Pregnancy Related Low Back and Pelvic Pain: a Surgical Approach

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Introduction

Introduction

Low back pain is a very common complaint, which may not only originate from pathology in the spine but also from the saroiliacal joints. This thesis will focus on the pain which originates in the pelvic ring and may develop during or after pregnancy. More than half of all pregnant women experience low back and/or pelvic pain of whom one third has severe complaints. In most cases the pelvic pain disappeares within a few months after delivery. In a minority of patients the pain persists even after a multidisciplinary rehabilitation program and may cause severe disability. After failure of all conservative treatment, surgical fixation of the pelvic ring seems to be the only remaining treatment option for those women. Internal fixation of the pelvic ring is commonly used in unstable pelvic fractures, but in pelvic pain it has only been described in a few cases.
Concerning pregnancy related low back and pelvic pain (PLBP) several aspects, which are still subject of discussion, will be addressed in this thesis. First of all, in literature no uniform criteria exist for the diagnosis PLBP. Treatment, especially operative intervention, is controversial regarding indications, clinical results and surgical techniques. Main subject of this thesis is the outcome of surgical fixation of the pubic symphysis and the sacroiliac joints (SIJ) in patients severely disabled by pregnancy related low back and pelvic pain (PLBP). Furthermore, the biomechanical properties of different fixation methods of the pelvic ring are investigated. The technique has been developed for fixation of pelvic fractures, but in this thesis their use in women suffering from PLBP is described.

In order to define the symdrome, in *chapter 2* a review is given of the complaints, physical signs, diagnostic tests, radiological and histological findings in PLBP. The conservative and surgical treatment options are discussed. Furthermore, a description is given of the various surgical fixation techniques of the pelvic ring.
In *chapter 3 to 6* the results of our in vitro studies into the biomechanical properties of sacroiliac screw fixation are described. In unstable pelvic fractures, sacroiliac screws are one of the most stable methods for internal fixation of the posterior pelvic ring and have the advantage of percutaneous placement. In *chapter 3* we compare different positionings of sacroiliac screws in order to find the optimal configuration. We used a standardized model of a completely unstable pevic fracture in embalmed human pelvises. In *chapter 4* we study whether a sacroiliac screw provided additional stability to symphyseal plate fixation in partially unstable pelvic fractures. *Chapter 5* showes the results of anterior plate fixation combined with sacroiliac screws under dynamic loading

conditions in order to see if a stable fixation can be maitained in completely unstable pelvic fractures. In *chapter 6* we examine whether 1 or 2 sacroiliac screws supply additional stiffness to the intact sacroiliac joint.

In *chapter 7* we report on the functional outcome of internal fixation of the pelvic ring in patients suffering from severe pregnancy-related low back and pelvic pain (PLBP) in whom all conservative treatment has failed. Objective was to determine whether in very severe cases surgical fixation relieves pain and reduces disability and to make an attempt to identify characteristics which may predict the outcome of the intervention.

Malpositioning of sacroiliac screws may lead to serious neurological complications. In *chapter 8* the safety of sacroiliac screw positioning using inlet and outlet fluoroscopy is assessed. We investigated the correlation between screw position on peroperative fluoroscopy, and postoperative CT scan and clinical results.

The histology of the symphysis of patients with severe PLBP is described in *chapter 9*. The specimens removed during surgical fixation of the pelvic ring are examined and compared to the symphysis of women without complaints. Finally, recommendations for further development and research are given.

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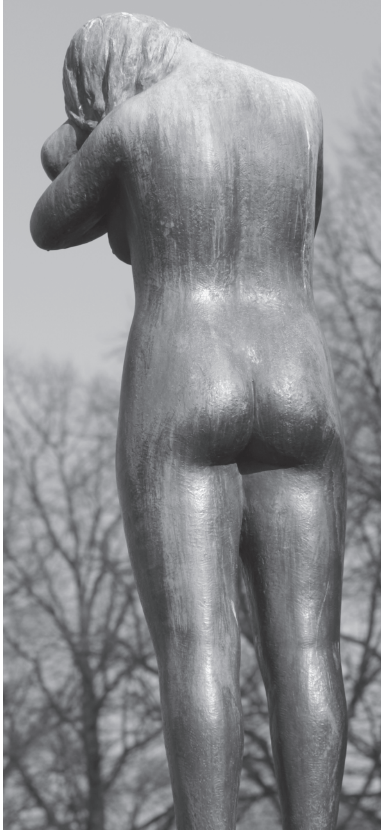
Pregnancy Related Low Back and Pelvic Pain



Pregnancy Related Low Back and Pelvic Pain

Introduction

Pain in the pelvic ring during pregnancy or after delivery has already been described since 1849 by Cederschjöld[43], Snelling[132], Skajaa[130], and Cantin[1;72]. Approximately 50 % of all women suffer from pelvic pain during their pregnancy[5;11;15;62;76;102]. One-third of these patients has severe complaints which interfere with normal activities[15;39;47;51;62;76;102]. In most cases pelvic pain disappears soon after delivery and can be managed by conservative treatment[3;27;62;67;104]. In a minority of patients the pain persists and may cause severe disability[3;10;67;94;101]. In literature a great number of terms have been used to describe the same symptoms: pelvic insufficiency[10;43;160], symptom giving pelvic girdle relaxation[30;47;67], pelvic girdle syndrome[2;5], posterior pelvic pain in/after pregnancy[83;85;104;107], peripartum pelvic pain[87;88], pregnancy-related pelvic pain[26;27], symphysiolysis[2;5;11], pelvic instability[1;157;158], pelvic arthropathy of pregnancy[163], and sacroiliac joint dysfunction[11]. Since a clear distinction based solely on the localization of the pain is difficult to make we have used a descriptive term: pregnancy related low back and pelvic pain (PLBP).
Furthermore, the criteria and definitions used to categorize the complaints vary as widely as the nomenclature. Therefore, the diagnosis pelvic pain is controversial especially after pregnancy[122]. Frequently the complaints are believed to be of psychological origin[113]. In this chapter the complaints and diagnostic tests are discussed to describe the criteria which can help to establish the diagnosis pregnancy related low back and pelvic pain.

Epidemiology

During pregnancy low back pain is a common complaint. The reported nine-month prevalence ranges from 30 to 81 %[2;5;11;15;39;62;76;81;98;100-102;104;106;107;141;152]. Nine to 36 % of the pregnant women describe their back pain as severe or disabling[15;39;47;51;62;76;102] and 5 to 21 % are unable to continue their work because of severe low back pain[11;67;101]. The point prevalance of back pain during pregnancy was reported to raise from 40 % at 12 weeks to 63-70 % at 36 weeks[61;100;106], whereas in another study the point prevalence remained stable around 25%[102].

Table 1

Nomenclature	Definition
insufficientia pelvis (43)	A condition that arises during the latter half of pregnancy and manifests itself in a deficient firmness of the pelvic joints. There are positive Lasegue and/or Trendelenburg signs on one or both sides as well as disturbances in gait, in extreme cases even waddling. It involves tenderness in the pelvic joints and difficulties in performing various movements (turning over in bed, walking up and down stairs, rising from deep chairs).
pelvic insufficiency (10)	A condition manifesting itself during pregnancy or the puerperium. It is characterized primarily by an affection of the pelvic joints causing pain and tenderness and impaiment of locomotor function. The symptoms are referable in part to decreased pelvic stability.
pelvic insufficiency (160); symptom giving pelvic girdle relaxation (47, 67)	Pelvic pain arisen during pregnancy. The pain must compromise normal functioning and occur repeatedly during at least 2 of the following 5 functions: turning in bed, climbing stairs, lifting a few kilograms, changing of position/getting up from a chair, and walking
symptom giving pelvic girdle relaxation (30)	ligament relaxation that causes considerable pain and/or pelvic instability (so that daily function is impaired)
pelvic joint syndrome (30)	pain in relation to one or more of the pelvic joints (the pubic symphysis and the joints between os ilium and os sacrum) outside preganancy and puerperium
posterior pelvic pain (104, 107)	a history of time- and weight-bearing-related pain in the posterior pelvis, deep in the gluteal area, a pain drawing with well-defined markings of stabbing in the buttocks distal and lateral to the L5-S1 area, with or without radiation to the posterior thigh or knee, but not into the foot, a positive posterior pelvic pain provocation test, free movements in the hips and spine and no nerve root syndrome, pain when turning in bed, pain-free intervals, pain was experienced for the first time during a pregnancy

posterior pelvic pain since/after pregnancy (PPPP) (83 - 86)	pain in the pumbopelvic region between the upper level of the iliac crest and the gluteal fold that began during pregnancy or within 3 weeks after delivery
peripartum pelvic pain (87)	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
pregnancy-related pelvic pain (PRPP) (26, 27)	moderate to severe pelvic pain felt in the region of the SI joints and/or the pubic symphysis
pelvic instability (157, 158)	clinical entity characterized by pain localized to the pubic symphysis and/or sacroiliac joints, often associated with radiation of pain into the leg; hypermobility of the pelvic joints has been suggested as a cause of the pain
sacroiliac joint dysfunction (11)	pain at provocation testing and/or a disturbed motion of the sacroiliac joint at functional testing
pelvic girdle syndrome (2, 5)	daily pain in all three pelvic joints, confirmed by positive pain provocation test at these joints
sacroiliac joint syndrome (2, 5)	daily pain from one or both sacroiliac joints, confirmed by positive pain provocation test at these joints
symphysiolysis (2, 5, 11)	daily pain in the pubic symphysis only, confirmed by positive pain provocation test at the symphysis (symphysiolysis does not imply an actual lysis)
pelvic arthropathy (163)	the disabilities arising form excessive relaxation of the pelvic joints, a) those dependent upon an excessive mobility both at the sacro-iliac and the pubic joints (pubo-sacro-iliac arthropathy), b) those dependent upon an excessive mobility at the sacro-iliac alone (sacro-iliac arthropathy)

In a retrospective study 10-15% of the women with low back pain stated that their LBP had started during pregnancy and continued after delivery[143]. Östgaard et al.[102;107] differentiate low back pain from posterior pelvic pain, which is experienced by 14 to 49 % of all pregnant women [2;5;15;62;65;67;102;104;107]. The pain intensity was found to be higher among women with posterior pelvic pain than among women with back pain during pregnancy[104].
Part of the differences in the reported prevalences may be explained by the lack of uniform definitions, the choice of the study population and the variety of study designs (prospective and retrospective).
It has been suggested that pregnancy related low back and pelvic pain is more common in northern European countries [51;74]. In the few studies which have been conducted in non-European countries similar prevalences of 38 to 81% have been reported, with a similar location and severity of the pain[12;39;98;152;153].

Pathophysiology

The etiology and pathogenesis of pregnancy-related low back and pelvic pain (PLBP) are still subject of debate, but several theories are described: hormonal (relaxine)[63;75], mechanical (pelvic instability)[10;45 96;97;131;133;157], postural changes [19;32;39;90;103;155;163])[38], and traumatic[15;131;158;163].

Hormonal

In 1926 Hisaw discovered that the presence of a hormone, later known as relaxin, caused separation of the pubic symphysis of guinea pigs during pregnancy[53]. Relaxin is a peptide hormone of the insulin-like growth factor family[63]. In humans it is produced by the corpus luteum, the decidua and the placenta[74]. Relaxin is thought inhibit myometrial contractility until late pregnancy, to facilitate cervical ripening and to promote connective tissue remodelling leading to relaxtion of the pelvic ligaments[74;75]. MacLennan et al. found significantly higher serum relaxin concentrations in patients with severe pelvic pain compared to a control group of normal pregnancies, using porcine relaxin antibody[75]. They suggested that there may be a causative association between high serum relaxin levels and pelvic pain[74;75]. Using human relaxin antibodies, Kristiansson et al. described a significant correlation of mean serum relaxin level with pelvic pain and with positive provocation tests[63;64]. No correlation was found between pain intensity or disability and relaxin values[63]. Three other investigators, however, did not confirm an association between high relaxin concentrations and the presence of pelvic pain or the severity of the complaints[4;13;46;108]. Furthermore, Björklund et al. found no correlation between serum relaxin levels and the degree of symphyseal distension or disabling pelvic pain in pregnancy[13]. Another study suggested that a high level of progesterone and a low concentration of propeptide of type III procollagen (a collagen turnover marker) early in pregnancy may indicate an increased risk of pelvic pain late in pregnancy[64].

Hypermobility

Several authors describe hypermobility of the pelvic joints to be a causative factor[10;45;97;131;157;158]. After years of complaints usually no mechanical hypermobility can be demonstrated, whereas the pain persists[45;157;158]. Noren reported significant weakness in the back extensor and hip abductor muscles in women still suffering from PLBP 3 years after pregnancy. This may indicate that pelvic pain after pregnancy does not come from the joints but from strained ligaments and joint capsules caused by muscular insufficiency[94].

In studies of Buyruk and Damen on PLBP sacroiliac joint stiffness was determined by means of color Doppler imaging of vibrations. In women with PLBP a significant difference in stiffness of the left and right SIJ was found[22;26;27]. Based on biomechanical modeling we assume that the pain is related to the mechanics of the SIJ and surrounding ligamentous structures[133].

Postural changes

Changes in posture due to the increased abdominal weight have been proposed as a factor related to PLBP[19;32;39;103]. However, both flattening of the lumbar spine[90;134], increased lordosis[21;32;40] and no change[103] have been reported. Significant increase in lumbar lordosis is described during pregnancy, but no significant relationship between back pain and posture[21;40]. Moore et al[90] found a significant relation between the anterior position of the line of gravity and the degree of PLBP at 34-42 weeks, although the position of the line did not change significantly during pregnancy. Furthermore a large increase in lordosis was associated with a large increase in pain[90]. Ostgaard et al. [103]found that back pain was significantly correlated with a large lumbar lordosis, although the lordosis did not change from the 12th to the 36th week of pregnancy. Furthermore Farbrot described a predisposition for pain during pregnancy in gravidae with a sacral angle over 55 degrees[38].

Traumatic

Some authors suggest connective tissue microtrauma as a consequence of the trunk extensor muscle forces to balance the anterior flexion moment caused by the growing uterus.[79;103;163] Others mainly refer to damage of the pelvic joints during delivery.[15;131;158;163]

Risk factors

Several authors found a history of low back pain before pregnancy and low back and pelvic pain during previous pregnancies to be risk factors for the development of pregnancy-related low back and pelvic pain[11;13;16;20;26;27;65;67;81;98;100;102]. Some studies have described a higher risk of developing back pain during pregnancy in women with a higher number of previous pregnancies[13;26;51;62;76;100;102;143;152], whereas other articles did not show an association[5;11;27;39;67;81;98]. Uncomfortable working conditions and physically strenuous work with repetitive lifting, twisting and bending are reported to give an inreased risk of developing low back pain in pregnancy.[11;51;67;102] A few articles have described a correlation between low back pain during pregnancy and age[51;76;87;100;102;152], but the results are conflicting.[5;15;26;39;62;65;67;81;98] The same applies to the association between high maternal body weight and the occurrence of low back pain, which is found by some authors[26;27;51;62;98], but rejected by others[15;15;39;67;76;81;98;102;103]. The use of oral contraceptives has also been described as a risk factor[65;122], but this was not confirmed by other authors[15;16;26;102;103].

