); these 40 women were excluded from further analysis. Consequently, we report only on the 123 women that were tested both during pregnancy and postpartum.

General and anthropometric data of the 123 subjects who completed both measurements are presented in Table 2; these subjects were divided into four subgroups (Table 1). The subjects in whom PRPP persisted postpartum (subgroup D) had a higher body weight during and after pregnancy than those with no or mild complaints (subgroup A). Significantly more subjects with PRPP during pregnancy (subgroup C and D) had a history of pelvic pain in previous pregnancies than subgroup A. Subgroup D reported a significantly earlier onset of pelvic pain than the other 3 subgroups.

Table 2. General and anthropometric data of the subgroups.

	Subgroup A $n = 64$	**Subgroup B** $n = 4$	**Subgroup C** $n = 29$	**Subgroup D** $n = 26$
Age (yrs)	31.3 ± 6.0	32.5 ± 2.9	29.6 ± 5.4	31.7 ± 5.3
Height (cm)	167.1 ± 7.3	163.8 ± 4.9	165.2 ± 8.4	165.7 ± 6.6
Weight prior to pregnancy (kg)	64.0 ± 12.2	68.8 ± 13.2	66.2 ± 11.8	73.9 ± 17.5
Weight 36 wks during pregnancy (kg)	76.0 ± 12.1	78.5 ± 13.2	78.6 ± 14.0	86.8 ± 16.3*
Weight 8 wks after childbirth (kg)	67.2 ± 11.4	70.3 ± 8.2	71.0 ± 13.9	78.2 ± 15.4*
Parity	0.7 ± 0.9	0.5 ± 0.6	0.9 ± 1.0	1.1 ± 1.0
Nulliparous	32 (50.0%)	2 (50.0%)	12 (41.4%)	9 (34.6%)
Parous	32 (50.0%)	2 (50.0%)	17 (58.6%)	17 (65.4%)
Use of oral contraceptives	56 (87.6%)	4 (100.0%)	26 (89.7%)	25 (96.2%)
Sports activity before pregnancy	43 (67.2%)	2 (50.0%)	21 (72.4%)	19 (73.1%)
Pelvic pain during previous pregnancies	3 (4.7%)	0 (0.0%)	8 (27.6%)*	12 (46.2%)*
Reported onset of pelvic pain (wks)	26.0 ± 5.6	32.0 ± 5.2#	26.6 ± 5.9#	18.4 ± 6.5*

Values are means ±SD and numbers (percentages) of subjects, respectively.
* $p < 0.05$ versus subgroup A.
# $p < 0.05$ versus subgroup D.

SIJ Laxity

Figure 1 shows the mean SIJ laxity values for the subgroups at 36 weeks of pregnancy and at 8 weeks postpartum. There were no significant differences in the mean SIJ laxity values between subgroups either during pregnancy or postpartum. The SIJ laxity measurements obtained at 36 weeks of pregnancy were significantly higher than those at 8 weeks postpartum for subgroup A (a decrease of 0.8 ± 2.0 TU; $p = 0.01$) and for subgroup D (a decrease of 0.7 ± 1.5 TU; $p = 0.03$). No

significant differences between subgroups were found for the reduction of the SIJ laxity after delivery.

Figure 1. Mean SIJ laxity values expressed in threshold units (TU) at 36 weeks of pregnancy and 8 weeks postpartum by subgroups (see Table 1).

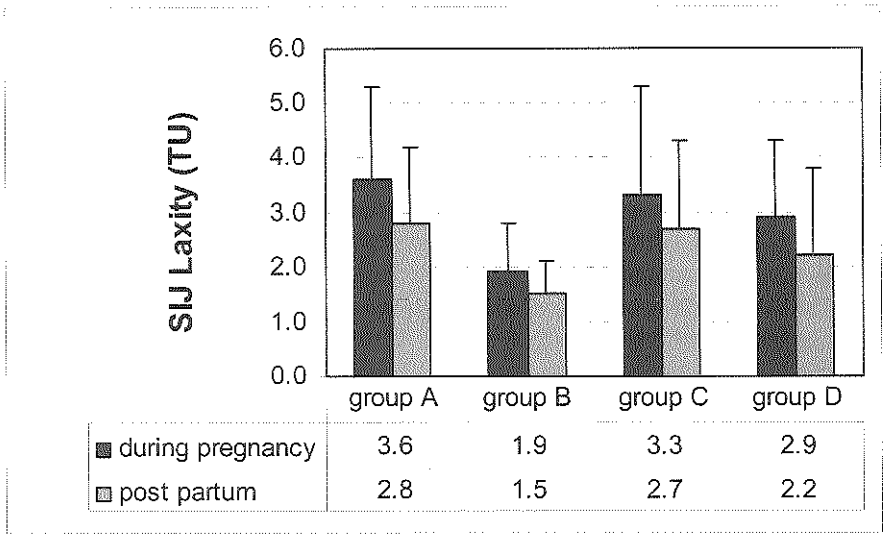
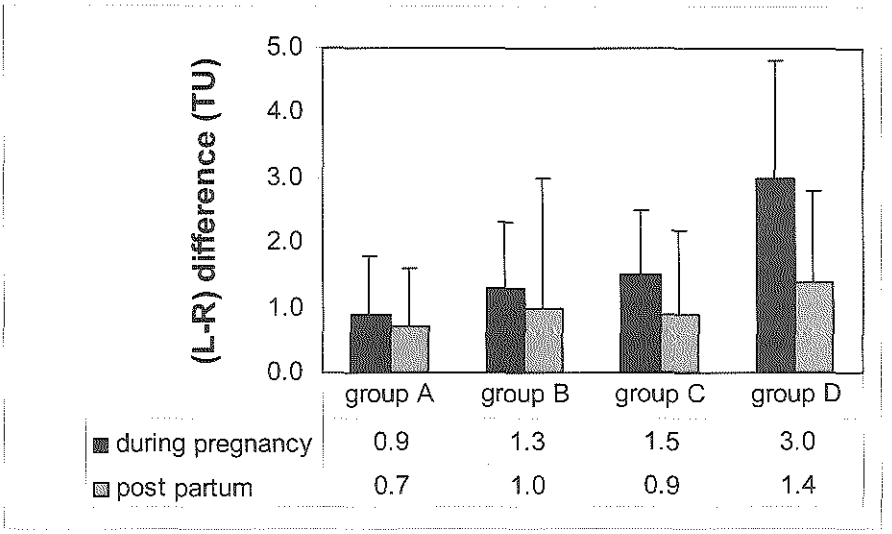


Figure 2 shows the mean differences between left and right SIJ laxity values [(L-R) differences] for all subgroups. Subjects with moderate to severe PRPP both during pregnancy and postpartum (Subgroup D) had a greater (L-R) difference during pregnancy than subjects in the other 3 subgroups. Subjects with moderate to severe PRPP during pregnancy only (subgroup C) also had a greater mean (L-R) difference at 36 weeks of pregnancy than subjects with no or mild PRPP (subgroup A). During pregnancy, asymmetric laxity of the SIJs was found in 17 of the 26 subjects (65.4%) in subgroup D, compared with 3 of the 64 subjects (4.7%) in subgroup A ($p < 0.001$), 0 of the 4 subjects (0%) in subgroup B ($p = 0.001$) and 5 of the 29 subjects (17.2%) in subgroup C ($p < 0.001$). At 8 weeks postpartum, subgroup D still had a greater (L-R) difference than subgroup A ($p = 0.03$) but not compared with subgroup B and C (Figure 2). Postpartum, asymmetric laxity of the SIJs was found in 5 of the 26 subjects (19.2%) in subgroup D compared with 3 of the 64 subjects (4.7%) in subgroup A ($p = 0.03$), 1 of the 4 subjects (25.0%) in subgroup B (not significant), and 2 of the 29 subjects (6.9%) in subgroup C (not significant). In subjects with moderate to severe complaints during

pregnancy (subgroups C and D) there was a significant decrease in the mean (L-R) difference between 36 weeks of pregnancy and 8 weeks postpartum; this decrease was significant compared with subgroup A (Figure 2).

Figure 2. Mean differences between left and right SIJ laxity values [(L-R) difference] expressed in threshold units (TU) at 36 weeks of pregnancy and 8 weeks postpartum by subgroups (see Table 1).