Complaints and natural history

Pregnancy related low back and pelvic pain is characterized by pain in one or both sacroiliac joint regions, which may radiate into the legs[1;10;11;39;43;45;76;87;98;101;107;131;141;146;155;157;158;163]. There is a strong correlation between sacroiliac joint pain and pain in the symphyseal region of which the prevalence varies between different articles from 42 to 100 % [1;10;11;15;45;87;102;131;157;158;163]. Ostgaard[107] considered pain in the symphysis pubis not important. Pain in the groins especially at adduction of the hips is also described [10;45;86;87;157;158;163]. Usually the pain increases during movement which may impair ADL activities, like walking, climbing stairs, lifting objects and turning in bed[39;43;45;47;62;76;87;122;131;155;157;158;163]. However, sitting or standing in one position can also provoke pain[39;76;87;157;158]. A large number of the patients experiences pain during sexual intercourse[47;76;87;158]. In severe cases patients walk with short steps and a waddling gate[1;10;43;45;132;155;158;163]. Furthermore, crepitations in the pelvis, a locking sensation in one of the sacroiliac joints and a "catching" feeling of the leg when walking have been described[141;157;158]. The severity of the complaints can vary from mild discomfort to severe disability in a minority of patients[47;132].

Symptoms tended to begin between the 3rd and 8th month of pregnancy or during 48 hours after delivery [10;11;39;45;76;87;163]. Relapses of pregnancy related low

back and pelvic pain occur in 41 to 94 % of subsequent pregnancies, at a progressively earlier moment and with an increasing intensity[10;20;45;87;99].
After childbirth low back pain disappears in most cases within six months[3;27;45;62;67;101;104;106]. Of all patients 19-42% had any remaining pain at 3-6 months postpartum[10;15;60-62;101;106;152]. One to three years after pregnancy the incidence of back pain had returned to the prepregnancy level of circa 20%[94;106]. Pain intensity showed a substantial regression at 3 months postpartum[106]. The pain score in this group was higher than the prepregnancy level, but lower than the average score during pregnancy[101;152]. However, among the women with severe pelvic pain during pregnancy 45-65% still suffered from pain 2-4 months after delivery[10;11;27;104;163;163]. Of all women 2-6% experienced no regression after delivery[10;67;94;104] and 12-18 months postpartum 2-9% reported severe pain[3;60;67;101]. Furthermore high pain intensity during pregnancy [3;10;27;62;104;106], long periods of back pain and sick leave during pregancy[20;101], early onset of pain during pregnancy[27], having a back pain history before pregnancy[101;106;152], physically heavy work[3;20;101], a high number of positive pain provocation tests[3], and multiparity[3;101] correlated with slow regression of pain after delivery, and with much residual pain.

Physical examination

A wide variety of diagnostic tests are described and used in literature. Most of these test have shown to have low reproducibility and discriminatory power and only a few are validated[61;68;88;105;160].
Pain provocation tests have shown better reliability than configuration or mobility tests[2;61;68;160]. Pain provocation tests used for the lumbosacral part of the spine were painful femoral compression (posterior pelvic pain provoking), tender sacrospinous / sacrotuberous ligament, tender posterior superior iliac spine, painful lumbar movements, lumbar tenderness, painful supine iliac gapping, painful supine iliac compression, tenderness of the iliopsoas muscle at palpation, tenderness at palpation of the symphysis, tenderness at the symphysis during Trendelenburg test, and Patrick's "fabere" sign[2;47;61;160]. The sensitivity of the tests ranged between 4 and 90%, the specificity between 89 and 100%[2;61]. Kristiansson reported that the best discrimination was achieved by combining the first six tests, which yielded a positive predictive value of 68%. A correlation was reported between the total number of positive tests and pain intensity at rest as well as at daily acitvities[47;61;160].

Table 2 Risk factors

	Albert (5)	Berg (11)	Bjorklund (15)	Damen (27)	Fast (39)
Number of patients	1460	862	49	123	200
study design	prosp.	prosp.	prosp.	prosp.	retrosp.
questionnaire	+	+	-	+	+
physical examination	+	+/-	+	+	-
prevalence LBP in present pregnancy	32%	49%			56%
prevalence pelvic pain in present pregnancy	20%		49%	45%	
Maternal age	-		-	-	-
maternal weight			-	+	
maternal weight gain			-		-
baby's weight		-	-		-
maternal origin					+ (4)
parity	-	-		-	-
LBP before pregnancy		+			
LBP in previous pregnancy		+		+	
physically strenuous work		+			
uncomfortable working conditions					
exercise habits		-		-	
satisfaction at work		-			
use of oral contraceptives			-	-	
smoking	-	-			

1: younger age
2: older age
3: in nulliparae
4: Caucasian
5: Sephardic
6: first pregnancy

Heiberg (51)	Kristians-son (62)	Kumle (65)	Larsen (67)	Mantle (76)	Melzack (81)	Orvieto (94)	Ostgaard (100, 102)
5438	200	2078	1600	180	114	449	855
retrosp.	prosp.	retrosp.	prosp.	retrosp.	retrosp.	retrosp.	prosp.
+	+	+	+	+	+	+	+
-	+	-	+	-	-	-	-
58%	76%			48%	58%	55%	49%
42%	47%	27%	14%				+/- 24%
+ (1)	-	+ (1)	-	+ (2)	-	-	+ (1)
+	+		-		-	+ (3)	-
							-
+		-			-		
						+ (5)	
+	+		-	+	-	-	+ / +/ -
	+		+		+	+	+
	+	+	+			+	
+			+				+
			+				+
			+				
							+
		+ (6)					+/-
+	-	-	-				

- *no significant correlation*
+/- *tendency ($p < 0.10$)*
\+ *significant correlation ($p < 0.05$)*

Trendelenburg test
The woman is standing on one leg and she flexes the other at 90 degrees (hip and knee). The test is considered positive for the stance leg if the hip is descending on the flexed side[2]. A positive Trendelenburg's sign in 17-95% of the patients[1;10;43;45;99;157;158]. If pain is experienced in one of the pelvic joints, the test is considered positive as a pain provocation test for the symphysis or sacroiliac joints[2].

Posterior pelvic pain provocation test (PPPP)
In the posterior pelvic pain provocation test (also called femoral compression or thigh thrust test) the hip is flexed to 90 degrees when the patient is lying in supine position. Gentle pressure is applied to the raised knee along the longitudinal axis of the femur. The test is considered positive if the patient feels pain deep in the gluteal area on the ipsilateral side[105]. The sensitivity of the test ranged between 44 and 93%, and the specificity between 72 and 98 %. The positive predictive value was 67 to 76 % and the negative predictive value 68 to 88%[2;26;27;61;83;105].

Active straight leg raising test (ASLR)
For the active straight leg raising test the patient lies in supine position and is asked to actively raise the extended leg twenty cm above the underground, left and right leg separately. Impairment was scored on a four-point scale[85;88] or six-point scale; the scores of both sides were added[83;84]. The sensitivity was 58 to 87% and the specitivity 55 to 97%[26;27;83].
The ASLR is a suitable diagnostic instrument to discriminate between patients who are disabled by PLBP and healthy subjects. Furthermore it can be used to measure disease severity in PLBP patients and correlates well with the endurance of standing, walking, cycling, and sitting and with pain provocation tests[84]. In patients with PLBP a correlation was found between impairment of the ASLR and mobility of the pelvic joints measured with Chamberlain radiographs[88].

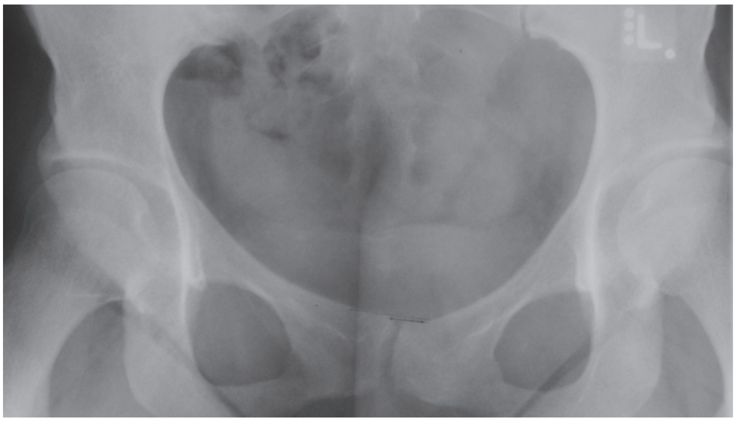
Hip adduction strength test
Mens et al found that measurement of the hip adduction strength can be used to measure disease severity in PLBP patients to evaluate the course of the disease. 80% of the patients felt pain in the pubic symphysis during testing hip adduction strength. The mean adduction strength was markedly lower in PLBP patients than measured in healthy subjects. The range of normal values however was large. Hip adduction strength correlated well with other disease severity measures and had a large responsiveness[86].

Radiological findings

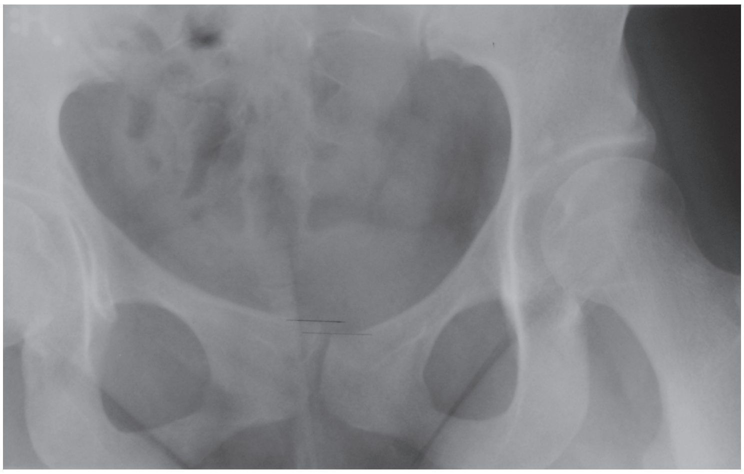
Since the 19th century it has been increasingly accepted that in pregnancy physiological ligamentous relaxation occurs, which causes increased vertical mobility and widening of the symphysis. In 1899 Cantin reported that he found tactile evidence of an increased mobility of the symphysis pubis over that of non-pregnant controls in 98 percent of a series of 500 pregnant women, in whom the separation of the symphysis varied from 1 to 3 mm[1;72]. Before the hazards of ionizing radiation to the fetus were recognized the pelvic ring was studied during pregnancy with radiographs[1;8;38;52;72;91;146]. During pregnancy decalcification with a thinning and absorption of the cortical layer at the pubic margins is described, together with the development of slight proliferative changes giving an appearance of greater irregularity to the symphyseal space and occasional the appearance of small, round cyst-like areas and secondary sclerosis[1;8;25;52;91;130;163]. Several authors found a physiological increase in the symphyseal width during pregnancy (without further widening during labour) and a decrease after delivery[1;8;19;38;52;56;72;91;146]. Similar observations were made for the increase in vertical movement of the symphysis during pregnancy[38;56]. Furthermore, widening of the joint space in the sacroiliac joints was demonstrated during pregnancy[19;72].

Some authors reported that the severity of the pelvic pain corresponded in a general way to the amount of separation and movement of the symphysis, but that this relationship was by no means constant[1;57;163]. However, no simple correlation is found between the degree of symphyseal relaxation and the presence and degree of pelvic pain during pregnancy[10;38;43].
Skajaa and Dale conducted roentgenological studies of symphyseal distention in pregnant women with and without pelvic pain, reporting that the symphyseal width was 4 to 9 mm in both groups[25;130]. Björklund[13] analyzed the tables and calculated a mean symphyseal width of 7.5 mm (SD 1.1 mm, median 8 mm) in cases and 5.7 mm (SD 1.6 mm, median 5.0 mm), which yields a significant difference. In the group with symptoms he could far oftener than in controls observe cavity and fissure formations in the cartilage and now and then spotty decalcifications in the symphyseal ends of the pubic bones as well as fraying on the boundary between bone and cartilage[25;130].
As a sign of pelvic instability most authors refer to an increase in vertical symphyseal mobility. Chamberlain introduced a method by which sacroiliac joint motion could be estimated by radiographically measuring vertical symphyseal mobility. With the patient standing and bearing full bodyweight on alternate legs the height of both the pubic bones is determined. Vertical symphyseal motion varied from 0 – 0.5 mm in the adult male, 0 – 1.0 mm in nulliparous

women to a maximum of 2.0 mm in multiparous women. He stated that all women with symphyseal mobility exceeding 2 mm had sacroiliac symptoms. The upper normal value was put at 2 mm[23]. Hagen defined a separation of the symphysis of more than 10 mm and a vertical mobility of more than 5 mm as pathologic[45]. Mens et al concluded that the step at the symphysis on a Chamberlain radiograph is caused by caudal shift of the of the pubic bone at the side of the leg hanging down instead of cranial shift of the pubic bone at the side of the standing leg[88].



Standing on the left leg.



Standing on the right leg.

Figure 1
Vertical mobility of the pubic symphysis is measured using radiographs according to Chamberlain. The patient is standing on one leg, alternating left and right.

Berezin described a larger width and mobility of the pelvic joints assessed by the Chamberlain method in a group of puerparal women with pelvic pain compared to a group puerparal women without complaints (range of motion between the pubic bones 5.9 +/- 3.3 mm versus1.9 +/- 2.2 mm[10].
Björklund[13;15] used ultrasound to determine symphyseal width and vertical shift during and after pregnancy. A pregnancy-induced physiological increase in laxity of the symphysis was found[13;15]. No significant difference between PLBP patients and controls was found in both symphyseal width and shift at 12 weeks pregnancy. At 35 weeks and 5 months postpartum, patients with disabling pain during pregnancy and no pain at follow up had greater symphyseal shift than controls. However, those with disabling pain during pregnancy and persistent pain at follow up did not differ significantly from controls. They concluded that no evidence exists that the degree of symphyseal distention determines the severity of pelvic pain in pregnancy or after childbirth[15]. In another study, Björklund reported a correlation between severe pelvic pain during pregnancy and increased symphyseal distention. At 35 week of pregnancy the mean symphyseal width was 4.5 mm for women with no or mild pain, 5.7 mm and 7.4 mm in two groups with disabling pain. However, the severity of pain did not predict the degree of symphyseal distention[13]. Furthermore he measured the distention of the symphyseal joint intra partum. He found that the symphyseal distention is minimal during labor regardless of the parity and size of the child. No added symphyseal distensibility was found in patients with a history of pelvic pain[14].