Predictors of moderate to severe PRPP persisting postpartum

In the present study the intensity of pain during pregnancy is a strong predictor of PRPP postpartum, because 26 of our 55 subjects with moderate to severe PRPP during pregnancy still had PRPP postpartum in contrast to 4 of the 68 subjects with no or mild PRPP during pregnancy. Furthermore, subjects with moderate to severe PRPP persisting postpartum (subgroup D) reported significantly higher VAS and QBPDS scores during pregnancy (8.1 ± 1.5 and 62.4 ± 15.3, respectively) than subjects with moderate to severe PRPP during pregnancy but not postpartum (subgroup C) (6.8 ± 1.6 and 50.7 ± 15.4, respectively). Early onset of pelvic pain during pregnancy also predicts moderate to severe PRPP persisting postpartum, because subgroup D reported a significantly earlier onset of pain (18.4 ± 6.5 weeks) than subgroup C (26.6 ± 5.9 weeks).

In the present study only the clinically relevant sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPP) and relative risk

(RR) were calculated for subjects with moderate to severe PRPP during pregnancy (subgroup C and D) because intensity of pain is a strong predictor and asymmetric laxity of the SIJs during pregnancy is rare (4%) in subjects with no or mild complaints. As shown in Table 3, for the asymmetric laxity measurement during pregnancy, the sensitivity (*i.e.*, the ability to identify PRPP postpartum) was 65.4% and the specificity (*i.e.*, the ability to exclude PRPP postpartum on the basis of a negative test) was 82.8%. The PPV of the test (*i.e.*, the probability that a patient with asymmetric laxity of the SIJs during pregnancy had moderate to severe PRPP persisting into the postpartum period) was 77.3%, and the NPV of the test (*i.e.*, the probability that a patient with symmetric laxity of the SIJs during pregnancy did not have moderate to severe PRPP persisting into the postpartum period) was 72.7%. The relative risk (RR) of moderate to severe PRPP postpartum in subjects with asymmetric laxity of the SIJs during pregnancy was 2.8. Table 3 also shows the sensitivity, specificity, PPV, NPV, and RR for the PPPP test and the ASLR test. Optimal prediction was obtained when the asymmetric laxity measurement was combined with the PPPP test, as the sensitivity increased to 84.6% and the RR to 3.4, albeit at the cost of reduced specificity (58.6%). Adding the ASLR test results did not improve the test characteristics.

Table 3. Predictors (measured during pregnancy) of moderate to severe pelvic pain persisting into the postpartum period

	Moderate to severe PRPP during pregnancy						
	Moderate to severe PRPP postpartum ($n = 26$)	None or mild PRPP postpartum ($n = 29$)	Sensitivity %	Specificity %	PPV %	NPV %	RR
Asymmetric laxity (asym)	17 (65.4%)	5 (17.2%)	65.4	82.8	77.4	72.7	2.8
PPPP test	16 (61.5%)	8 (27.6%)	61.5	72.4	66.7	67.7	2.1
ASLR test	20 (76.9%)	13 (44.8%)	76.9	55.2	60.6	66.7	2.4
asym + PPPP	22 (84.6%)	12 (41.4%)	84.6	58.6	64.7	81.0	3.4
asym + ASLR	22 (84.6%)	14 (48.3%)	84.6	51.7	61.1	79.0	2.9
asym + PPPP + ASLR	23 (88.5%)	17 (58.6%)	88.5	41.4	57.5	80.0	2.9

PPV: Positive predictive value; NPV: Negative predictive value; RR: Relative risk; PRPP: pregnancy-related pelvic pain; PPPP test: posterior pelvic pain provocation test; ASLR test: active straight leg raise test.

Discussion

Subjects

A history of pelvic pain in previous pregnancies and early onset of pelvic pain during pregnancy are reported to be factors that predispose to pelvic pain during pregnancy. [5, 17, 22] The results of the present study imply that pelvic pain during pregnancy is associated with high body weight during pregnancy, a history of pelvic pain in previous pregnancies, and early onset of pelvic pain. However, multiparity alone does not increase the risk of PRPP in pregnancy. Although body weight has not consistently been reported as a predisposing factor, [4, 21, 22] our study confirms the suggestion that it is. [15]

Previous studies have shown that, in the majority of women with PRPP, pain disappears within one or two months after childbirth. [3, 17, 25] Our study confirms this finding; *i.e.*, in 29 of the 55 subjects (52.7%) with pelvic pain during pregnancy, the pain had disappeared at 8 weeks postpartum.

SIJ laxity

It is well-recognized that joint laxity increases during pregnancy. [1, 4, 9, 23] In a previous study we observed a normal mean SIJ laxity of 2.8 TU in non-pregnant women. [8] The observation in the present study that pregnancy values are increased, is in agreement with previous studies. [1, 4, 9, 23] Comparing our results (Figure 1) with a normal mean SIJ laxity of 2.8 TU in non-pregnant women, [8] we think that the increased laxity during pregnancy returns to prepregnancy values within 8 weeks postpartum.

Several authors have suggested an association between increased pelvic girdle relaxation and PRPP. [1, 5, 13, 18] However, as previously reported [11] and confirmed in the present study, absolute SIJ laxity values in pregnant women with moderate to severe PRPP are not significantly different from those in pregnant women with no or mild PRPP. This suggests that it is not the magnitude of the SIJ laxity *per se* that determines the presence of moderate to severe PRPP.

The present study confirms our previous observation that asymmetry between left and right SIJ laxity during pregnancy is more directly related to PRPP than to absolute SIJ laxity values. [11] The present study also demonstrated that, postpartum, PRPP is related to asymmetric laxity of the SIJs, rather than to absolute SIJ laxity.

Predictors of moderate to severe PRPP persisting postpartum

Our data confirm that persistence of pain postpartum is related to the intensity of the pain during pregnancy. [25] Subjects with moderate to severe PRPP persisting postpartum (subgroup D) reported significantly more pain and experienced more disability during pregnancy than the subjects with moderate to severe PRPP during pregnancy but not postpartum (subgroup C). In addition, the data show that early

onset of pelvic pain during pregnancy is also indicative of persistence of moderate to severe PRPP postpartum.

The asymmetric laxity measurement can be used in the prognosis of PRPP postpartum. Study participants with asymmetric laxity of the SIJs during pregnancy have a threefold higher risk of moderate to severe PRPP persisting into the postpartum period than subjects with symmetric laxity. By combining this test with the PPPP test, the test characteristics can be further improved to discriminate between those women who will have persistent PRPP postpartum and those who will not. Of note, the results of the PPPP test and ASLR test are based on subjective outcomes and specific movement procedures designed to elicit pain, whereas the asymmetric laxity measurement is independent of the subject's pain. Therefore, addition of the objective asymmetric laxity measurement in subjects with moderate to severe PRPP could help to identify the subjects who need special attention during pregnancy and postpartum.

At this time, discussing the course of asymmetric laxity of the SIJs will result in speculations. Because we have not measured SIJ laxity early in pregnancy, we cannot give an answer to the question if PRPP is caused by asymmetric laxity of the SIJs. Asymmetric laxity can also be a symptom caused by pain in the pelvic region. Further studies are needed before any statement can be made.

Conclusion

This study shows that it is not the magnitude of SIJ laxity *per se* that determines the presence of moderate to severe PRPP but rather the asymmetric laxity of the SIJs. Subjects with asymmetric laxity of the SIJs during pregnancy have a threefold higher risk that moderate to severe PRPP will persist into the postpartum period than subjects with symmetric laxity during pregnancy. Our data suggest that in subjects with moderate to severe complaints during pregnancy, the measurement of SIJ asymmetric laxity is predictive of moderate to severe postpartum PRPP.

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Chapter 5

Does a pelvic belt influence sacroiliac joint laxity?

Abstract

Objective. To evaluate the influence of different positions and tensions of a pelvic belt on sacroiliac joint laxity in healthy young women. ***Background.*** Clinical experience has shown that positive effects can be obtained with different positions and tensions of a pelvic belt. A functional approach to the treatment of the unstable pelvic girdle requires an understanding of the effect of a pelvic belt on a normal pelvic girdle. ***Methods.*** Sacroiliac joint laxity was assessed with Doppler imaging of vibrations. The influence of two different positions (low: at the level of the symphysis and high: just below the anterior superior iliac spines) and tensions (50 and 100 N) of a pelvic belt was measured in ten healthy subjects. Data were analysed using repeated measures analysis of variance. ***Results.*** Tension does not have a significant influence on the amount by which sacroiliac joint laxity with belt differs from sacroiliac joint laxity without belt. A significant effect was found for the position of the pelvic belt. Mean sacroiliac joint laxity value was 2.2 (SD, 0.2) threshold units nearer to the without-belt values when the belt was applied in low position as compared to the case with the belt in high position. ***Conclusions.*** A pelvic belt is most effective in a high position, while a tension of 100 N does not reduce laxity more than 50 N.