Delivery causes some traumatic damage: the ligaments stretch and the fibrocartilaginous disc tears. On a CT scan performed 24 hours after an uncomplicated vaginal delivery, 7 % of the women had and increased sacroiliac joint width, and 42 % showed gas in the sacroiliac joint space. Widening of the symphysis was present in 42%, and intra-articular gas was seen in the symphysis in 28% of the women[41]. On a MRI scan women a significantly larger intrapubic gap was seen 2-5 days postpartum compared with nulliparous women. The mean signal intensity of the cartilage of the symphysis pubis was significantly different compared to nulliparous women indicating a higher water content. 13 of all 19 postpartum women had bruises of the parasymphyseal pubic bones. No significant differences were found for the postpartum group with and without pelvic pain[161].

Other authors have studied persistent pelvic pain originating from pregnancy or childbirth. They have found a poor correlation between the symphyseal distention and the magnitude of the symptoms. In this patient category Hagen[45] and Walheim[158] found no hypermobility of the symphyseal joint with X-rays and electromechanical measurements respectively. Hagen found a separation

of more than 10 mm or a vertical mobility greater than 5 mm in 4 out of 21 patients. Walheim found vertical symphyseal mobility exceeding 2 mm on Chamberlain radiographs in 5/12 patients[157]and 7/15 patients[158], but with electromechanical measurements pathological values for vertical motion were recorded in only 2 out of 14 patients[158]. These were the only two individuals in whom widening of the symphysis had been demonstrated radiologically. There was considerable divergence between the vertical mobility measured on radiographs and by the electromechanical method[158]. Slatis and Eskola[131] reported a vertical shift in the symphysis pubis of 4 mm or more in 8 out of ten patients. Sturesson used roentgen stereophotogrammetry to examine movements of the sacroiliac joints in patients with sacroiliac joint disorders. He described very small movements: a mean rotation of 2.5 degrees and a mean translation of 0.7 mm in the SIJ under load with no difference between symptomatic and asymptomatic joints[139].
LaBan[66] studied 50 patients with lumbosacral symptoms and inguinal pain and found that a pelvic roentgenogram showed more than 2 mm vertical displacement (mean 3 mm) of the pubic bones in all patients. In most instances the degree of slip was greater on the symptomatic side. Controls exhibited no such motion. Decalcification and sclerosis of the symphysis showed in 16 to 39% of the patients[38;155]. Sclerosis, erosions, cystic changes and narrowing or widening of the sacroiliac joints was described in 14 to 73 % of the patients[10;38;45;57;66;155;158]. Berezin noted that the sclerotic changes of the sacroiliac joint tended to appear 2 to 3 years after onset of pelvic insufficiency[10].

Additional investigations

Colour Doppler imaging of vibrations
Research has been done to develop a non-invasive way to measure sacroiliac joint stiffness. Using colour Doppler imaging of vibrations at both sides of each sacroiliac joint the stiffness can be determined in threshold units[29]. Damen et al found no association between pregnancy related low back and pelvic pain and increased sacroiliac joint laxity. In both healthy subjects and patients a wide range of stiffness values was found, and pregnant women with moderate or severe PLBP have the same sacroiliac joint laxity as pregnant women with no or mild pain[26;27]. However, a clear relation between asymmetric laxity of the sacroiliac joints and PLBP is found[22;26;27]. The sensitivity of asymmetric laxity was 37 to 65%, the specificity 83 to 96% with a positive predictive value of 77%[26;27]). Subjects with PLBP and asymmetric laxity of the sacroiliac joints during pregnancy have a threefold higher risk of PLBP postpartum than women with symmetric laxity[27].

Invasive diagnostic procedures
Intra-articular injection with a local anaesthetic into the sacroiliac joint relieved the pain for more than 12 hours in four out of five patients[131]in over half of the cases immediate reduction of the pain, the remainder at least partial relief[66].
In two articles external fixation with a trapezoidal compression frame was used as an aid to the diagnosis of sacroiliac joint instability[131;157]. Walheim[157] reported that all symptoms decreased considerably or disappeared in six patients, and at least half the symptoms in 5 patients. One patient became worse and developed pain in the contralateral sacroiliac joint. No stabilising effect of the frame on symphyseal mobility could be detected. In the study of Slatis and Eskola[131] the pain disappeared in seven patients, was reduced in two and remained unchanged in one patient. The mean vertical shift of the symphysis was reduced from 5.0 to 2.6 mm. Walking ability improved in five patients.
With a radiostereometric analysis Sturesson et al. found significant reduction in the movements of the sacroiliac joint in 8 out of 10 patients with severe and long-lasting PLBP after external fixation using a Hoffmann-Slätis frame[140].

Pathology findings

Most of our knowledge about the histological changes of the symphysis and the sacroiliac joint during or after pregnancy dates from the first half of the twentieth century, when mortality during pregnancy and labor was not exeptional. Changes in the pelvic joints during pregnancy and after delivery were already described by Luschka (1854) and Loeschcke (1912)[70;71]. They described that the pubic symphysis is wider in pregnant than in non-pregnant women and movement between the pubic bones can be demonstrated due to loosening of the pelvic ligaments and cartilages under hormonal influences. Characteristic changes include edema and irregular cavities in the cartilage, connective tissue hypertrophy and increased vascularization in the ligaments in both the symphysis and the sacroiliac joints[37;49;50;70;71;111]. Loeschcke found these changes as early as the second month of pregnancy and noted that they disappeared shortly after birth[70]. In Loeschcke's opinion increased growth occurred during pregnancy at the osteochondrous junction with the formation of new bone and increase in the pelvic diameter[70]. This was refuted by Putschar[111]. In a comprehensive monograph he considered the most characteristic pregnancy change to be the resorption and remodeling of the posterior margin of the pubic facette in combination with ligamentous hypertrophia, which contributes to the formation of a retropubic eminence[111;112].

The formation of traumatic, irregular fissures of the fibrous and hyalin cartilage of the symphysis are described[37;49;50;70;111;112]. In both male and female pelves cleft formations arise in the course of time, but in women either both prevalence and extent of the clefts is larger[49;50;70;111;112]. Putschar did not find actual mechanical damage such as hemorrhage in the symphyseal ligaments or clefts and tears in cartilage and ligaments in pregnant but undelivered individuals. Even in multiparas with evidence of previous parturition damage, fresh tears have not been observed due to undelivered pregnancy alone. According to his observations delivery of a mature infant always causes traumatic damage to the symhysis pubis. This consists of hemorrhage or serosanguineous transsudation into symphyseal ligaments and into the cleft cavity[50;70;111;112]. Cartilage tears with hemorrhagic margins are usually present, single or multiple in the hyaline cartilage or near the ostecartilaginous border. Ruptures of the bony endplate are also seen. The fibrocartilage of the disc frequently tears in extention of the preexisting cleft, medially and/or eccentrically. The hemorrhage is resorbed, but the cartilage tears do not heal. In multiparas fresh additional tears from the most recent pregnancy are observed superimposed on old, unhealed tears.

All these traumatic cartilage changes contribute to the disruption, attrition and expulsion of the disc cartilage. Extrusion of disc cartilage occurs in the posterior, but also in he anterior and inferior ligaments. Disruption of the continuity of the osteocartilaginous border with herniation of cartilage into the underlying bone, formation of proliferating cartilage nodules, cyst formation, fibrous

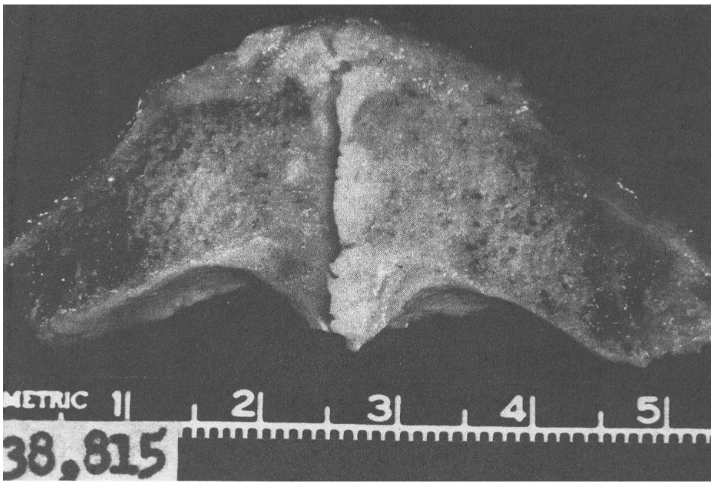


Figure 2
Fresh coronal cut of the pubic symphysis showing a complete cleft, large retropubic eminence and cartilage nodule. 52 Year old white female, 5 children. From: Putschar, 1931.

transformation of the bone marrow and reactive, sometimes sclerotic bone formation is observed[37;50;70;111;112]. Eymer and Haslhofer also noted ruptures in the subchondral bony plate and interpreted these changes in the osteochondral junction as osteo-arthritis deformans[37;49;50].

Obstetric trauma may also produce haemorrhages in the sacroiliac joint cavity[49;50;70]. Putschar observed less parturition damage in the sacroiliac joint than in the pubic symphysis. Often only a considerable hyperaemia, small haemorrhages, widening of the joint cavity and stretching of the anterior ligaments are seen. Large haemorrhages and tears of the cartilage and ligaments occur less frequently. In the long term he described cartilage degeneration and expulsion[111]. Brooke described that during pregnancy mobility of the sacroiliac joints increased with a factor two and a half compared to non-pregnant women, slowly at first, but easily recognizable in the 4th month. Stability is not completely recovered until 3 months postpartum[18;19].

Therapy

Non-operative treatment

Conservative treatment includes bedrest (with a broad pelvic sling)[1;10;43;45;132;146;163], physiotherapy with muscle strengthening exercises[45;87;107] and a pelvic belt or corset[1;19;43;45;87;107;132;133;146;157;158;163]. The application of a pelvic belt just below the anterior superior iliac spines results in a significant decrease of sacroiliac joint laxity measured with Doppler imaging of vibrations[28]. Ability to perform the ASLR was improved by a pelvic belt[88].

Only a few studies investigate the results of physical therapy for pregnancy-related low back and pelvic pain. Stuge et al. performed a systematic review of prospective controlled clinical trials to assess the effectiveness of physical therapy for prevention and treatment of PLBP. Because of heterogeneity and varying quality of the studies, no meta-analysis could be performed[136]. Mens et al [82] found that training of the diagonal trunk muscle systems by videotape instruction is not more effective than training of the longitudinal trunk muscle systems or no excercises in patients with pelvic pain 6 weeks to 6 months after pregnancy. In pregnant women with pelvic pain Nilsson-Wikmar compared a home training and stretching program and a medical training program to a control group. All three groups received a non-elastic sacroiliac belt and were given information. No significant difference in pain and functional status was described in week 38 of pregnancy or 3 months postpartum[93]. Kihlstrand reported that in pregnant women watergymnastics resulted in significantly less days of sick leave compared with controls given no treatment. The treatment group showed significantly lower mean pain values, but no signifant differences in the incidence of pain were seen[59]. Ostgaard[107] reported that in pregnant women with "back pain" sick leave during pregnancy could be reduced by an individual back training program. No pain intensity reduction was seen on a VAS. Women with "posterior pelvic pain" did not benefit from the program. In this group a non-elastic sacroiliac belt reduced the pain when walking. Noren et al.[95] studied the effects of an individual-based education and training program in patients who were pregnant and had PLBP. They found that days lost to sick leave were reduced to 30 days in the intervention group compared with 54 days in a group of women from another antenatal clinic who received no treatment. In a prospective randomized trial, Dumas et al.[33] investigated the value of excercise classes in the prevention and treatment of PLBP. They found no effect on back pain during pregnancy and after child birth. In a non-randomized study Mantle et al studied the effects of ergonomic advice given in "back care classes" on the development of back pain during pregnancy. In the treated group 32 % experienced significant backache versus 54 % of the control group[77]. To evaluate the effectiveness of a treatment program focusing on specific stabilizing exercises (SSE) a randomized controlled trial was performed by Stuge et al.[137] The SSE group showed statistically and clinically significant lower pain intensity, lower disability, and higher quality of life compared with the control group. This benefit persisted at 2 years follow up[138]. Over time the control group also demonstrated a significant improvement in disability, but not in pain intensity. Patients with the highest level of disability and greatest potential for improvement recovered most, regardless of intervention group[138].

Therapy in a specialized rehabilitation clinic might be needed in more severe cases with persisting pain. In some patients even therapy in a specialized rehabilitation clinic remains unsuccessful and surgical fixation of the symphysis and sacroiliac joints then seems to be the only remaining treatment option for patients seriously disabled by PLBP.

Operative treatment

Internal fixation of the pelvic ring is commonly used in unstable pelvic fractures[78;92;118;125;144;147], but little experience has been gained with surgical intervention in PLBP. Surgical intervention in PLBP patients is described in only a few small series[17;45;48;96;97;126;131;142]. Some authors did an isolated symphysiodesis[48;96], others did only a sacroiliac joint arthrodesis[131;142], or used various combinations of operations[17;45;97]. Sacroiliac screws were applied only in two small series of PLBP patients[17;126], and in one case the SI screws reached only in the lateral mass of the sacrum[126]. More often the SIJ was fixated through an anterior[45;131] or open posterior approach[142]. Hagen[45] reported six good, one fair, one poor result and two non-unions in eight patients. Among eight patients Olerud and Walheim[97] had seven with almost complete relief of symphyseal pain and four with residual pain in the SI region. In the study of Slatis and Eskola[131] seven out of ten patients who responded well to external fixation were operated. Five of the seven patients were improved, two remained unchanged of whom one had a non-union. Brink and Jensen[17] described full relief of pain in two of the nine cases, partial relief in seven and three reoperations. In eighty-one patients Sudmann and Weber[142] fused hundred-and-twenty sacroiliac joints, of which sixty-three were relieved, thirty-one partly relieved and twenty-three not relieved of pain of which sixteen had a non-union and nine were reoperated.

Surgical techniques used in pelvic fractures

Anatomy and biomechanics of the pelvis
The pelvis is a complete articulated bony ring formed by the sacrum and both innominate bones, which are a fusion of the ilium, ischium and pubic bone. Anteriorly both innominate bones are connected by the symphysis, a cartilaginous joint. Posteriorly the sacrum articulates with the left and right ilium in the sacroiliac joints. These joints are protected by several ligaments (anterior and posterior sacroiliac ligaments, sacrospinal, and sacrotuberal ligament). In the sacroiliac joints the weight of the trunk is transferred from the sacrum to the hipbones.

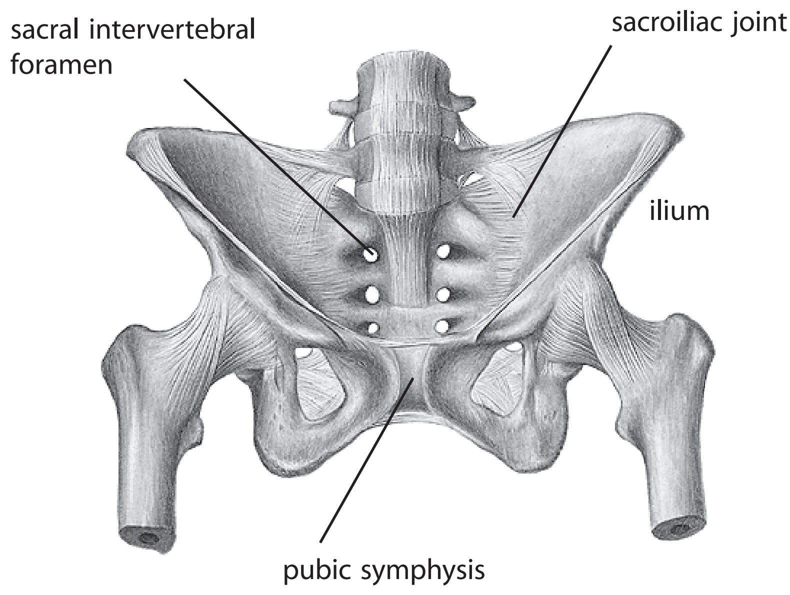


Figure 3 Pelvic anatomy

Laboratory tests on the load displacement behaviour of the sacroiliac joint show that at maximum test loads displacement in the direction of the force range from 0.76 to 2.74 mm, and that in bending and torsion mean rotations range from 1.4 to 6.21 degree[89]. With a roentgen stereophotogrammetic analysis of living subjects Sturesson found a mean rotation of 2.5° (range 0.8 – 3.9°) and a mean translation of 0.7 mm (range 0.1 – 1.6 mm) in the sacroiliac joint. With an electromechanic method Walheim measured the mobility of the pubic symphysis in living subjects. In the craniocaudal direction he reported a translation up to 3.1 mm, in the dorsoventral direction a translation up to 1.3 mm and a rotation of up to 1.6°[156;159].

Fracture classification

Fractures of the pelvis are most commonly classified according to the classification of Tile. Based on the stability of the pelvic ring three types of fractures are distinguished. In type A, the pelvic ring remains intact, only involving the avulsions of the iliac wing and transverse sacral fractures. Tile B fractures are partially stable: the anterior pelvic ring is interrupted completely and the posterior ring incompletely. This leads to a rotational instability around a vertical axis. The B1-type, or "open book" injury, is caused by anteroposterior compression leading to external rotation of the hemipelvis and disruption of the pubic symphysis. When the diastasis is less than 2.5 cm the sacroiliac joint remains intact and stability of the pelvis is retained. If the symphysis opens wider, the sacrospinous and anterior sacroiliac ligaments are torn, but the strong poste-

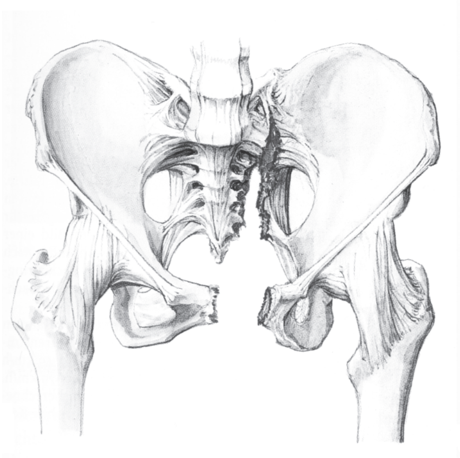


Figure 4a
Tile B or "open book" injury: disruption of the symphysis and anterior sacroiliac ligaments causes rotational instability.

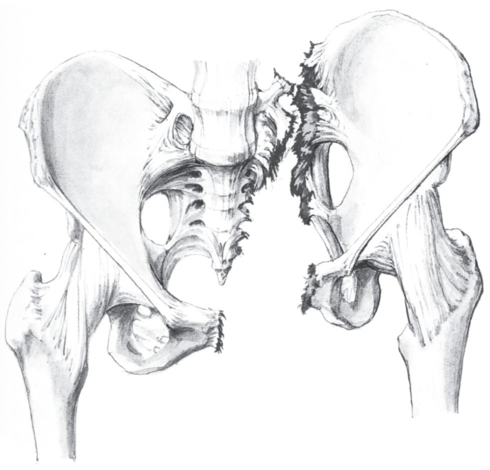


Figure 4b
Tile C fracture: both anterior and posterior pelvic ring are completely disrupted leading to both rotational and vertical instability.

rior sacroiliac ligaments remain intact. In a B2-type lesion lateral compression has caused internal rotation of the hemipelvis. The superior and inferior pubic rami break and a crush injury occurs anteriorly at the sacroiliac joint or through the sacrum, either on the ipsilateral or contralateral sides (bucket handle type). A B3-lesion is a bilateral injury of either B1- or B2-type. In a Tile C injury both anterior and posterior pelvic ring are completely disrupted causing both rotational and vertical instability. The posterior lesion may be either a fracture through the ilium or sacrum or a (fracture)dislocation through the sacroiliac joint. In a C1-lesion the contralateral posterior ring is intact, in C2 –lesions a contralateral B-type injury is present and in a C3 fracture a bilateral C-type injury is found[148-150].

Fixation techniques

Surgical reduction and fixation of pelvic fractures can be performed through external and internal fixation. From biomechanical studies can be concluded that in unstable pelvic fractures an external frame alone, regardless of the geometrics of the frame, is not enough to restore stability and allow weight-bearing[69;114;119;124;135;147;148]. Greater stability can be achieved by internal fixation[58;69;78;114;148].

Usually in fixation of pelvic ring fractures the procedure is started by stabilization of the anterior pelvic ring through a Pfannenstiel incision. For fixation of the anterior pelvic ring various devices such as plates, screws, tension bands and external fixation have been used[6;31;44;54;69;73;80;114;119-121;124;127;128;135;148;154;162]. Plate fixation is recommended for the disrupted symphysis and severely displaced pubic rami fractures[78]. Hofmann and Varga concluded that tension band wiring was superior to plating in the osteoporotic pelves, but under dynamic loading Meissner found symphyseal plates to be the strongest construction[54;80;154]. No significant difference was found between 1 or 2 symphyseal plates[69;73;135].

In Tile B lesions, fixation isolated anterior fixation of the disrupted symphysis is advocated[150]. In a (rotationally unstable) Tile B injury, fixation of the symphysis maintains reduction of the SIJ[73;148], which is refuted by others[31;127;128].

In Tile C injuries both anterior and posterior fixation is recommended[114;148]. Posterior fixation is used in combination with anterior plate fixation[58;78;115;118;125] or an external fixator[35;58;118]. Some authors use isolated sacroiliac screw fixation[58;115;125]. It is not sufficient to stabilize Tile C fractures without posterior fixation[78;114;115;119;148].

In literature a large number of devices have been used for posterior fixation: sacral (transiliac) bars, sacroiliac screws, ventral plates, dorsal small fragment plates, pediculoiliac screws and a "double cobra" plate[6;24;31;44;54;69;109;110;114;119-121;123;124;127;129;135;148;154;162].

Biomechanical studies have been performed to compare various fixation techniques for different injuries. In a sacroiliac joint disruption, ventral sacroiliac plates were less resistant to torsion than screws and bars, but during axial loading transiliac bars and a tension band plate proved to be the weakest construct[24;121;148;162]. Others found no significant difference in stiffness and strength between sacroiliac screws, plates and sacral bars[6;31;44;69;114;127]. For a sacral fracture posterior fixation of with a posterior small-fragment plate showed lower stiffness than sacral bars[110] and sacral bars had a significantly higher load to failure and higher stiffness than an internal fixator[109]. No significant differences in the load to failure were found between sacral bars, SI screws and posterior small-fragment posterior plates[110]. Simonian found no difference in stiffness between sacroiliac screws, dorsal tension band reconstruction plate and transiliac bars[129]. Simonian and Sagi could not discover a significant difference between 1 and 2 sacroiliac screws for a transforaminal sacral fracture[120;129]. For a sacroiliac disruption in artificial pelves Yinger found that 1 sacroiliac screw was the least stiff of the fixations tested and 2 sacroiliac screws showed much greater stiffness[162].
Internal fixation for sacroiliac joint disruptions and fractures of the sacrum can be done through an anterior or posterior approach. The major disadvantage of the posterior approach has always been the high risk of wound infection and more tissue damage. The advantage of sacroiliac screws is that fixation can be performed percutaneously, which minimizes blood loss and carries less risk of wound infection than the open reduction required for plate fixation[92;115;117;118;125;144]. Recent advances in imaging and operating techniques have allowed screws to be placed under either fluoroscopic[58;115;117;118;125;144] or CT guidance[34;35;92].

Sacroiliac screw positioning can be performed in prone or supine position[58;115;116;118]. Intra-operatively the posterior pelvic ring is evaluated through inlet, outlet and lateral views using C-arm fluoroscopy, which allows real-time imaging during positioning [115;116;118]. First guide-wires are drilled through the ilium into the first or second sacral vertebra, directed at the center part of the body. After correct positioning has been confirmed by fluoroscopy the canulated screw is positioned over the guide-wire[116;118;125;145]. Fluoroscopic placement of percutaneous sacroiliac screws requires a high degree of "three-dimensional thinking" and thorough knowledge of pelvic anatomy by the surgeon[116]. When two sacroiliac screws are used they can be inserted parallel into the first and second vertebral body, but also converging into the first vertebral body[78;115;116;118;145]. Because there are indications of an increased risk of sacral foramina intrusion when positioning the lower screw into the second vertebral body, currently both screws are positioned into the first vertebral body, unless sacral abnormalities prevent the use of this technique[42]. Although posi-

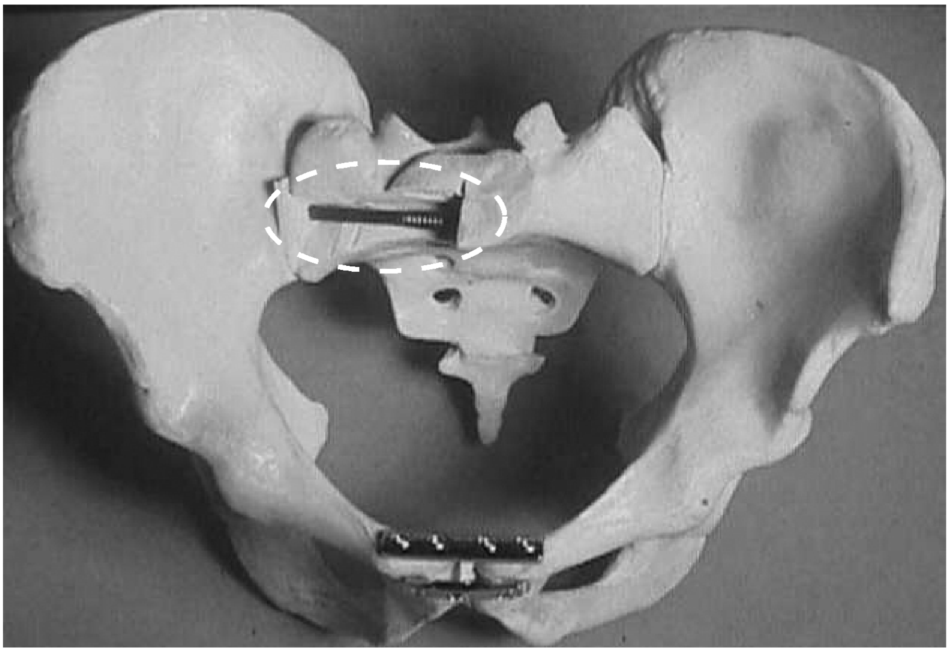


Figure 5
Sacroiliac screw in a plastic pelvis. Part of the sacral ala and the vertebral body have been removed to clarify the exact position of the screw.

tioning sacroiliac screws using an open technique is easier because it makes a smaller demand on the accuracy of the surgeon's hand[145], percutaneous positioning results in minimal invasion of usually severely compromised soft tissue[92;115;117;118;125;144].

Operation related morbidity

Complications of anterior fixation include haemorrhage, wound infection, damage of the bladder, screw or plate failure and non-union. For posterior fixation haemorrhage and wound infection are less frequently seen after percutaneous screw fixation compared to the open technique[92;115;117;118;125;144]. Specific complications of sacroiliac screw fixation are intrusion into the intervertebral foramina with possible nerve injury, loosening of the fixation, peroperative guidewire breakage and screw breakage[35;115;118;125;144]. One case of superior gluteal artery injury, requiring embolization is described[7]. In about 0 – 6.6 % of the patients in whom the posterior pelvic ring has been stabilized using screws, a neurological injury due to intrusion of the screws into the sacral canal or the sacral foramina occurs[34;35;58;78;115;118;125;144;145]. Using fluoroscopy misplacement of the screws occurred in 2.8 – 13 % of the patients[58;115;118;145]. These results could be improved by the use of computed tomography-guided screw placement or computer navigated fluoroscopy[9;34;34-36;55;92;92;151]. Although these techniques promise superior results due to the improved quality of the imaging techniques, malpositioning is still possible[55].

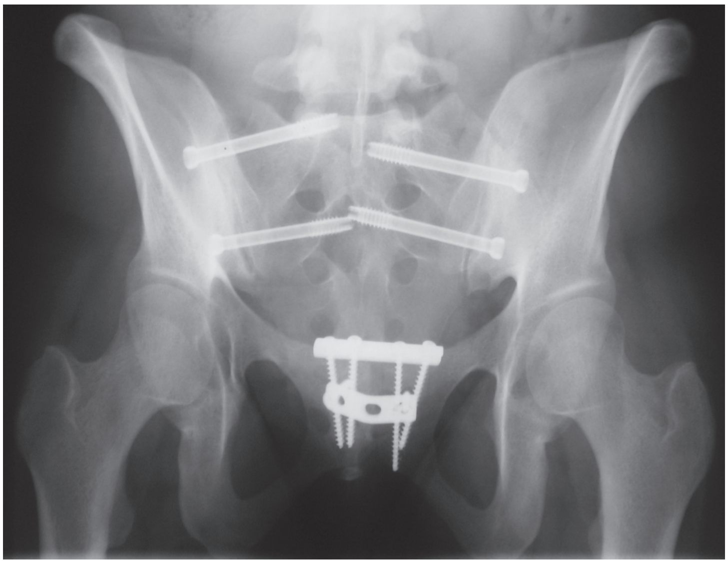


Figure 6a
Outlet view of a patient with sacroiliac screws placed parallel in the first and second sacral vertebral body.

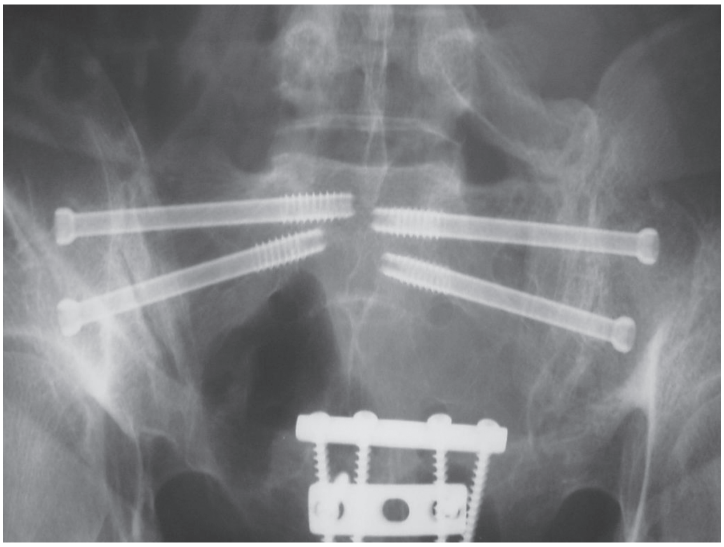


Figure 6b
Outlet view of a patient with sacroiliac screws inserted converging in the first sacral vertebral body.