Introduction

The role of the pelvic belt in the treatment of subjects with pregnancy-related pelvic pain is still controversial. Clinical experience has shown that positive effects can be obtained with different positions and tensions of the belt. [1] In an anatomical study, the mobility of the sacroiliac joint (SIJ) was significantly restricted by application of a pelvic belt with a tension of 50 N, while larger forces did not give better results. [2] The underlying theory of the use of a pelvic belt is that the articular surfaces of the SIJ will be pressed together, which raises friction to resist shearing. [2-4] However, there is no in vivo proof of this mechanical effect. Therefore, first, a rational approach to the treatment of the unstable pelvic girdle requires an understanding of normal stability of the SIJs with and without the application of a pelvic belt. The next step will be measurements with patients with pregnancy-related pelvic pain.

For a better understanding of the stability of the SIJs, a conceptual model of Panjabi may be helpful. [5] This model describes the interaction between a passive, an active and a control system that provide stability. The passive system pertains to the osteoarticuloligamentous structures, the active system pertains to the myofascia while the control system through its central and peripheral neural connections co-ordinates the actions of all. Furthermore, he defined a zone of motion, which he called the neutral zone. This is a small range of displacement near the joint's neutral position, where minimal resistance is offered by the osteoligamentous structures. It is the zone of high flexibility or laxity. Several experimental studies have supported the view that the neutral zone is a more sensitive parameter than the range of motion in characterising SIJ dysfunction. [6] So, stability is not about how much movement there is or is not but rather about the laxity of the joints. [7]

The SIJ is an articulatio plana with small physiological mobility: translations of approximately 1.5 mm and rotations of approximately 4° were measured by roentgen stereophotogrammetry in vivo. [8] So, in the clinical setting laxity in the SIJ joint is difficult to assess when compared with, for example, the elbow or knee joint. Some years ago, a method using low energy vibrations has been developed to measure joint laxity in vivo. This method, Doppler imaging of vibrations (DIV), was shown to be a reproducible and reliable method to measure the laxity of the SIJ [9] as well as the first tarsometatarsal (TMT 1) joint. [10]

The aim of the present study is to evaluate the influence of different positions and tensions of a pelvic belt on the laxity of the SIJ in healthy young women.

Methods

Subjects

Ten healthy subjects with a mean age 25.4 (SD, 2.7) years, mean height 171 (SD, 4.0) cm and mean body weight 66.0 (SD, 10.3) kg were recruited to participate in this study. The inclusion criteria were female and aged 18 to 30 years. Subjects with a history of pelvic and/or low back pain in the previous year were excluded from the study.

SIJ laxity measurement

The DIV technique was used to measure SIJ laxity. [9, 11] During a measurement the subject was lying in prone position with relaxed muscles on a mattress. A colour Doppler imaging scan (Quantum Angio Dynograph 1, Philips Ultrasound, Santa Ana, California, USA) was used to produce the Doppler imaging of vibrations images. Vibrations (Derritron Electronics, Hastings, England) with an amplitude not exceeding 0.05 mm and a frequency of 200 Hz were applied to the anterior superior iliac spine. These vibrations with low energy have been shown to be safe and useful for this kind of measurement. [9] The vibrations propagate in the pelvis across the SIJ. In a stiff joint, there is a small or imperceptible difference in vibration amplitude between both sides. The vibrations at both sides of the joint are picked up by the colour Doppler imaging transducer. The intensity of the vibration pixels of the ilium and sacrum appears simultaneously on the monitor at high threshold values (dimension power dB). Using the threshold button on the control panel of the colour Doppler imaging apparatus allows measurements by comparing the vibration amplitude of the ilium and of the sacrum as follows. At first, a threshold level is found at which the colour of the vibrating sacrum disappears and changes to grey scale. Next, a second threshold level is found for the ilium. The difference in threshold levels is expressed in *threshold units* (TU). Since the threshold levels as measured by DIV are directly related to the vibration amplitude of the bone, a small or absent difference between the threshold levels of the sacrum and ilium is accepted as an indication of a stiff joint (low laxity < 2 TU). [9] A large difference between the threshold levels of the sacrum and ilium is an indication of a loose joint (high laxity > 5 TU). [9] The measurements were performed with unloaded SIJ, so laxity values found are representative for the neutral zone. [10]

Experimental procedure

We performed three consecutive SIJ laxity measurements without postural change and used the mean laxity value of each SIJ for further analysis. SIJ laxity was tested with and without a pelvic belt. For this purpose a belt of non-elastic material (model 3221/3300; Rafys, Hengelo, The Netherlands) was used which was 5 cm wide at the anterior and 7 cm at the posterior side. The tension was measured by means of strain gauges in the buckle of the pelvic belt.

SIJ laxity was measured at both sides at five subsequent conditions:

1. without a pelvic belt;
2. with a pelvic belt at the level of the symphysis (low position) and a tension of 50 newton (N);
3. with a pelvic belt at the level of the symphysis (low position) and a tension of 100 N;
4. with a pelvic belt just below the anterior superior iliac spines (high position) and a tension of 50 N;
5. with a pelvic belt just below the anterior superior iliac spines (high position) and a tension of 100 N.

In all tests the belt position was adjusted in the erect posture while the tension was set at 50 or 100 N in prone position. Between measurements the pelvic belt was removed and the subjects walked around for a few minutes to minimise possible influence of an earlier measurement.

Statistical analysis

The data were analysed using 3-factor repeated measure analysis of variance (ANOVA). In this procedure, the dependent variable was the difference in SIJ laxity between the condition with a pelvic belt and the condition without a pelvic belt. The independent variables were side (left *versus* right), tension (50 N *versus* 100 N), and position (high and low). The residual covariance structure was assumed to be of the type compound symmetry. A p-value of < 0.05 was taken to represent statistical significance.

Results

The mean SIJ laxity values in threshold units (TU) are presented in Table 1 for five conditions: without a pelvic belt, with a pelvic belt in low position and a tension of 50 N, with a pelvic belt in low position and a tension of 100 N, with a pelvic belt in high position and a tension of 50 N, and with a pelvic belt in high position and a tension of 100 N.

SIJ laxity values were on average lower with belt than without belt. In Table 1 we present the SIJ laxity values averaged across both sides, because side does not have a significant effect on the amount by which SIJ laxity with belt differs from SIJ laxity without belt ($p = 0.15$). Also tension did not have a significant influence on this amount ($p = 0.39$). A significant effect was found for the position of the pelvic belt ($p < 0.001$). Mean SIJ laxity values were on an average 2.2 (SD, 0.2) TU nearer to the without-belt values when the belt was applied in low position as compared to the case with the belt in high position.

Table 1. Mean sacroiliac joint (SIJ) laxity values measured in threshold units (TU) at five conditions.

	Mean (SD) threshold units
Without a pelvic belt	6.1 (1.6)
Belt in low position with 50 N tension	5.4 (1.1)
Belt in low position with 100 N tension	5.1 (1.6)
Belt in high position with 50 N tension	3.0 (1.3)
Belt in high position with 100 N tension	3.1 (1.2)

Discussion

In the present study, we applied DIV to assess the laxity of the SIJs. To exclude the influence of muscle tension, we performed the experiment without weight bearing, with the subjects in prone position. DIV gives an indication of the amount of laxity rather than the maximal excursions of a joint, because of the very small amplitude of the vibrations, far below the physiological range of motion of the joints. In unloaded position this laxity reflects the neutral zone, which was shown to be a more sensitive parameter in characterising SIJ dysfunction than range of motion. [6]

An increase of belt tension from 50 N to 100 N did not lead to a significant change of laxity, although a small decrease was seen with the belt in low position. Our data are in agreement with earlier studies. [1, 2] Mens *et al.* found that a pelvic belt with 50 N was sufficient to influence the active straight leg raise test in patients with pregnancy-related pelvic pain, and increased tension produced results similar to those at 50 N. [1] We ascribe the effect of a pelvic belt to enlargement of intra-articular friction in the SIJs. [2-4] The tension of a pelvic belt can be compared with the muscle activity of the transversus abdominis (and the obliquus internus abdominis) muscle. Due to the anterior attachment of the transversus abdominis muscle to the iliac crest, this muscle is ideally placed to act on the ilia to produce, in combination with stiff dorsal sacroiliac ligaments, compression of the SIJs. [3, 4] According to Richardson *et al.*, [4, 12] forces of only 30-40% of the maximum voluntary forces of the transversus abdominis are sufficient to achieve stability of the pelvis. Because the lever arm of the transversus abdominis is almost equal to the lever arm of the pelvic belt no higher tension is needed to achieve joint stabilisation. Higher tension is also not recommended because of skin pressure and discomfort.