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3

Biomechanical Comparison of Sacroiliac Screw Techniques for Unstable Pelvic Ring Fractures

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Abstract

Objective
To determine the stiffness and strength of various sacroiliac screw fixations in order to compare different sacroiliac screw techniques.

Design
Randomized comparative study on embalmed human pelvises.

Materials and Methods
In 12 specimens we created a symphysiolysis and sacral fractures on both sides. Each of these 24 sacral fractures was fixed with one of the following methods: one sacroiliac screw in the vertebral body of S1, two screws convergingly in S1 or one screw in S1 and one in S2. On the left and right side of a pelvis different techniques were used. The pubic symphysis was not stabilized. We measured the translation and rotation stiffness of the fixations and the load to failure, using a 3-dimensional videosystem.

Results
The stiffness of the intact posterior pelvic ring was superior to any screw technique. Significant differences were found for the load to failure and rotation stiffness between the techniques with two screws and a single screw in S1. The techniques utilizing two screws showed no differences.

Conclusions
Based on the results of this study we can conclude that a second sacroiliac screw in completely unstable pelvic fractures increases rotation stiffness and improves the load to failure.

Introduction

Nonoperative treatment of unstable pelvic fractures has a significant chance of long-term complications: mal- and nonunion, pain, and neurological dysfunction[14;30;32;33]. Surgical reduction and fixation of pelvic fractures can be performed through external and internal fixation. With an external fixator direct postoperative weight bearing is not possible[30;32;33]. Greater stability can be achieved by internal fixation, consisting of a combination of posterior and anterior fixation[9;14;33]. Ideally the fixation would provide enough stability to allow early mobilization of the patient, thus avoiding complications associated with prolonged bed rest[19;32;33]. Most authors advise limiting weight bearing on the injured side for 10 to 12 weeks after internal fixation [9;20;21;25;31].

Several authors have tried to quantify the stabilizing effect of different internal fixation methods of the pelvic ring. A wide variety of injuries have been studied. Furthermore the loading techniques differed: one-leg stance[4;11;13;16;17;24;30], bilateral stance[3;22;24;26-28;35], vertical loading [2;23] or lateral compression[8]. The loads varied from 250 to 2000 N, which makes it difficult to compare the results. Most authors fixed the pelvic ring with various combinations of anterior and posterior fixation[2;4;8;11;12;16;17;22-24;26;30;33;35]. Some, however, only did an anterior[13;26;27;33] or posterior fixation[3;24;26;28]. For fixation of the SI joint one, two or three SI screws, a ventral SI plate, tension band plate or sacral bars were used[2-4;8;11;12;16;17;22-24;26;28;30;33;35]. The pubic symphysis was fixed using one or two plates or a metal or PDS banding[2;4;8;11-13;16;17;22-24;26;27;30;33;35]. Some also used an isolated external frame[12;18;22;24;30;33].

In most cases the displacement of the fracture was measured in one direction[2-4;8;12;23;24], sometimes at several points in the pelvis[11;13;22;26-28;30;33;35]. Most often shear or diastasis of the pubic symphysis or the sacroiliac joint was measured[11;13;22;26-28;30;35]. In only a few cases were 3-dimensional measurements made of the movements in the fracture plane[16;17;30;33]. However, the multiaxial nature of the forces and displacement require 3D description of translations and rotations of the fracture parts. Furthermore, not all fixation techniques tested are still commonly used. A few studies indicate that plates and SI screws show biomechanically equal results[17;28]. However, no study has compared different positioning of these screws.

The objective of this study is to compare the stiffness and strength of various sacroiliac screw fixations in a standardized way. An infrared 3-dimensional videosystem was used to measure displacement.

Materials and methods

Specimens and injury

We used twelve embalmed cadaveric pelvises, which were dissected, leaving the ligamentous structures intact, including the ischiosacral ligaments. The femora, lumbar vertebrae and all muscles were removed. The average age of the specimens was 78.3 years (range 67-92). In one pelvis a Girdlestone was present and in another a hemisacralisation of L5 on the left side was found. In each pelvis we created a Tile C1 pelvic ring injury with a symphysiolysis and sacral fractures on both sides. In order to obtain a similar injury in all pelvises we created a sacral fracture through the sacral ala using a saw. The saw-cut (width 1.5 mm) was started halfway between the sacroiliac joint and the foramen S1 and continued in the sagittal plane. The pubic symphysis was cut with a scalpel.

Fixation methods of the SI joint

Each sacral fracture was fixated with one of the following methods: one sacro-iliac screw in the vertebral body of S1 (technique S1), two screws convergingly in S1 (technique S1-S1) or one screw in S1 and one parallel to the first in S2 (technique S1-S2) (Figure 1). All fixations were performed by the second author. The aim of this study was to compare the properties of the three techniques for posterior fixation. Hence in order to perform a paired analysis for the screw techniques on both sides of one pelvis, the pubic symphysis was not fixated, as is required in the clinical setting for a Tile C fracture.

We used cannulated partially threaded (16mm), cancellous lag screws with a length of 70 mm and a diameter of 6.5 mm(Biomet®, Warsaw, In, U.S.A.) in combination with washers placed over a K-wire. The screws were inserted through the posterior ilium and into the vertebral body of S1 (and S2) across the sacral fracture, according to the technique of Matta and Saucedo[14]. Drilling was started two to three cm anterior to the posterior superior iliac spine and at the mid-point between the iliac crest and the sciatic notch. Drilling was directed to the center of S1 (or S2) vertebral body. After the position and direction of the K-wire had been checked by both first and second author, the screws were inserted. All the threads were positioned across the fracture and the tip of the screw was placed in the vertebral body of S1 and/or S2 just short of the mid-line. This was checked visually after measurement of the load to failure when taking apart the fixation.

Loading arrangement

In order to enable the application of load to the pelvic ring the sacrum was fixed between two plates with screws and methylmethacrylate-polymere resin

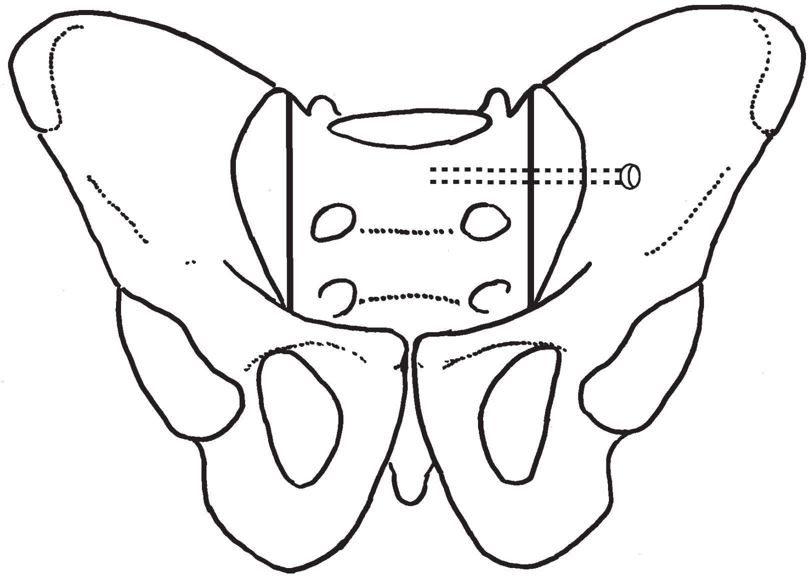

Figure 1a
Sacral fractures were created with a saw on both sides of the pelvis. The left side of the figure shows the unfixed fracture through the sacral ala. The right side shows the posterior fixation technique with one sacroiliac screw in the vertebral body of S1.

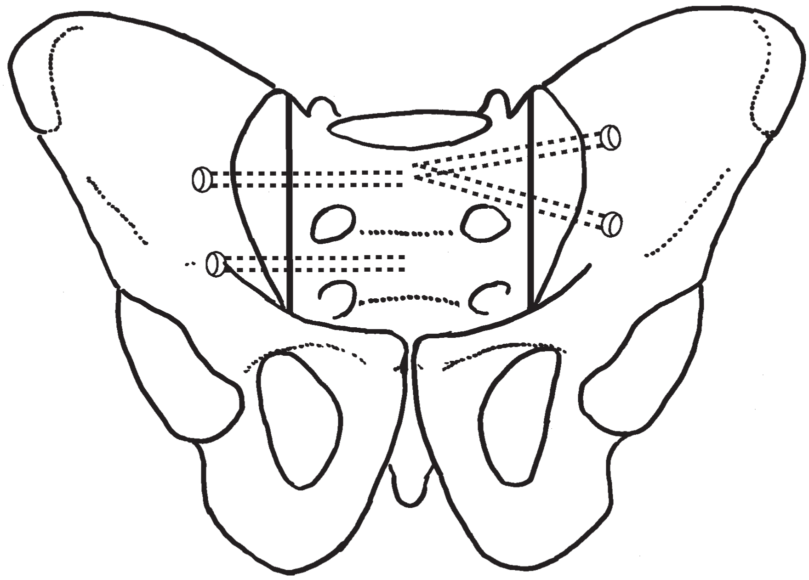

Figure 1b
The left side of the figure shows the posterior fixation method with one sacroiliac screw in the vertebral body of S1 and one parallel to the first in S2. The right side shows the technique two screws convergingly in S1.

(Demotec®) and mounted to a frame. The pelvis was oriented with anterior superior iliac spines and the pubic symphysis in the frontal plane which is approximately comparable to the physiological position during standing[13;17]. The ilium was loaded by a force acting through a rope on a plate with an extension device, which was attached to the ilium in such a way that the line of action of the load passed in a vertical direction through the fracture plane (Figure 2 and 3). This enabled us to investigate the resistance of the fixation against shear force, which is an important part of the load during weight bearing. Both sides of the pelvis were loaded to a maximum of 150 N under two conditions: intact and after disruption of the symphysis, the sacrotuberous and sacrospinous ligaments. The load was applied in three cycles to investigate reproducibility. After these measurements a Tile C1 fracture was created unilaterally, which was fixed with one of the three SI screw techniques. During measurements of the stiffness the maximum load was restricted to 150 N in the intact situation and 100 N after fixation, avoiding permanent damage to the pelvic bones and fixation. These values were chosen since up to 150 and 100 N respectively no permanent displacement was seen in any of the pelvises in a pilot study. Furthermore the load to failure was determined. After failure a sacral fracture was created on the contralateral side, which was measured after fixation. The initial side was

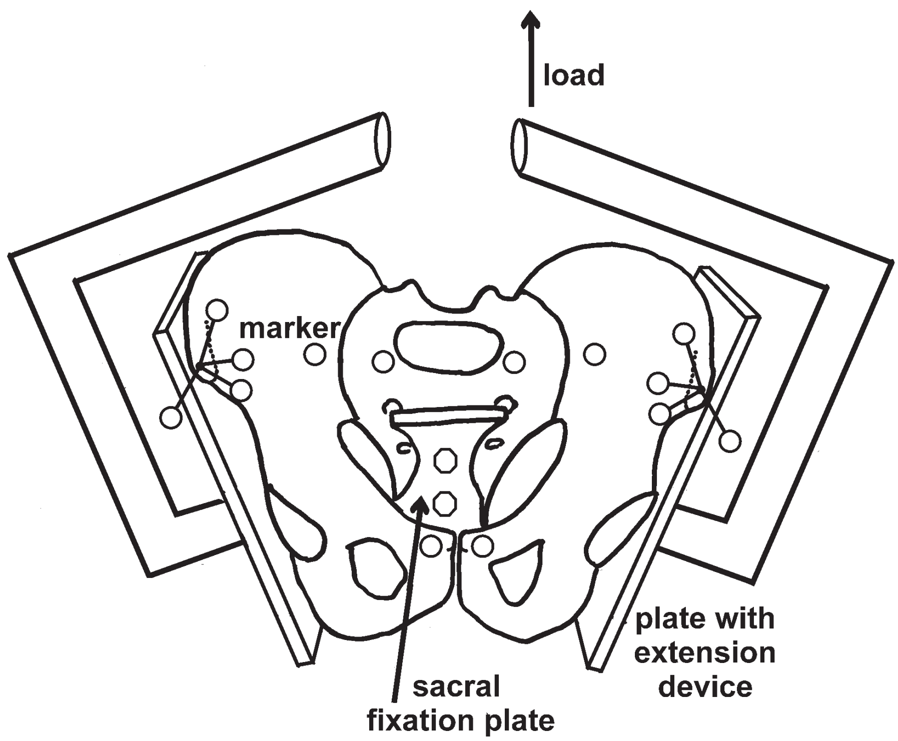

Figure 2 Loading arrangement

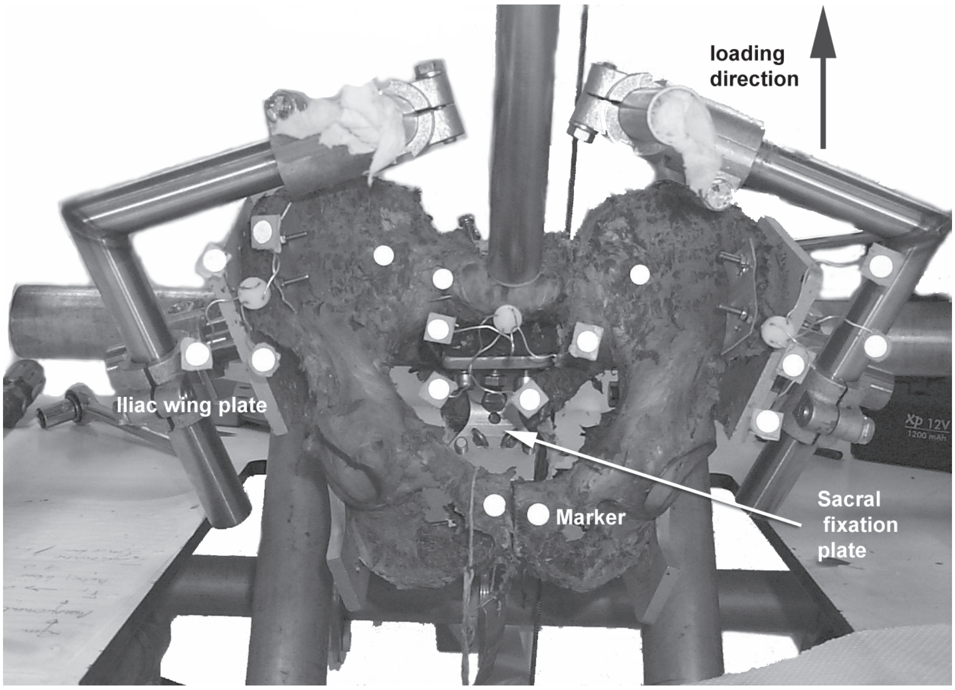

Figure 3 Pelvis in the loading frame

replaced in its original position and if necessary, fixated additionally to obtain this position. The two sacral fractures of one pelvis were fixed with different screw techniques, which yielded six different combinations when left and right sides were reversed in a subsequent specimen. We randomized the order in which these six combinations were used. The quality of the fixation was scored on a three-point scale based on the grip of the screws and we made a clinical estimation of the bone quality during dissection. For quality of fixation we defined "good" as "excellent grip comparable to healthy adults", "moderate" as "relatively good grip, no signs of slipping" and "bad" as "poor grip with slipping of the screws". For bone quality we defined "good" as "strong cortical bone comparable to healthy adults", "moderate" as "signs of weakness of the cortex present" and "bad" as "soft cortical bone, easily penetrable with a scalpel".

Motion measurements

Simultaneously displacements were measured between the pubic bones, at the sacroiliac joint or sacral fracture, and between the sacrum and the ilium. A 3D videosystem was used to measure displacements in all 6 degrees of freedom (3 dislocations and 3 rotations). To enable the computerized video registration of bone displacements, clusters of four infrared light reflecting markers were attached to the cranioventral edge of the first sacral vertebral body and to both superior anterior iliac spines. Two markers were placed bilaterally, about 2 cm from the fracture plane of the sacrum and two markers were positioned on both superior rami of the pubic bone close to the symphysis. Using a technique similar to that of Keemink et al[10], these markers were illuminated by infrared light sources mounted to the two video cameras[7]. Infrared filters in front of the camera lenses ensured good contrast in the video images. With the help of a video image processing board (Vision Dynamics VCS512-II) in a personal computer, the image coordinates of the centers of the markers were determined. The image coordinates from the two cameras were combined to three-dimensional spatial coordinates using Direct Linear Transformation[1]. The algorithms described by Spoor and Veldpaus were used to calculate displacements between the ilium and the sacrum, at the fracture plane and at the pubic symphysis[29]. The resolution of the system proved to be about 0.1 mm, based on previous tests.

Data analysis

As outcome measures we investigated the stiffness of the fixation and the load to failure. We defined the translation stiffness (in N/mm) of the fixation as the slope of the load displacement curves of the ilium with respect to the sacrum up to 150 N in the nonfixated pelvises and up to 100 N in the fixated pelvises. Although we tried to apply the force exactly in the fracture plane, inadvertently a small lever arm will be present between the force and the fracture plane. Since the magnitude of the resulting moment is unknown, the rotation stiffness (moment divided by observed angular displacement) could not be calculated. Therefore we determined the applied load divided by the observed rotation as an indication of rotation stiffness. In a linear model, the slope of the load displacement curves from the 3 cycles was calculated using the least squares method. The load to failure was defined in two ways, the force required to produce 5 mm displacement of the fracture parts in the sacrum[17] and 10 mm displacement of the pubic symphysis[18]. For the statistical calculations we used SAS version 6.12 (SAS institute inc., Cary, NC, USA). In order to compare the translation stiffness, the rotation stiffness and the load to failure of the three screw methods we performed a MANOVA with the translation/rotation stiffness or load to failure of the fixated pelvis as the dependant variable. As baseline the translation/rotation stiffness of the intact pelvis and the pelvis with disrupted ligaments were examined. As covariables we used the fixation technique, bone quality, fixation quality and fracture side. Because the distribution was skewed we applied a log transformation to the data.

Results

Displacement at the sacroiliac joint / the sacral fracture

The displacements measured at the sacroiliac joint and later at the sacral fracture are summarized in Table 1. At a load of 150 N, the mean displacement in the cranial direction was 0.4 mm in the intact pelvis, and 0.7 mm after dissection of the symphysis and ligaments. Movements occurred mainly in the direction of the applied force and displacement at the SI joint in the ventrodorsal or mediolateral direction was less than 0.2 mm. After fixation, mean cranial displacements were 2.0 mm for the technique with one screw and 1.8 mm and 1.3 mm for the methods with two screws in S1-S2 and S1-S1 respectively when loaded up to 100 N. Movements in the ventrodorsal and mediolateral directions were randomly distributed around zero, but the larger standard deviation shows that absolute displacements were larger for the technique with one screw compared to the techniques with two screws.

	X		Y		Z		Total	
	mean	SD	mean	SD	mean	SD	mean	SD
intact	-0.09	0.18	-0.03	0.10	0.38	0.35	0.44	0.35
symphysis cut	-0.12	0.21	0.03	0.15	0.60	0.54	0.69	0.51
S1 fixation	0.03	1.57	-0.01	1.02	2.03	1.65	2.46	2.00
S1S2 fixation	-0.13	0.25	-0.05	0.13	1.83	1.65	1.86	1.63
S1S1 fixation	0.05	0.81	-0.05	0.17	1.31	1.42	1.44	1.52

Table 1 Displacement in mm measured at the sacroiliac joint / sacral fracture

The X-axis is the ventrodorsal axis with the ventral direction being positive
The Y-axis is the mediolateral axis with lateral movement of the loaded side being positive
The Z-axis is the craniocaudal axis with the cranial direction being positive
In the intact situation and after disruption of the symphysis and ligaments a load up to 150 N was used. After sacroiliac screw fixation the pelvises were loaded up to 100 N.

Displacement at the symphysis pubis

Less than 0.5 mm displacement was observed between the pubic bones with a load up to 150 N in the intact situation (Table 2). After dissection of the symphysis and ligaments the loaded side moved cranially and ventrally (mean 1.1 and 1.6 mm respectively) with less than 1 mm diastasis of the symphysis. After fixation, mean displacements were 7.4 mm for the technique with one screw and 4.1 mm and 4.4 mm for the techniques with two screws in S1-S2 and S1-S1 configurations respectively when loaded up to 100 N. Most displacement was seen in the anterior and cranial direction, with less than 1.5 mm diastasis. The direction of the movements was similar in all three fixation techniques, except in three out of eight sacral fractures fixated with only one screw in which displacement dorsally and caudally was seen.

	X		Y		Z		Total	
	mean	SD	mean	SD	mean	SD	mean	SD
Intact	0.05	0.20	-0.01	0.07	0.10	0.14	0.22	0.17
Symphysis cut	1.62	1.45	0.74	0.71	1.09	0.99	2.19	1.77
S1 fixation	4.79	7.79	0.53	0.59	3.31	4.27	7.37	7.47
S1S2 fixation	3.05	3.42	0.71	1.13	2.30	2.76	4.12	4.30
S1S1 fixation	2.26	3.25	1.10	1.62	1.64	3.19	4.36	6.36

Table 2 Displacement in mm between the two symphysis markers

The X-axis is the ventrodorsal axis with the ventral direction being positive
The Y-axis is the mediolateral axis with lateral movement of the loaded side being positive
The Z-axis is the craniocaudal axis with the cranial direction being positive
In the intact situation and after disruption of the symphysis and ligaments a load up to 150 N was used. After sacroiliac screw fixation the pelvises were loaded up to 100 N.

Displacement and rotation of the ilium

Displacement and rotation of the entire ilium with respect to the sacrum was observed simultaneously with the measurements between the pubic bones and at the sacral fracture. The average total translation of the ilium was 1.2 mm in the intact situation, and 2.0 mm when the pubic symphysis was disrupted at a load of 150 N. In the stabilized pelvises the average total displacement was 6.7 mm when loaded to 100 N. Movements were mainly in the cranial direction (mean 5.5 mm) with some ventral displacement (mean 2.0 mm). Movements in the mediolateral direction were small (less than 1 mm) and randomly distributed around zero. The average rotation of the iliac wing was 0.5 degrees in the intact situation, 0.7 degrees when the pubic symphysis was disrupted and 2.1 degrees for the fixated sacral fracture. In all three situations, the rotation axis of the loaded ilium was on average the transverse axis through the center of the sacroiliac joint at the level of S1. The craniocaudal and ventrodorsal angles of the axis were small and the average did not differ from zero. The ilium rotated backwards with respect to the sacrum in all cases. At the pubic symphysis this rotation showed as movement of the loaded pubic bone upwards and forwards. In three pelvises fixated with one screw, however, the ilium rotated forwards with the pubic bone moving downwards and backwards.

Translation and rotation stiffness

In addition to the absolute translations and rotations, the stiffness of the ilium with respect to the sacrum was calculated. The averages and standard deviation for both translation and rotation stiffness are summarized in Table 3. The translation stiffness in the vertical direction was also calculated, because this was the loading direction. Furthermore the translation stiffness was determined for the total displacement which does include some movement in other directions (mainly ventral). The translation and rotation stiffness after dissection of the pubic symphysis was superior compared to the various fixation techniques

	Translation Stiffness (N/mm)				Rotation Stiffness (N/degree)	
	Z		total			
	mean	SD	mean	SD	mean	SD
intact	346	564	650	1841	1787	4014
symphysis cut	178	265	219	296	1647	4618
S1 fixation	23	32	69	92	90	105
S1S2 fixation	41	28	65	62	243	258
S1S1 fixation	48	111	91	80	368	539

Table 3 Translation and rotation stiffness

In the intact situation and after disruption of the symphysis and ligaments a load up to 150 N was used. After sacroiliac screw fixation the pelvises were loaded up to 100 N.
The Z-axis is the craniocaudal axis with the cranial direction being positive.
The rotation axis is the transverse axis through the center of the sacroiliac joint at the level of S1. Backward rotation of the ilium espect to the sacrum (nutation) is positive, forward rotation negative.

(p = 0.0068 and 0.0072 respectively). As was expected, based on the setup of the experiments, the stiffness of the intact pelvis was not significant as a covariable (p = 0.29). Because the stiffness of the pelvis with disrupted ligaments was a more accurate predictor we continued with this as baseline (p = 0.014). The effect of the other covariables (bone quality, fixation quality and fracture side) was not significant (p>0.3). The overall effect of technique on the translation stiffness for both the vertical and the resulting total displacement was not significant (p > 0.35). When comparing the rotation stiffness of the different screw methods the overall p value was 0.026. Fixation with one screw in S1 was significantly inferior compared to the techniques with two screws (p = 0.015 and p = 0.018 for S1-S1 and S1-S2 respectively), which did not differ (p = 0.99). Bone quality, fixation quality and fracture side were not significant as covariables.

Load to failure

After the loading cycles up to 150 and 100 N, the load to failure of the fixation was measured (10mm displacement at the pubic symphysis and 5 mm displacement at the sacral fracture). Descriptive statistics of the load to failure for various fixation methods are shown in table 4. For the load to failure measured at the fracture, bone quality and fracture side were not significant. The fixation quality was a significant covariable (p = 0.037). The overall p value for the technique was 0.012, techniques S1-S1 and S1-S2 were significantly better (p = 0.021 and p = 0.005 respectively) than S1. No significant difference was found between S1-S1 and S1-S2 (p = 0.37). For the load to failure measured as 10 mm displacement at the pubic symphysis similar results were found. The overall p value for the technique was 0.024. P values for technique S1 versus S1-S1 and S1 versus S1-S2 were 0.016 and 0.015 respectively. No difference was seen between S1-S1 and S1-S2 (p = 0.97).
Correlating the various outcome measurements a significant correlation was found for all outcome parameters (p < 0.02).

	5mm displacement fracture, N			**10mm displacement symphysis, N**		
	S1	**S1-S2**	**S1-S1**	**S1**	**S1-S2**	**S1-S1**
Mean	137	199	224	124	160	202
SD	89	88	97	81	55	102

Table 4 Load to failure: loading force required to achieve failure level

Discussion

The purpose of this study was to perform a biomechanical comparison of three different isolated posterior fixation techniques with sacroiliac screws and to determine the relative contribution of the screw techniques to the stiffness and strength of the posterior fixation. We did not try to make an estimation of the load which can be tolerated clinically in completely unstable pelvic ring fractures. We therefore fixated 24 sacral fractures created on both sides in 12 embalmed pelvises with various SI screw techniques, using a 3D videosystem to measure displacement of the fracture parts. In the literature several authors have used sacroiliac screws[3;4;8;11;17;23;26;28;35]. However, no study has examined the biomechanically optimal technique for SI screw positioning. Although various authors simulated muscle forces of the abductor muscles[11;17]or the hip flexors and extensors[26;28] we dissected all the muscles and made no attempt to simulate the additional stability of these muscles in order to exclude any unpredictable forces which might influence the measurements. For the same reason the sacral fracture was created with a saw, the smooth fracture surface representing a worst case scenario[16;28]. We did not simulate the interdigitations seen in sacral fractures, because this would yield a much less reproducible model. No anterior fixation was added either as would have been done for a Tile C fracture in the clinical setting[9;14;21;33]. Therefore, mechanical failure of the posterior fixation can not be compensated for by anterior fixation. This design was chosen to eliminate the additional variable created by anterior fixation. Overall this resulted in a situation in which the stability of the fixed fracture depended entirely on the stiffness of the posterior osteosynthesis. In this model, physiological forces could not be reached, however it allowed a biomechanical comparison of the different posterior fixation techniques. The two SI screw techniques on the left and right side of one pelvis limited the interference from interspecimen variance.

In the application of the force we did not try to simulate physiological conditions during one leg stance as closely as possible and therefore chose a more abstract experimental setup with a better defined loading direction . Several authors simulated one-leg [30], or bilateral stance [24] by applying an axial load to the lumbar vertebrae and using the femoral shafts (3;13;26-28) or a hip prosthesis to support the pelvis(11;16;17;35). Like two other authors[2;23] we used a load in a purely cranial direction without the 7.5 degrees medial tilt and 2.9 degrees posterior tilt described by Stocks et al[30].

Three-dimensional measurements have been performed in only a few previous cases [16;17;30]. Most studies used the vertical displacement at the point of load application representing the total displacement of the entire structure[2-4;8;12;23] or displacement transducers in one[24] or more directions[11;13;22;26-28;30;33;35]. In this study we used 3D-measurements to examine the stiffness and load to failure of the various screw positions and additionally examined the direction of the displacement and rotation of the fracture parts.

The literature shows that no method of fixation comes close to the stability of the intact pelvis[28;30;35]. In a SI joint disruption with (not fixated) ipsilateral pubic rami fractures, sacral bars were inferior to SI screws and a SI plate[3]. SI screws and a SI plate gave similar results[17;28]. The advantage of sacroiliac screws is that fixation can be performed percutaneously using fluoroscopy[9;20;21;25;31] or computed tomography[5;6;15]. The percutaneous procedure minimizes blood loss and carries less risk of wound infection than an open reduction, which is required for plate fixation[15;20;21].