With the application of a belt just below the anterior superior iliac spines (high position) the results in this study showed at both tension levels a significant decrease of SIJ laxity. Laxity decrease was also shown with the belt applied at the level of the symphysis (low position), but it was less. This may be explained by a less direct compression because, in the latter position, most of the belt is below the contact area of the SIJ and the belt compresses the symphysis rather than the SIJs.

Limitations of the study and directions for the future

The main limitation of this study was that SIJ laxity was only measured in prone position. At present it is not possible to quantify SIJ laxity values in loaded position. By measuring in prone position, we measured the influence of the pelvic belt on SIJ laxity and tried to exclude muscle activity and tension of ligaments that could have contributed to the decreasing SIJ laxity. Earlier studies have shown that both activation of the local stabilisers (transversely oriented abdominal muscles) as well as the global mobilisers (biceps femoris, gluteus maximus, erector spinae, latissimus dorsi) can significantly decrease SIJ laxity. [4, 13] Further studies will focus on the performance of measurements in standing position with the aim to investigate how SIJ laxity will behave in the standing position with and without a pelvic belt.

Conclusions

The decrease of SIJ laxity values with the application of a pelvic belt is due to the position of the pelvic belt rather than the tension of the belt. Tensions of 50 N and 100 N do not have a significant influence on the amount by which SIJ laxity with belt differs from SIJ laxity without belt. A pelvic belt was more effective when the application was just below the anterior superior iliac spines (high position) as compared to the application at the level of the symphysis (low position).

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Chapter 6

The mechanical effect of a pelvic belt in patients with pregnancy-related pelvic pain

Abstract

Study design. Two different positions of a pelvic belt were tested in 25 subjects with pregnancy-related pelvic pain (PRPP) and their effects compared in relation to sacroiliac joint (SIJ) laxity. ***Objective.*** To investigate the mechanical effect of a pelvic belt on the laxity of the SIJ in patients with PRPP. ***Summary of background data.*** Many patients experienced relief of pain when using a pelvic belt, but there is no in vivo evidence of the mechanical effect of the application of a pelvic belt in patients with PRPP. ***Methods.*** SIJ laxity values were recorded by means of Doppler imaging of vibrations in prone position with and without the application of a pelvic belt. The belt was positioned either just below the anterior superior iliac spines (high position) or at the level of the pubic symphysis (low position). ***Results.*** SIJ laxity values decreased significantly in both positions of the pelvic belt ($p < 0.001$). Application of the pelvic belt in high position decreased SIJ laxity to a significantly greater degree than application of the belt in low position ($p = 0.006$). ***Conclusion.*** Application of a pelvic belt in high position significantly decreases the laxity of the SIJs; this decrease is larger than with application of a pelvic belt in low position. These findings are in line with the biomechanical predictions and support the use of a pelvic belt for the treatment of PRPP.

Introduction

Pregnancy-related pelvic pain (PRPP) is a major problem for the society. The reported incidence in prospective studies, where diagnosis was based on pain history and/or clinical examination, ranges from 6-23%. [1, 11, 17] In the majority of women suffering from pelvic pain during pregnancy the pain disappears within the first three months after childbirth, but about 2-11% of the total obstetric population seem to develop a chronic pain condition. [1, 11, 19] Objective criteria with respect to cause as well as pain-evoking structures are difficult to find, which makes optimal choice of therapy uncertain or even controversial. Many patients experienced relief of pain when using a pelvic belt, which makes this therapy a common phenomenon. [2, 13, 18] The underlying theory of the use of a pelvic belt is that the articular surfaces of the sacroiliac joint (SIJ) will be pressed together to provide stability, but there is no in vivo evidence of this mechanical effect. [23-25]

Panjabi [20] has proposed a conceptual model which describes the interaction between a passive, an active and a control system to achieve stability. The passive system pertains to the osteoarticuloligamentous structures, the active system pertains to the myofascia, while the control system (via its central and peripheral neural connections) co-ordinates the actions of all these systems. Furthermore, he defined a zone of motion, which he called the neutral zone. This is a small range of displacement near the joint's neutral position, where minimal resistance is offered by the osteoligamentous structures. It is the zone of high flexibility or laxity. Several experimental studies have supported the view that the neutral zone is a more sensitive parameter than the range of motion in characterising SIJ dysfunction. [21]

In the clinical setting laxity of the SIJ is difficult to assess when compared with, for example, the elbow or knee joint. In the mid-1990s, a method using low energy vibrations has been developed to measure joint laxity in vivo. This method, Doppler imaging of vibrations (DIV), was shown to be reproducible and reliable for the SIJ [3, 7] as well as sufficiently sensitive to detect SIJ laxity changes as a result of specific contractions of the transversus abdominis muscle. [23]

In an anatomical study, the mobility of the SIJ was significantly restricted by application of a pelvic belt with a tension of 50 N, while larger forces did not give better results. [25] In another study the influence of two different positions (low: at the level of the symphysis, and high: just below the anterior superior iliac spines) and two different tensions (50 and 100 N) of a pelvic belt was measured with DIV in ten healthy women. [8] Application of a pelvic belt in the high position resulted in a significant decrease of SIJ laxity in all subjects. In agreement with the anatomical study, an increase of belt tension from 50 N to 100 N did not result in a significant decrease of laxity. With a pelvic belt applied in the low position the effect on SIJ laxity was small at 100 N and absent at 50 N.

The aim of the present study was to investigate the mechanical effect of two different positions of a pelvic belt on the laxity of the SIJ in patients with PRPP.

Material and Methods

Study population

A group of 25 patients were selected from the outpatient clinic of a rehabilitation centre, specialised in treatment of PRPP (Table 1). Included were non-pregnant women with PRPP that started during pregnancy. The duration of the postpartum period was restricted to 5 years. PRPP was defined as moderate or severe pain experienced in (at least) the region of the SIJs and/or in the pubic symphysis region. The main exclusion criterion was the presence of low back and/or pelvic pain *before* pregnancy. Also excluded were subjects with pain radiating to below the knee, known congenital anomalies of the spine, known rheumatologic disease affecting the locomotion system or previous surgery of the lumbar spine or pelvis. The study was approved by the hospital's Ethical Committee and written informed consent was obtained from each subject.

Table 1. General data and pain scores for 25 subjects with pregnancy-related pelvic pain.

	Mean	S.D.	Range
Age (years)	33.0	4.0	24-43
Body weight (kg)	70.5	11.0	55-95
Height (cm)	170.6	7.0	160-183
Parity	1.8	1.0	1-5
Duration of complaints (months)	28.0	14.3	12-60
Pain on visual analogue scale (mm)	63.8	18.5	31-90
Quebec back pain disability scale	46.5	15.8	19-76

Severity of pain was measured by means of a 100-mm horizontal visual analogue scale for the worst pain during the preceding week (VAS_{week}) with a range from 0 to 100, where 0 denoted no pain and 100 worst possible pain. [19] Only subjects with pain classified as moderate to severe ($VAS_{week} > 30$) were included in this study. [5] Disability was measured with a modified Quebec back pain disability scale (QBPDS, range 0-100). [10] This scale was originally developed to measure the grade of disability in non-specific low back pain, but has also been used for patients with PRPP. [6, 14, 16]

SIJ laxity measurement

SIJ laxity was measured with DIV. [3, 4, 6] During a measurement each subject was lying on a mattress in prone position with relaxed muscles. Vibrations, with an amplitude not exceeding 0.05 mm and a frequency of 200 Hz, were applied unilaterally to the anterior superior iliac spine. Vibrations were generated by a Derritron VP3 vibrator and driven by a TA120 power amplifier (both Derritron Electronics, Hastings, England). The vibrations propagate in the pelvis through the ilium to the SIJ. At the dorsal side, the intensity of the vibrations was measured across the ipsilateral SIJ with colour Doppler imaging (Quantum Angio Dynograph 1, Philips Ultrasound Inc. 1987, Santa Ana, California, USA). The colour processing in our measurement instrument is based on fast Fourier transformation. At the dorsal side the transducer was positioned across the sacroiliac region and the intensity of vibrations was measured successively on both sides of the SIJ. In a stiff joint, there is a small or imperceptible difference in vibration amplitude between both sides. The vibrations at both sides of the joint are picked up by the colour Doppler imaging transducer. The intensity of the vibration of the ilium and sacrum appears simultaneously on the monitor at high threshold values (dimension power dB). Using the threshold button on the control panel of the colour Doppler imaging apparatus allows measurements by comparing the vibration amplitude of the ilium and of the sacrum as follows. At first, a threshold level is read from the monitor at which the colour of the vibrating sacrum disappears and changes to grey scale. Next, a second threshold level is found for the ilium. The difference in threshold levels is expressed in *threshold units* (TU, dimension dB). Since the threshold levels as measured by DIV are directly related to the vibration amplitude of the bone, a small or absent difference between the threshold levels of the sacrum and ilium is accepted as an indication of a stiff joint (low laxity < 2 TU). [3] A large difference between the threshold levels of the sacrum and ilium is an indication of a loose joint (high laxity > 5 TU). [3] The measurements were performed with unloaded SIJ, so laxity values found are representative for the neutral zone. [9]

We performed three consecutive SIJ laxity measurements without any postural change and used the mean laxity value of each SIJ for further analysis. In a previous study it was postulated that a difference between left and right SIJ laxity is an important feature for pregnancy-related pelvic pain. [4, 6] The absolute difference between left and right SIJ was calculated (|left-right|). [4, 6] Based on previous studies a difference of 3 TU or more was defined as asymmetric laxity of the SIJs. [4, 6]

The SIJ laxity measurements were repeated with a pelvic belt. The belt was adjusted in two different positions: just below the anterior superior iliac spines (high position) and at the level of the symphysis (low position). A belt of non-elastic material was used (model 3221/3300, Rafys, Hengelo, The Netherlands) 5 cm wide at the anterior and 7 cm at the posterior side. The applied tension of the

belt was ranged between 50 and 100 N, because 50 N was the minimum tension needed to influence SIJ laxity and the active straight leg raise (ASLR) test. [8, 14, 25]

Active straight leg raise (ASLR) test

The ASLR test is a well-documented, reliable, sensitive and specific diagnostic test to assess PRPP. [14-16] Furthermore, the influence of a pelvic belt on the ASLR test predicts the usefulness of a pelvic belt during activities of daily living in individual subjects. [15] In this study, the effect of a pelvic belt on the active straight leg raise (ASLR) test was used to investigate the relation between SIJ laxity and clinical parameters. The ASLR test was performed in supine position with straight legs and feet 20 cm apart. [14-16] The subject had to raise the legs, one after the other, 20 cm above the examination table without bending the knee. The patient was asked to score impairment on a six-point scale: not difficult at all = 0; minimally difficult = 1; somewhat difficult = 2; fairly difficult = 3; very difficult = 4; unable to do = 5.

The subject was asked whether the ability to actively raise the leg changed when the test was performed again with a pelvic belt in the high and low position fastened around the pelvic girdle. One observer (LD) who was specially trained in the DIV technique performed all SIJ laxity measurements and all active straight leg raise tests.

Statistical analysis

Statistical analysis involved the calculation of the means and standard deviations for each of the variables measured. The data were analysed using 3-factor repeated measure analysis of variance (repeated measures ANOVA). In this procedure, the dependent variable was the difference in SIJ laxity between the condition with a pelvic belt and the condition without a pelvic belt. The independent variables were side (left *versus* right), and position (high and low). Another analysis was done with the results of the ASLR test. The residual covariance structure was assumed to be of the type compound symmetry. The correlation between the ASLR test and SIJ laxity values was determined by calculating the Pearson's correlation coefficient. A p-value of < 0.05 was taken to represent statistical significance.

Results

SIJ Laxity

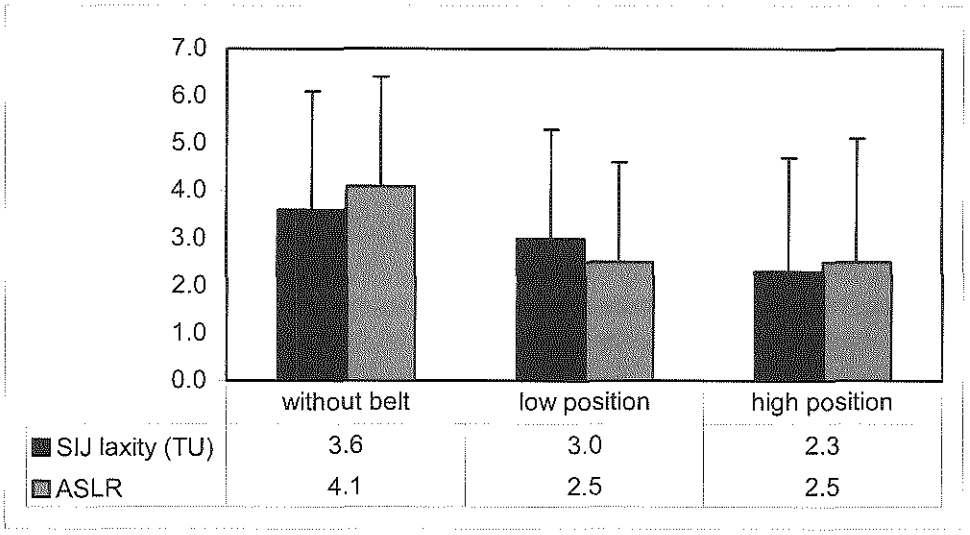
The mean SIJ laxity values, measured in threshold units (TU) are shown in Figure 1 for three conditions: without a pelvic belt, with a pelvic belt in low position and with a pelvic belt in high position. SIJ laxity values showed a significant decrease with the application of a pelvic belt in low and high position (both $p < 0.001$) as compared to the condition without belt. The application of a pelvic belt in high position decreased SIJ laxity to a significantly greater degree (1.3 TU) than the

application of a belt in low position (0.6 TU) (p = 0.006). Side did not have a significant effect on the amount by which SIJ laxity with belt differs from SIJ laxity without belt: the mean difference between left and right SIJ laxity values was without a pelvic belt 1.1 ± 1.5 TU, with a belt in low position 0.8 ± 0.8 TU, and with a belt in high position 0.8 ± 1.3 TU (p = 0.74).

ASLR test

The mean score on the ASLR test (0-10) is also shown in Figure 1 for the same three conditions as the SIJ laxity values. ASLR scores showed a significant decrease with the application of a pelvic belt in both low and high position (both p < 0.001) as compared to the condition without belt. The ASLR test performed with a belt reduced the impairment (ASLR scores) in 24 subjects on the left side and 21 subjects on the right side. In contrast to the laxity values, no significant difference in ASLR scores was found between the application of a pelvic belt in low and high position. For the left side 10 subjects preferred the low position of the belt, 11 the high position and 4 had no preference. For the right side these numbers were 9, 9 and 7, respectively. Side did not have a significant effect on the amount by which ASLR scores with a belt differ from ASLR scores without a belt.

Figure 1. Mean SIJ laxity values in threshold units (TU) and ASLR scores (range 0-10) of 25 subjects with pregnancy-related pelvic pain measured in three conditions: without a pelvic belt, with a pelvic belt in low position, and with a pelvic belt in high position.



	without belt	low position	high position
SIJ laxity (TU)	3.6	3.0	2.3
ASLR	4.1	2.5	2.5

Correlation between SIJ laxity values and clinical parameters

The decrease in mean laxity value with the application of a pelvic belt in low position compared with the condition without belt was significantly correlated with the decrease in ASLR score (Pearson's correlation coefficient 0.48, $p = 0.02$). The same observation was found for the decrease with the application of a pelvic belt in high position compared with the condition without belt (Pearson's correlation coefficient 0.51, $p = 0.01$).

In this study group, only five of the 25 women with PRPP (20%) had asymmetric laxity of the SIJs. Table 2 gives the clinical scores and the ASLR scores of the subjects with asymmetric and symmetric laxity. Although a significant difference was found only on the VAS for the worst pain during pregnancy, subjects with asymmetric laxity had higher scores on self-reported severity scales on disability (QBPDS), on pain (VAS for the worst pain during the preceding week) and on the ASLR test than subjects with symmetric laxity.

Table 2. Clinical scores and positive ASLR test score in relation to results of sacroiliac joint laxity measurements in 25 subjects with pregnancy-related pelvic pain.