The translation and rotation stiffness of the intact pelvis were, as might be expected, clearly superior to the solely posteriorly fixated pelvis. Even after dissection of the pubic symphysis and the sacrotuberous ligaments, the intact posterior pelvic ring is superior to any sacroiliac screw technique. Movements between the various bones in the intact pelvis were very limited. In the fixated state the direction of translation was mainly in the direction of the applied force. At the sacral fracture, ventrodorsal and mediolateral displacement did not differ significantly from zero. The cranial and ventral displacement seen at the pubic symphysis in the fixated situation will be caused by rotation of the ilium. Rotation occurred in the same direction in most cases, which means that the ilium tended to rotate backwards around the SI screws. In three pelvises fixated with only one screw dorsal displacement and forward rotation of the pubic bone was seen. This will be due to the location of the working line of the load relative to the pivoting point of the fixation. In our results we found significant differences for the load to failure and the rotation stiffness between the techniques with two screws and a single screw in S1. No difference was found for the translation stiffness. As expected the single screw technique was more susceptible to rotation. It can be assumed that the addition of a second screw plays an important part in the prevention of rotation and the overall load to failure. Clinically the technique with one screw will be more dependent on the quality of the anterior fixation. No difference was found between the two techniques using two screws. Although these techniques may seem biomechanically similar, adequate positioning of the lower screw in the second vertebral body technically is more difficult with a higher risk of nerve injury [34]. No significant differences were found for the bone quality and the fixation quality (grip of the screws). In all outcome measurements a wide variation between specimens was observed similar to other studies[13;16;17;24;26-28]

The extrapolation of our results to the physiological situation is limited by the fact that we used, because of availability, aged embalmed pelvises, lacking soft tissue support and muscle activity. In the average young trauma patient both the stiffness and load to failure are expected to be better because of a much better bone density. Although this may alter the absolute data, the relative difference between the techniques should remain the same. No anterior fixation was used and fatigue of the fixation was not examined either. Future experiments should be conducted to investigate the stability of combined posterior and anterior osteosynthesis during cyclic loading. The use of our 3D measurement system may be of great value to gain insight into the 3D motions of the fracture parts.

Based on the results of this study, in which we compared three sacroiliac screw techniques, we can conclude that a second screw in completely unstable pelvic fractures gives additional posterior stability. Based on clinical studies the combination of both screws in S1 seems to be safer than two screws parallel in S1 and S2 and may be preferable given the biomechanical similarity between the two techniques.

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Sacroiliac Screw Fixation for Tile B Fractures

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Abstract

Objective
To investigate whether the stability of partially unstable pelvic fractures can be improved by combining plate fixation of the symphysis with a posterior sacroiliac screw.

Design
Comparative cadaveric study.

Materials and Methods
In 6 specimens a Tile B1 (open book) pelvic fracture was created. We compared the intact situation to isolated anterior plate fixation and plate with SI screw fixation. Using a 3-dimensional video system we measured the translation and rotation stiffness of the fixations and the load to failure.

Results
Neither absolute displacements at the os pubis or at the sacroiliac joint or stiffness of the ilium in respect to the sacrum were significantly different for the techniques with or without sacroiliac screw or the intact situation. Load to failure was only reached in one of the six cases. In all other cases the fixation of the pelvis to the frame failed before failure of the fixation itself. In these cases a load of about 1000N or more could be applied.

Conclusions
The addition of a sacroiliac screw in a Tile B1 fracture does not give significant additional stability. Although cyclic loading was not tested, in these experiments forces could be applied similar to full body weight. Clinical experiments into direct postoperative weight bearing are recommended to examine the clinical situation.

Introduction

In Tile B1 pelvic injury, also known as open book fracture, the pelvic ring is only rotationally unstable without vertical instability. Although the anterior pelvic ring is disrupted completely, the posterior sacroiliac ligaments remain intact. Most studies have investigated the stability of various techniques in Tile C fractures[1-9], while only a few reported about the optimal fixation for Tile-B fractures[10-13]. In a Tile B1 injury (disrupted symphysis in combination with disrupted SIJ) various combinations of fixation techniques were described. These included one or two anterior plates [10;12;14] in combination with external fixation [14] or posterior plate fixation and sacroiliac screw fixation[10;15]. Some studies indicate that only anterior fixation of the pelvis is sufficient to stabilize Tile B injuries[12;14]. Because there is no agreement in literature about the optimal fixation technique for partially unstable pelvic fractures we investigated whether additional stability of the pelvis can be obtained by combining plate fixation of the symphysis with a posterior sacroiliac screw in partially unstable pelvic fractures using a 3D measurement system.

Materials and methods

We used 6 embalmed cadaveric pelves, which were dissected, leaving the ligamentous structures intact, including the sacrospinous and sacrotuberous ligaments. The femora, all lumbar vertebrae and all muscles were removed. The average age of the specimens was 78.9 years. One pelvis showed signs of arthrosis of the sacroiliac joint, the other pelves showed no abnormalities during dissection. A Tile B1 fracture was created by disruption of the pubic symphysis while dissecting the anterior sacroiliac ligaments [10;12]. In order to ensure sufficient horizontal instability a diastasis of at least 2.5 cm at the symphysis was applied.
All pelves were stabilised anteriorly with a 4-hole self compression plate (3.5 mm x 50 mm) of the symphysis (Biomet®, Warsaw, Indiana, U.S.A.), posteriorly one 70 mm cannulated partially threaded, cancellous lag screw (Biomet®) with washer was inserted over a K-wire. We inserted the screw through the posterior ilium and into the vertebral body of S1 across the sacroiliac joint, according to the technique of Matta and Saucedo[16]. The quality of the fixation was scored based on the grip of the screws and we made a clinical estimation of the bone quality during dissection on a three point scale.
To enable the application of load to the pelvic ring, the sacrum was fixed between two plates with screws and methylmethacrylate-polymere resin

(Demotec®, Demotec Siegfried Demel, Nidderau, Germany). The pelvis was oriented with anterior superior iliac spines and the symphysis in the frontal plane which is approximately comparable to the physiological position during standing[1;12]. A pelvis fixated in the frame can be seen in figure 1 and 2.
The load was applied by introducing a force to a plate attached to the ilium. Through an extension device the pelvis was loaded along a vertical line of action passing through the SI joint. This approximates force during weight bearing.
With a 3D video system displacements were measured in all 6 degrees of freedom (3 dislocations and 3 rotations). To enable the computerized video registration of bone displacements, clusters of four infrared light reflecting markers were attached to the cranioventral edge of the first sacral vertebral body and to both superior anterior iliac spines. Two markers were placed bilaterally, about 2 cm from the sacroiliac joint and two markers were positioned on both superior rami of the pubic bone, close to lateral edges of the plate. For reference of the markers see figure 1. The markers were illuminated by an infrared light source mounted on the cameras. The image coordinates from the two cameras

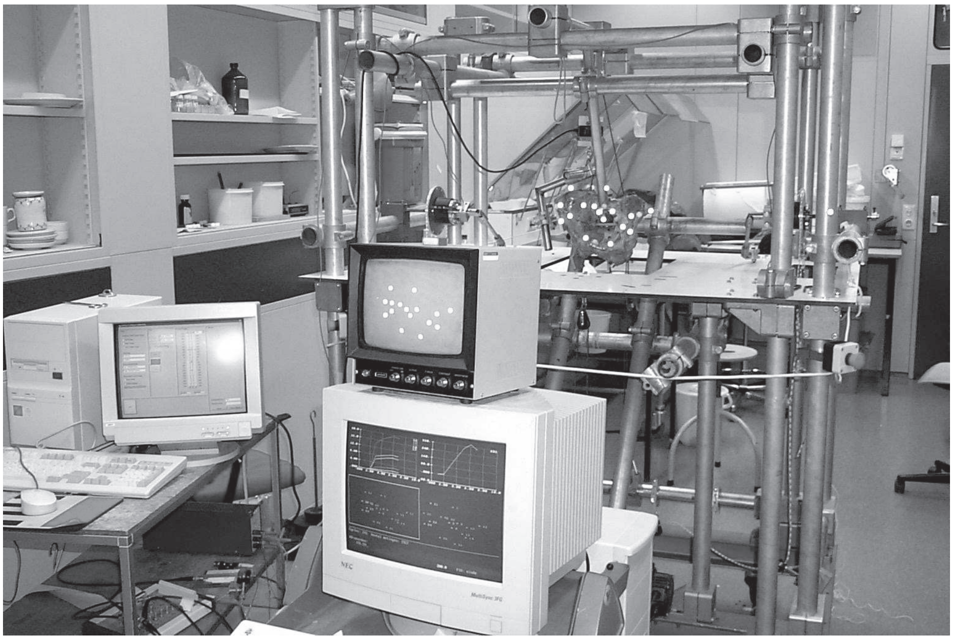

Figure 1
Laboratory setting for loading pelves. On the foreground right the PC required for measuring displacements with on top the view from the camera. On the left the PC required for loading the pelvis. In the middle the pelvis mounted in the frame. Clearly visible on the pelvis are the markers.

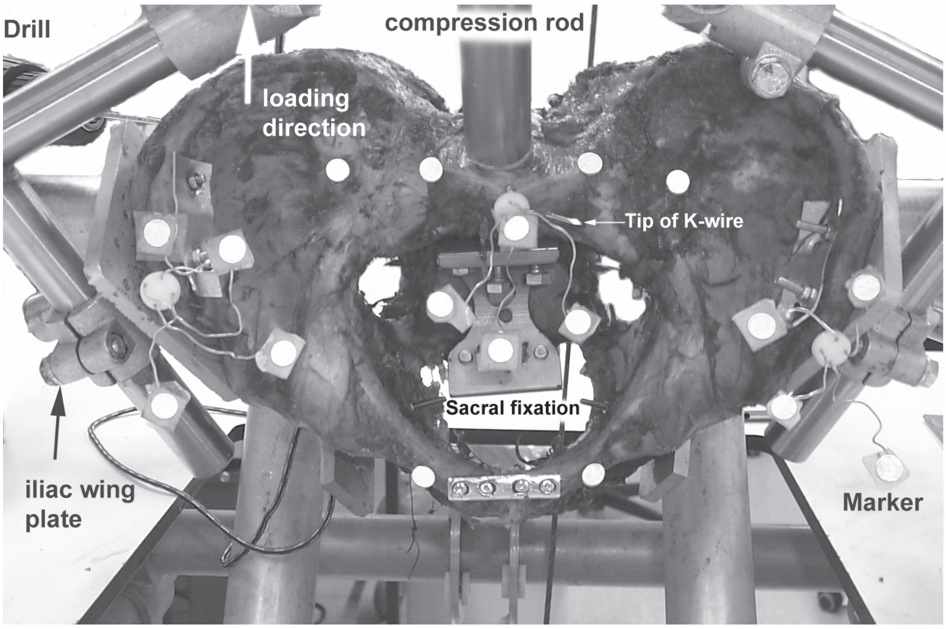

Figure 2
Pelvis with markers while fixated in the loading frame. Positioning of the K-wire is shown.

were combined to three-dimensional spatial coordinates using Direct Linear Transformation[17;18]. From previous tests the resolution of the system proved to be about 0.1 mm.
For baseline measurements the intact pelvis was loaded on the left and right side. After a unilateral Tile B1 fracture was created and the pelvis was fixated with anterior plate fixation, it was loaded on both sides. Subsequently a sacroiliac screw was added to the fixation. During three consecutive cycles a maximum load of 300N was used, similar to forces used by Macavoy and Dujardin [12;15]. In a pilot study this has proven to be safe, avoiding failure levels and permanent displacement. After this the load to failure was measured (loaded to a maximum of 700N) of the combined anterior and posterior fixation. If failure levels could not be reached when loaded up to 700 N, the SI screw was removed and load to failure measured of the isolated anterior fixation. In one pelvis the iliac plate, to which the load was applied, loosened from the pelvis at 600N. In this case final measurements were made while loading the contralateral side. We investigated the stiffness of the fixation and the load to failure. We defined the translation stiffness (in N/mm) of the fixation as the slope of the load displacement curves of the ilium with respect to the sacrum up to 300 N. The rotation stiffness was defined as the applied load divided by the observed rotation in N/degree because the exact moment was not known. In a linear

model the slope of the load displacement curves from the three cycles was calculated with the least squares method. The load to failure was defined as the force required to produce 5 mm displacement of the fracture parts. For the statistical calculations we used S.A.S. version 6.12 of the SAS institute inc, Cary, NC, USA.. In order to compare the translation stiffness, the rotation stiffness and the load to failure of the two fixation methods we performed a MANOVA with the translation/rotation stiffness of the fixated pelvis as depending variable. As baseline we examined the translation/rotation stiffness of the intact pelvis. As co-variables we used the fixation technique, bone quality, fixation quality. Because the distribution was skewed we applied a log transformation to the data and provided median and range instead of mean and standard deviation.

Results

Initially the maximum load for all pelves was restricted to 300 N, thus avoiding permanent damage of the pelvic bone, ligaments and fixation. Both displacement between the pubic bones and the between the sacrum and the ilium at the sacroiliac joint were measured. The maximum displacement measured between the pubic bones was 0.5 mm median (range 0.2 - 0.9 mm). Most displacement after fixation was seen in the anteroposterior and craniocaudal direction, diastase of the pubic symphysis was less than 0.1 mm. When fixated the median displacements were median 0.8 mm (0.4 - 1.7 mm) with isolated plate and median 0.7 mm (0.4 - 1.9 mm) with SI screw and plate. The displacements measured at the sacroiliac joint were in the direction of the applied force, i.e. the ilium moved upward. For the intact pelvis the median displacement was 0.7 mm (0.3 - 1.3 mm), with isolated plate 1.1 mm (0.5 - 1.8 mm) and after addition of the SI screw the displacement was 0.9 mm (0.5 - 1.2 mm) (no significant differences). Some gapping of the SI joint was seen (all <1.5 mm, no significant differences).
Additional to the measurements between the pubic bones or at the sacroiliac joint, the displacement of the entire ilium in respect to the sacrum was observed. The medians of the maximum displacements were 1.4 mm (0.5 - 2.5 mm) intact, 2.1 mm (1.0 - 5.0 mm) with isolated plate and 2.0 mm (0.6 - 3.9 mm) when loaded up to 300 N ipsilateral. Loaded contralateral to 300 N, the medians were 1.2 mm (0.7 - 1.7 mm), 0.6 mm (0.6 - 2.0 mm) and 1.0 mm (0.6 - 1.6 mm) respectively (no significant differences). The median rotation of the iliac wing was 0.9 degree (0.5 – 1.5 degree) in the intact situation, 1.0 degree (0.5 – 1.9 degree) with isolated plate fixation and 1.0 degree (0.4 – 1.3 degree) for plate with SI screw. In all three situations the rotation axis of the loaded ilium

was directed mainly along the transversal axis. When loading the ipsilateral side, both in the intact and in the fixated pelves the ilium rotated upwards with respect to the sacrum in all cases. At the pubic symphysis this rotation showed as movement of the loaded pubic bone upwards and forwards.
Besides the absolute displacements and rotations, the stiffness of the ilium in respect to the sacrum, when loaded up to 300 N, was measured. These values were summarized in table 1 and 2. No significant differences were observed between intact, fixated with isolated plate or with plate and sacroiliac screw

Translational stiffness (N/mm)			
loaded on ipsilateral side			
	intact	with isolated plate	additional SI screw
median	268	187	184
range	160 - 4861	57 - 326	79 - 2499
loaded contralateral			
median	540	679	666
range	196 - 42102	139 - 2105	227 - 8479

Table 1 Movements of the ilium versus the sacrum: translational stiffness

Rotational Stiffness (N/deg)			
Loaded on ipsilateral side			
	intact	with isolated plate	additional SI screw
median	902	487	461
range	398 - 9563	171 - 2824	261 - 11714
Loaded contralateral			
median	2339	2719	2556
range	622 - 7647	382 - 6778	616 - 6095

Table 2 Movements of the ilium versus the sacrum: rotational stiffness

(p>0.1). The effect of the other co-variables (bone quality, fixation quality and fracture side) was not significant (p>0.12). The overall effect of technique on the stiffness was not significant either (p = 0.41).
After the loading cycles up to 300 N, the pelves were loaded up to 700 N. In none of the pelves signs of failure of the fixation were observed and in all cases the sacroiliac screw was removed. Neither the stiffness, nor the displacements at the pubic symphysis or at the SI joint showed any significant differences between the techniques with or without SI screw. The maximum loading force and the reason of termination of the experiment are shown in table 3. Only in one pelvis the predefined criterion of load to failure (5 mm displacement at the sacroiliac joint) was reached after removal of the SI screw. In all other cases a sacral fracture at the edge of the fixation to the frame or a failure of the plate at the ilium limited further measurements. In these cases a load of 960 to 1481 N could be reached.