	Laxity measurement		
	Symmetric $n = 20$	Asymmetric $n = 5$	p-value
Pain (VAS) during pregnancy (mm)	71.4 ± 22.6	93.0 ± 4.7	0.02
Pain (VAS) last week (mm)	64.1 ± 19.3	67.0 ± 17.7	0.77
Quebec back pain disability scale	45.5 ± 15.3	52.6 ± 17.6	0.53
ASLR score (left + right)	3.7 ± 2.3	5.6 ± 2.0	0.08

Discussion

SIJ laxity

In this study the effect of different positions of a pelvic belt on the laxity of the SIJ was studied in 25 patients with PRPP. SIJ laxity was significantly restricted by application of a pelvic belt at the level of the symphysis (low position) as well as just below the anterior superior iliac spine (high position). The application of a pelvic belt in high position decreased SIJ laxity to a significantly greater degree than the application of a belt in low position. This may be explained by a less direct compression because, in the low position, most of the belt is below the contact area of the SIJ and the belt compresses the symphysis rather than the SIJs. Furthermore, earlier studies have shown that independent contractions of the transversus abdominis (in co-contraction with multifidus) can significantly decrease SIJ laxity

and have beneficial effects in relieving pain and disability in chronic low back pain patients. [22, 23] By varying the location of the pelvic belt, the action of different local stabilisers can be simulated. A pelvic belt in high position simulates the action of the transversus abdominis (anterior compression on ASISs) and the action of the multifidus (posterior compression on PSISs) while approximation of the pelvis at the level of the pubic symphysis (low position) simulates the action of the pelvic floor. [12]

In this study the mean SIJ laxity value observed (3.6 ± 2.5 TU) was comparable with that found in earlier studies on pain-free pregnant women (3.4 ± 1.8 TU) and healthy subjects (3.6 ± 2.9 TU), but higher than the levels found in pregnant women with PRPP (3.0 ± 1.7 TU) and patients with chronic PRPP (2.7 ± 2.8 TU). [3, 4, 6] Similar results were found for the mean difference between the left and right SIJ laxity values. The mean difference between left and right SIJ laxity values in the present study (1.1 ± 1.5 TU) was also similar to that reported in pain-free pregnant women (0.9 ± 0.9 TU) and healthy subjects (1.5 ± 1.1 TU) but not comparable with pregnant women with PRPP (3.0 ± 1.7 TU) and patients with chronic PRPP (2.7 ± 2.8 TU). [3, 4, 6] The reason why the SIJ laxity values of our subjects were comparable to those of healthy subjects rather than to those of patients might be because our subjects were selected from an outpatient clinic of a rehabilitation centre, specialised in treatment of PRPP. In this centre, they learn the independent contraction of the transversus abdominis (in co-contraction with multifidus) and this contraction may have beneficial effects on the asymmetric laxity of the SIJs.

ASLR test

There was a significant decrease in ASLR scores with the application of a pelvic belt in low and high position as compared to the condition without belt, but the differences between the low and high position were not significant. These findings are in line with an earlier study in which a reduction of impairment was found in 95% of the patients when the ASLR test was performed with a pelvic belt and no preference of position of the belt was observed. [14]

Correlation between SIJ laxity values and clinical parameters

The present study demonstrated that the measurement technique used is sufficiently sensitive to detect changes in SIJ laxity resulting from two applications of a pelvic belt. Measurement of SIJ laxity and the ASLR test seem to have similar qualities to measure changes resulting from application of a pelvic belt in two positions. The correlation coefficients between the decrease of the mean laxity value and ASLR score with the application of a pelvic belt in low and high position, compared with the condition without belt, are satisfactory. An advantage of the SIJ laxity measurement is that the results are not dependent on the patient's pain score.

Advantage of the ASLR test is the simplicity of score measurement. [16] The results of this study show that the influence of a pelvic belt on the ASLR test used to determine the best position of the belt and the required tension is proven and substantiates the earlier suggestion made by Mens *et al.* [15]

The clinical scores of the subjects with asymmetric laxity of the SIJs are comparable to those reported earlier. [6] Subjects with asymmetric laxity of the SIJs reported significantly more pain during pregnancy than subjects with symmetric laxity. Scores on the VAS for the worst pain during the preceding week, the disability score and the ASLR score were also higher in the asymmetric group than in the symmetric group; the reason why the differences between the symmetric and asymmetric group were not significant may be due to the small number of patients in the asymmetric group.

Study limitations and future directions

At present it is not possible to quantify SIJ laxity values in loaded position. By measuring in prone position, we measured the influence of the pelvic belt on SIJ laxity and tried to exclude muscle activity and tension of ligaments that may have contributed to a decrease in SIJ laxity. Earlier studies have shown that both activation of the local stabilisers (transversely oriented abdominal muscles) and the global mobilisers (biceps femoris, gluteus maximus, erector spinae, latissimus dorsi) can significantly decrease SIJ laxity. [23, 26] Future studies should focus on measurements performed in standing position in order to investigate how SIJ laxity will respond to this position with and without a pelvic belt.

Conclusion

Application of a pelvic belt in high position significantly decreases the laxity of the SIJs; moreover this decrease in laxity is greater than with application of a pelvic belt in low position. The SIJ laxity measurement and the ASLR test appear to have similar qualities in measuring changes resulting from different applications of a pelvic belt, i.e. the correlation coefficients between the decrease of the mean laxity value and ASLR score with the pelvic belt in low and high position, compared with the condition without belt, are satisfactory. These results support the use of a pelvic belt for the treatment of PRPP.

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Chapter 7

General discussion and conclusions

The phenomenon that healthy women develop pain in the low back and pelvis during pregnancy has been a concern for many years. The term 'pelvic instability' was often used and still is to describe the increased laxity of the pelvic joints which is thought to facilitate the delivery. The aim of the work in this thesis was to gain insight into this syndrome, which can have drastic consequences such as being confined to a wheelchair or becoming bedridden. Mens *et al.* have provided substantial evidence to support the hypothesis that joint laxity and degeneration of the joints in the pelvic ring play a major role in pregnancy-related pelvic pain (PRPP). [8] The main problem was that no objective instrumental method was available to measure laxity of the pelvic joints. The department of Biomedical Physics and Technology and the department of Rehabilitation developed the method of Doppler imaging of vibrations (DIV) which provides non-invasive patient-friendly data on sacroiliac joint (SIJ) laxity. A distinction can be made between 'stiff' and 'unstiff' SIJs. However, the precise mechanism whereby vibrations are transferred through the pelvic bones and across the SIJ requires further studies focusing on a biomechanical modeling of multi-mass-spring-damper systems. With regard to the detection of vibrations we are aware of the fact that the color Doppler imaging apparatus used in our investigations was developed for other purposes. Therefore, studies are in progress to optimize the measurement technique. This may result in a physical parameter representing laxity, which is more appropriate than the currently used *threshold units* (TU).

Using the measurement technique in its present form, reproducibility and reliability was nonetheless shown to be good, provided that three repetitions during one test occasion were performed by an experienced tester (*chapter 2).* Some variation between occasions might be inevitable, despite strict standardisation of the measurements. The results from this study indicate that specific training and experience of a tester are necessary for reliable SIJ laxity measurements. With the help of the generalisability theory it was concluded that we can be 95% certain that a difference larger than 2.8 TU is above the 95th percentile of the difference between left and right SIJ laxity in healthy women. Thus, a woman with a difference ≥ 3 TU between left and right SIJ laxity is not within the normal range of difference and is then designated as having asymmetric laxity of the SIJs.

This latter study allowed us to drawn conclusions about measurements during pregnancy and after childbirth (*chapters 3 and 4*). Several authors have suggested an association between increased pelvic girdle relaxation and PRPP. [1, 2, 5, 7] Our prospective cohort study resulted in the spectacular observation that SIJ laxity as such is not an explanation for PRPP. We found that the increased laxity during pregnancy returns to pre-pregnancy values within 8 weeks postpartum, and that absolute SIJ laxity values in pregnant women with moderate to severe PRPP are not significantly different from those in pregnant women with no or mild PRPP. This suggests that it is not the magnitude of the SIJ laxity *per se* that determines the

presence of moderate to severe PRPP. This also means that use of the term "pelvic instability" is not justified in the diagnosis of these patients; therefore, we have avoided use of this term throughout this thesis.

The finding that increased SIJ laxity was not associated with PRPP may seem disappointing in view of our aim to increase insight into the syndrome of PRPP; however, we did find an important relationship between the (severity) of PRPP and asymmetry between left and right SIJ laxity during pregnancy. The relation between asymmetric laxity and moderate to severe PRPP during pregnancy was so striking that it allowed to conclude that asymmetric laxity of the SIJs measured during pregnancy is predictive of the persistence of moderate to severe PRPP into the postpartum period. Therefore, objective asymmetric laxity measurements in subjects with moderate to severe PRPP could help identify those subjects needing special attention during pregnancy and postpartum.

Two interesting questions have emerged from these studies for which we have no definite answers and which require further investigation. First: Does the existence of asymmetric laxity of the SIJs occur before or after the onset of PRPP? At this moment we can not answer this question because we have not yet measured SIJ laxity before or early in pregnancy; asymmetric laxity can also be a symptom caused by pain in the pelvic region. Second: What is the cause of asymmetric laxity of the SIJs?. The laxity measured by our methods depends on active factors (e.g. muscle activity) and passive factors (e.g. joint shape, ligaments and cartilage structure and tickness). [4] One possible cause of asymmetric laxity in the SIJs is a difference between the left and right muscle tension or size of the local muscle system, which includes the transversus abdominis and lumbar multifidus. Earlier studies have reported asymmetry of activity of the paraspinal muscles in low back pain patients, and marked side-to-side asymmetry of the cross-sectional area of the multifidus in low back pain patients but not in normal, non-back-pain subjects. [3, 6] Another study showed that independent contractions of the transversus abdominis (in co-contraction with multifidus) can significantly decrease SIJ laxity. [9] The consequence of this increased tension and/or size on one side is due to a difference in the position of the SIJ and increased compression of the joint parts of the SIJ at that side. It is hypothesised that PRPP occurs mainly in patients with a low passive laxity and that these subjects (over)compensate pain with active factors at one side, resulting in asymmetric laxity of the SIJs. Further studies are needed to validate the relationship between the asymmetric laxity of the SIJs and the activity of the transversus abdominis and lumbar multifidus.

The second aim of this thesis was to investigate the mechanical effect of a pelvic belt on the SIJ laxity in healthy women and in patients with PRPP (*chapters 5 and 6*). The study on healthy women demonstrated that a pelvic belt is most effective in a high position, while a tension of 100 N does not reduce laxity more than 50 N. The high position of the pelvic belt was also more effective in patients

with PRPP, decreasing SIJ laxity to a significantly greater degree than application of the belt in low position. The main limitation of these latter studies was that SIJ laxity was measured only in prone position. At present it is not possible to quantify SIJ laxity values in loaded position. Future studies should focus performing measurements in standing position to investigate how SIJ laxity will respond in this position with and without a pelvic belt. At this moment, the results of our studies support the use of a pelvic belt for the treatment of PRPP.

In summary, it can be concluded that DIV is a reliable measurement method that can be applied to address the question whether or not complaints during pregnancy are a risk factor for persisting complaints after childbirth. It can also be concluded that laxity of the SIJs is higher during pregnancy than after childbirth. Therefore, this conclusion does not justify the diagnosis of 'pelvic instability', because no relation was found between increased laxity and the (severity of) pain. The results of the studies investigating the mechanical effect of a pelvic belt on SIJ laxity in healthy women and in patients with PRPP, support the use of a pelvic belt for the treatment of PRPP. The present thesis is, therefore, one step further in our understanding of the phenomenon pregnancy-related pelvic pain.

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Summary

Unfortunately, many pregnant women suffer from pelvic pain at some stage during their pregnancy. In about one-third of these women the severity of the pain is such that it impedes their normal activities. Although in many cases pelvic pain resolves after childbirth, some women continue to have problems after delivery that may even result in disability. Due to inherent difficulties related to classification, terminology and the lack of 'objective' criteria, pregnancy-related pelvic pain (PRPP) is frequently considered to be a 'non-disease'.

Chapter 1 presents an overview of the literature on the origin, diagnosis and treatment of PRPP. This led us to the conclusion that laxity of the sacroiliac joints (SIJs) may play a central role in the understanding of this syndrome. Because no instrumented method was available, Snijders proposed and developed a new vibration method for the in vivo assessment of SIJ laxity. This resulted in the method of Doppler imaging of vibrations (DIV), which runs as a continuous thread throughout this thesis.

Chapter 2 describes a study testing the reliability of SIJ laxity measured with DIV using the generalisability theory. Ten healthy women (mean age 29.9 ± 6 years) participated in this study. SIJ laxity was measured at both sides with DIV in threshold units (TU). Reliability and measurement errors were assessed by means of repeated measurements by five testers on two occasions, as well as by one experienced tester. Intraclass correlation coefficients ranged from 0.53 to 0.80 for all five testers, and from 0.75 to 0.89 for the experienced tester. Only changes larger than 1.94 to 3.60 TU (any tester) or 1.45 to 2.38 TU (experienced tester) could be confidently detected. This study showed that DIV is a reliable technique for measurement of SIJ laxity in healthy subjects, when performed by an experienced tester.

Chapter 3 reports a study on the relationship between PRPP and SIJ laxity. A cross-sectional analysis was performed in a group of 163 women, 73 with moderate or severe PRPP (designated as PRPP+) and 90 with no or mild PRPP (designated as PRPP-) at 36 weeks of pregnancy. Pain, clinical signs and disability were assessed with a visual analog scale (VAS), the posterior pelvic pain provocation (PPPP) test, the active straight leg raise (ASLR) test, and the Quebec back pain disability scale (QBPDS), respectively. The results of this study showed that the mean SIJ laxity in the PRPP+ group was not significantly different from that of the PRPP- group (3.0 *versus* 3.4 TU). However, the mean left right difference was significantly higher in the PRPP+ group (2.2 TU) than in the PRPP- group (0.9 TU). In the PRPP- group, only 4% had asymmetric laxity of the SIJs in contrast to 37% of the PRPP+ group. In the PRPP+ subjects, comparison between those with asymmetric and those with symmetric laxity of the SIJs revealed significant differences in the mean VAS for pain (7.9 *versus* 7.0), positive PPPP

test (59% *versus* 35%), positive ASLR test (85 *versus* 41%) and mean QBPDS score (61 *versus* 50). The results of this study allow to conclude that increased SIJ laxity is not associated with PRPP. In fact, pregnant women with moderate or severe pelvic pain have the same laxity in the SIJs as pregnant women with no or mild pain. However, a clear relationship was found between asymmetric laxity of the SIJs and PRPP.

Chapter 4 presents a study designed to determine the prognostic value of asymmetric laxity of the SIJs during pregnancy on PRPP postpartum. From the 163 women studied in chapter 3, a group of 123 women were prospectively questioned and examined at 36 weeks gestation and at 8 weeks postpartum. A left to right difference in SIJ laxity ≥ 3 TU was considered to indicate asymmetric laxity of the SIJs. In subjects with moderate to severe PRPP during pregnancy, SIJ asymmetric laxity was predictive of moderate to severe PRPP persisting into the postpartum period in 77% of the subjects. The sensitivity, specificity and positive predictive value of SIJ asymmetric laxity during pregnancy for PRPP persisting postpartum were 65%, 83% and 77%, respectively. Subjects with moderate to severe PRPP and asymmetric laxity of the SIJs during pregnancy have a three-fold higher risk of moderate to severe PRPP postpartum than subjects with symmetric laxity. These data indicate that in women with moderate to severe complaints of pelvic pain during pregnancy, SIJ asymmetric laxity measured during pregnancy is predictive of the persistence of moderate to severe PRPP into the postpartum period.

Although many patients experience relief of pain when using a pelvic belt, in vivo evidence about the mechanical effect of the application of a pelvic belt in patients with PRPP is lacking. A functional approach to the treatment of the unstable pelvic girdle requires an understanding of the effect of a pelvic belt on a normal pelvic girdle. Therefore, in *chapter 5* the influence of a pelvic belt at two positions (low: at the level of the symphysis and high: just below the anterior superior iliac spines) and at two tensions (50 and 100 N) on SIJ laxity was evaluated in 10 healthy young women. The results show that the tension has no significant effect on SIJ laxity with or without a pelvic belt. However, a significant effect was found for the position of the pelvic belt. This study demonstrated that use of a pelvic belt was most effective in a high position, while a tension of 100 N did not reduce laxity more than 50 N.

Chapter 6 presents a study which tested two positions of a pelvic belt in 25 subjects with PRPP and describes the effects on SIJ laxity. The belt was positioned just below the anterior superior iliac spines (high position) or at the level of the symphysis (low position). Application of a pelvic belt in both the high and low position significantly decreased SIJ laxity compared to the non belt situation, and this decrease was greater with the belt in high position. These findings are in line with the biomechanical predictions and support the use of a pelvic belt for the treatment of PRPP.

Summary

Chapter 7 gives a summary of the main findings and conclusions of this thesis. Implications of this work for clinical practice and ideas for future research are also addressed.

Samenvatting

Helaas hebben veel zwangere vrouwen last van bekkenpijn tijdens bepaalde fases van hun zwangerschap. Bij ongeveer eenderde van deze vrouwen is de ernst van de pijn zodanig dat het hun normale activiteiten verhindert. Alhoewel in veel gevallen bekkenpijn vanzelf verdwijnt na de geboorte, blijven sommige vrouwen problemen houden die zelfs kunnen resulteren in invaliditeit. Door moeilijkheden inherent gerelateerd aan classificatie, terminologie en het gebrek aan 'objectieve' criteria wordt zwangerschap-gerelateerde bekkenpijn (ZGB) vaak beschouwd als een 'non-disease'.

Hoofdstuk 1 geeft een overzicht van de literatuur over het ontstaan, diagnose en behandeling van ZGB. Dit bracht ons tot de conclusie dat laxiteit van de sacro-iliacale gewrichten (SIG) mogelijk een centrale rol kan spelen in het begrip van dit syndroom. Omdat er geen instrumentale methode beschikbaar was, heeft Snijders een nieuwe trillingsmethode voorgesteld en ontwikkeld voor de in vivo bepaling van laxiteit van het SIG. Dit resulteerde in de methode van 'Doppler imaging of vibrations' (DIV), dat als een rode draad door dit proefschrift loopt.

Hoofdstuk 2 beschrijft een studie over de betrouwbaarheid van de laxiteit van het SIG gemeten met DIV en gebruik makend van de generaliseerbaarheidstheorie. Tien gezonde vrouwen (gemiddelde leeftijd 29.9 ± 6 jaar) namen deel aan deze studie. De laxiteit van het SIG werd aan beide kanten gemeten met behulp van DIV en uitgedrukt in 'threshold units' (TU). Betrouwbaarheid en meetfouten werden bepaald door middel van herhaaldelijke metingen door vijf onderzoekers op twee meetmomenten, alsook door een ervaren onderzoeker. Intraclass correlatie coëfficiënten bewegen zich tussen 0.53 en 0.80 voor de vijf onderzoekers, en tussen 0.75 en 0.89 voor de ervaren onderzoeker. Alleen veranderingen groter dan 1.94 tot 3.60 TU (iedere onderzoeker) of 1.45 tot 2.38 TU (ervaren onderzoeker) konden vertrouwelijk waargenomen worden. Deze studie toonde aan dat DIV een betrouwbare techniek is voor metingen van de laxiteit van het SIG bij gezonde proefpersonen, mits uitgevoerd door een ervaren onderzoeker.

Hoofdstuk 3 brengt verslag uit van een studie over de relatie tussen ZGB en de laxiteit van het SIG. Een dwarsdoorsnede analyse werd uitgevoerd in een groep van 163 vrouwen, 73 met gematigde of ernstige ZGB (aangeduid als ZGB+) en 90 met geen of milde ZGB (aangeduid als ZGB-) in week 36 van de zwangerschap. Pijn, klinische tekenen en beperkingen werden respectievelijk bepaald met behulp van een 'visual analog scale' (VAS), de 'posterior pelvic pain provocation' (PPPP) test, de 'active straight leg raise' (ASLR) test, en de 'Quebec back pain disability scale' (QBPDS). De resultaten van deze studie gaven aan dat de gemiddelde laxiteit van het SIG in de ZGB+ groep niet significant verschillend was dan dat in de ZGB- groep (3.0 *versus* 3.4 TU). Het gemiddelde links rechts verschil was

echter significant hoger in de ZGB+ groep (2.2 TU) dan in de ZGB- groep (0.9 TU). Slechts 4% van de ZGB- groep had asymmetrische laxiteit van de SIGs in tegenstelling tot 37% van de ZGB+ groep. Bij de ZGB+ proefpersonen gaven vergelijkingen tussen degenen met asymmetrische en symmetrische laxiteit van de SIGs significante verschillen tussen de gemiddelde VAS voor pijn (7.9 *versus* 7.0), een positieve PPPP test (59% *versus* 35%), een positieve ASLR test (85 *versus* 41%) en de gemiddelde QBPDS score (61 *versus* 50). De resultaten van deze studie staan de conclusie toe dat verhoogde laxiteit van het SIG niet verbonden is met ZGB. In werkelijkheid hebben zwangere vrouwen met gematigde of ernstige bekkenpijn dezelfde laxiteit van de SIGs als zwangere vrouwen met geen of milde pijn. Er werd echter wel een duidelijke relatie gevonden tussen asymmetrische laxiteit van de SIGs en ZGB.

Hoofdstuk 4 presenteert een studie ontwikkeld om de prognostische waarde te bepalen van asymmetrische laxiteit van de SIGs gemeten tijdens de zwangerschap voor ZGB postpartum. Van de 163 bestudeerde vrouwen uit hoofdstuk 3, werden 123 vrouwen prospectief ondervraagd en onderzocht in week 36 van de zwangerschap en 8 weken postpartum. Een links rechts verschil in laxiteit van de SIGs $\geq$ 3 TU werd beschouwd als asymmetrische laxiteit van de SIGs. Bij proefpersonen met gematigde tot ernstige ZGB tijdens de zwangerschap was asymmetrische laxiteit van de SIGs voorspelbaar voor aanhoudende pijn in de postpartum periode in 77% van de proefpersonen. De sensitiviteit, specificiteit en positieve voorspellende waarde van asymmetrische laxiteit van de SIGs tijdens de zwangerschap voor aanhoudende ZGB postpartum waren 65%, 83% en 77%. Proefpersonen met gematigde tot ernstige ZGB en asymmetrische laxiteit van de SIGs tijdens de zwangerschap hebben drie keer meer risico op gematigde tot ernstige ZGB postpartum dan proefpersonen met symmetrische laxiteit. Deze resultaten geven aan dat bij vrouwen met gematigde tot ernstige klachten van bekkenpijn tijdens de zwangerschap, asymmetrische laxiteit van de SIGs gemeten tijdens de zwangerschap voorspelbaar is voor het aanhouden van gematigde tot ernstige ZGB in de postpartum periode.

Alhoewel veel patiënten verlichting van pijn ervaren bij het gebruik van een bekkenband, ontbreekt in vivo bewijs van het mechanische effect van het aanbrengen van een bekkenband bij patiënten met ZGB. Begrip van het effect van een bekkenband op een normaal bekken is een vereiste voor een functionele benadering van de behandeling van een instabiel bekken. Daarom is in *hoofdstuk 5* de invloed van een bekkenband op de laxiteit van het SIG onderzocht in twee posities (laag: op het niveau van de symfyse en hoog: net onder de anterior superior iliac spines) en bij twee krachten (50 en 100 N) in 10 gezonde jonge vrouwen. De resultaten tonen aan dat de kracht geen significant effect heeft op de laxiteit van het SIG, gemeten met en zonder bekkenband. Er werd echter wel een significant effect gevonden voor de positie van de bekkenband. Deze studie toonde aan dat het

gebruik van een bekkenband het meest effectief was in hoge positie, terwijl een kracht van 100 N de laxiteit niet meer verlaagde dan een kracht van 50 N.

Hoofdstuk 6 presenteert een studie dat twee posities van een bekkenband testten in 25 proefpersonen met ZGB en beschrijft de effecten voor laxiteit van het SIG. De band werd geplaatst net onder de anterior superior iliac spines (hoge positie) of ter hoogte van de symfyse (lage positie). Het aanbrengen van een bekkenband, zowel in de hoge als in de lage positie verlaagde de laxiteit van het SIG significant vergelegen met de situatie zonder band, en deze verlaging was groter met de band in hoge positie. Deze bevindingen zijn in lijn met de biomechanische voorspellingen en steunen het gebruik van een bekkenband in de behandeling van ZGB.

Hoofdstuk 7 geeft een samenvatting van de voornaamste bevindingen en conclusies van dit proefschrift. Ook zijn implicaties van dit werk voor de klinische praktijk en ideeën voor toekomstig onderzoek beschreven.

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About the author

Léonie Damen was born on July 10 1972, in Spijkenisse, the Netherlands. After attending the *VWO* at the *Openbare Scholengemeenschap* Ring van Putten in Spijkenisse, she graduated at the Academy of Physical Therapy in Rotterdam in 1995. In 1995 she started her study of Health Sciences at the University of Maastricht and specialised in Human Movement Science. Before and during this study she worked in several practices as a physiotherapist. She graduated in December 1997 on the research project "Ambulatory monitoring of mobility-related activities in rehabilitation medicine" (Dr. J.B.J. Bussmann) at the Institute of Rehabilitation Medicine of Erasmus University Rotterdam. After her graduation, she started Ph.D. studies at the institute of Rehabilitation Medicine (Prof. dr. H.J. Stam) in co-operation with the department of Biomedical Physics and Technology (Prof. dr. ir. C.J. Snijders), Erasmus University Rotterdam. The research performed during this period is described in this thesis. During last two and a half years she also gave classes in Evidence Based Practice for physical therapists.
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