Spec.	Max. force applied	Reason for failure
1	1100N	transforaminal sacral fracture at edge of sacral fixation plate
2	1481N	transverse sacral fracture through foramina S2 at edge of plate
3	617N	side plate at ilium failed, other iliac wing loaded to 900N
4	1200N	transforaminal sacral fracture at edge of sacral fixation plate
5	960N	true sacroiliac joint dislocation (only failure of fixation)
6	960N	fixation of pelvis to frame failed

Table 3 Reason of failure
maximum loading force with isolated plate fixation and reason of termination of the experiment.

Discussion

To investigate whether the combination of sacroiliac screw fixation with anterior plate fixation gives additional stability compared to isolated anterior plate fixation in Tile-B fractures we loaded six embalmed pelves and measured the displacements of the fracture parts using a 3D video system. In the literature several authors have used sacroiliac screws[6;7;16;19], but little is known about their additional value in Tile-B fractures. Simonian examined the stability of various combinations of fixation techniques[10]. He concluded that combined anterior and posterior fixation was optimal for Tile B fractures. He did not find any difference between sacroiliac plate fixation and screw fixation, neither did Dujardin[15]. Limitations in his study design were the use of multiple chains to stabilize the pelvis which may have restrained motions in the fracture planes. Dujardin reported decreased micromotion at the SI joint when combining anterior plate fixation with sacroiliac fixation compared to isolated anterior plate fixation[15]. Combined anterior and posterior fixation gave similar results as in the intact situation. However the design with repeated measurements, which differed between specimens, made removal and refixation of the pubic plates necessary. This may have resulted in suboptimal plate fixation, which made the quality of pubic plate fixation difficult to judge.

We chose to fixate the anterior pelvic ring with one plate, which, according to MacAvoy et al, has similar biomechanical properties as two plates[12]. They reported decreased stability compared to the intact pelvis, but no difference between single and double plate fixation. For posterior fixation we used one sacroiliac screw. The addition of one sacroiliac screw is a small procedure, which can be carried out in supine position and percutaneously, although it carries some risk of neurological injury. If the addition of a sacroiliac screw to the anterior plate fixation would give a similar biomechanical situation as the intact pelvis, patients could be mobilized directly postoperatively.

Our results showed no significant difference in the translation and rotation stiffness between isolated plate fixation and plate and SI screw fixation when loaded up to 300N. This applied to both ipsilateral and contralateral loaded pelves. When determining the load to failure the fixation did not prove to be the limiting factor. In all but one pelves a load of over 900 N could be applied. Generally this is well above the force exerted by the upper body under physiological conditions. In most cases the experiment was ended by a sacral fracture at the edge of the sacral fixation plate. This suggests that isolated plate fixation can withstand even higher forces. In addition, the translation and rotation stiffness of the fixated pelves were similar to the intact situation when loaded up to 300 N.

The extrapolation of our results to the physiological situation is limited by the fact that we used aged embalmed pelves, lacking muscle activity, loaded in an experimental setting. Although the injury created by surgical transsection of the ligaments is reproducible, it is not entirely equal to open book fracture.

In contrast to the findings of Dujardin[15], we did not find a significant additional stability of a sacroiliac screw in Tile B1 fractures and recommend isolated plate fixation in Tile B1 fractures. Although we did not examine the fatigue of the fixation, the observed biomechanical stability seems sufficient to examine direct postoperative weight bearing in Tile B fractures in a clinical study.

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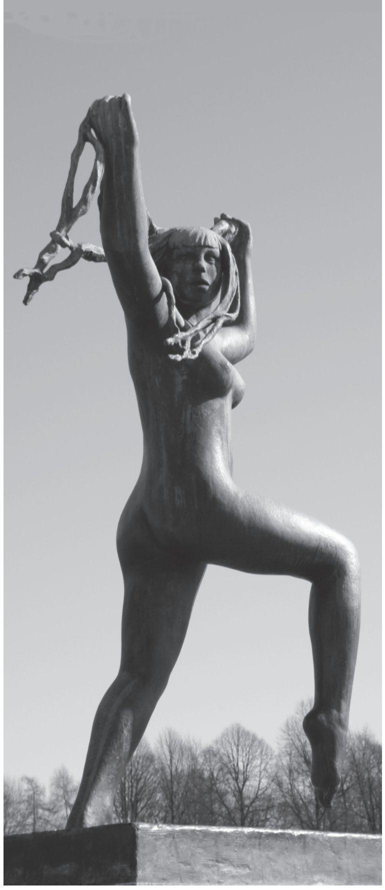
Cyclic Loading of Sacroiliac Screws in Tile C Pelvic Fractures



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Abstract

Objective

to investigate the stiffness and strength of completely unstable pelvic fractures fixated both anteriorly and posteriorly under cyclic loading conditions.

Design

Randomized comparative cadaveric study.

Materials and Methods

In 12 specimens a Tile C1 pelvic fracture was created. We compared the intact situation to anterior plate fixation combined with one or two sacroiliac screws. In 2000 measurements, each pelvis was loaded with a maximum of 400N. The translation and rotation stiffness of the fixations were measured using a three-dimensional video system. Furthermore the load to failure and the number of cycles before failure were determined.

Results

Both translation and rotation stiffness of the intact pelvis were superior to the fixated pelvis. No difference in stiffness was found between the techniques with one or two sacroiliac screws. However a significantly higher load to failure and significantly more loading cycles before failure could be achieved using two sacroiliac screws compared to one screw.

Conclusions

Although the combination of anterior plate fixation combined with two sacroiliac screws is not as stable as the intact pelvis, in this study embalmed aged pelves could be loaded repeatedly with physiological forces. Given the fact that the average trauma patient is younger and given the fact that the quality (or grip) of the fixation was a significant covariable for longer endurance of the fixation, this suggests that direct postoperative weight bearing could be possible if these results are confirmed in further research.

Introduction

In Tile C fractures anterior and posterior pelvic ring are disrupted leading to translation and rotation instability[1]. Because conservative treatment leads to a high percentage of complications and long-term disability, operative treatment is advocated[2;3]. However, with external fixation direct postoperative weight bearing is not possible.[1;4-9] Greater stability can be achieved by internal fixation, consisting of a combination of posterior and anterior fixation.[1;3;8-10] Despite the superior stability obtained by internal fixation several institutions still limit weight bearing after internal fixation for considerable time.[10-15] Although ideally internal fixation would provide enough stability to allow early mobilization of the patient, several biomechanical studies have shown inferior stability compared to the intact situation.[4;16;17]
Several authors studied the stabilizing effect of (internal) fixation for different types of unstable pelvic ring fractures[1;4;6-9;16-28]. For sacral fracures two sacroiliac screws, dorsal sacroiliac plates, sacral bars, triangular osteosynthesis or a tension band plate were used. The pubic symphysis was fixated with one or two plates, banding or an external frame[4;6;16;17;20;23;24;27]. The loading techniques differed: single leg stance[1;4;6;9;22-25;27-30], bilateral stance[6;7;16;17;19;20;31;32], vertical loading [18;26] or lateral compression[21]. Only a few reports have studied cyclic loading[24;27;33]. In most cases, either displacement of the entire pelvis was measured[6;8;18-21;26], or vertical shear or diastasis of the pubic symphysis and/or the sacroiliac joint was measured[1;4;7;9;16;17;22;25;28-32]. In only a few cases were three-dimensional measurements made of the movements in the fracture plane[1;4;23;24;27].
In our study, we investigated the combination of an anterior plate with posterior sacroiliac screw fixation in Tile C fractures. To simulate weight bearing the pelvis was loaded 2000 times with a maximum of 400 N, which equals the upper body weight in adults.[30] A three-dimensional video system was used to measure the displacement between the various fracture parts to determine the stiffness, strength and endurance of the fixation.[34-36]

Materials and Methods

Specimens and injury

We used 12 embalmed cadaveric pelves, which were dissected. The femurs, lumbar vertebrae and all muscles were removed. The ligamentous structures, including the sacrospinous and sacrotuberous ligaments, were left intact. However, in three specimens these ligaments were damaged in a previous experiment. All specimens were older than 60 years. A Tile C1 fracture was created by disruption of the pubic symphysis with a scalpel and a sacral fracture in the lateral mass was made using a saw.

Fixation of the pelvic fracture

All pelves were stabilized anteriorly with a four hole self compression plate (3.5 mm x 50 mm) across the symphysis and four 3.5 mm fully threaded, 50 mm long cortical bone screws(Biomet®, Warsaw, IN, U.S.A.). Posteriorly, one or two 70 mm canulated partially threaded, cancellous lag screws (Biomet®) with washers were inserted. The screw(s) were placed through the posterior ilium and into the first sacral vertebral body across the sacroiliac joint, according to the technique of Matta and Saucedo.[3] The quality of the fixation was scored on a three-point scale based on the grip of the screws and we made a clinical estimation of the bone quality during dissection. For quality of fixation we defined "good" as "excellent grip comparable to healthy adults", "moderate" as "relatively good grip, no signs of slipping" and "bad" as "poor grip with slipping of the screws". For bone quality we defined "good" as "strong cortical bone comparable to healthy adults", "moderate" as "signs of weakness of the cortex present" and "bad" as "soft cortical bone, easily penetrable with a scalpel".[35]

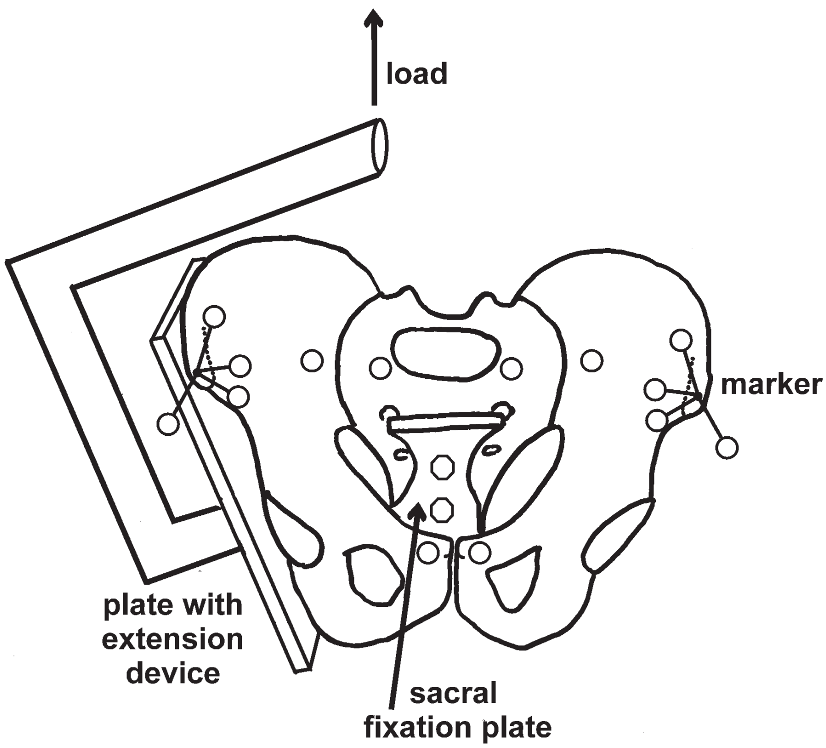

Figure 1 Experimental setup of the pelvis

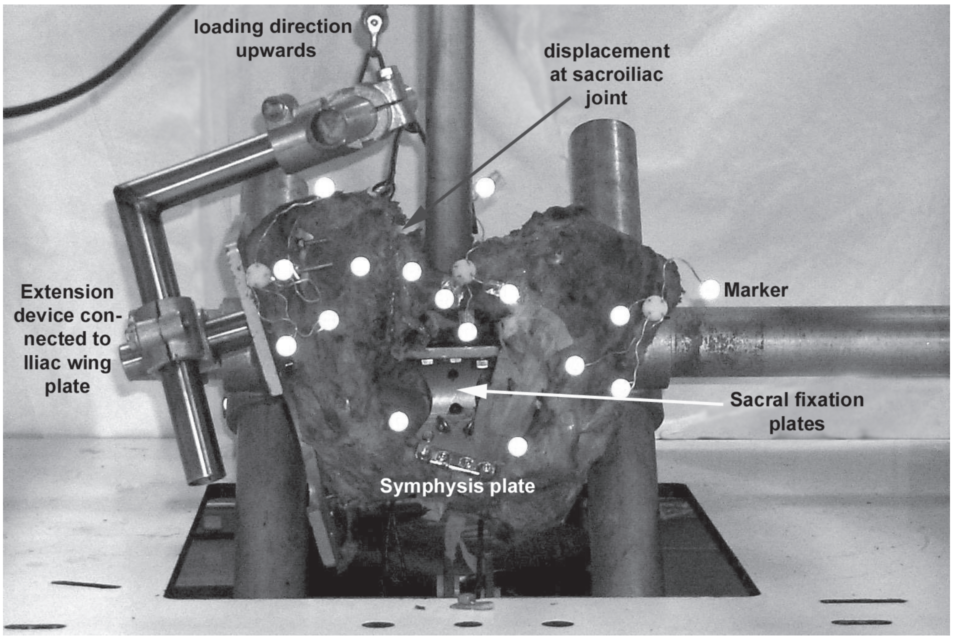

Figure 2 Pelvis with markers while fixated in the loading frame

Loading arrangement

To enable the application of load to the pelvic ring, the sacrum was fixed between two plates with screws and methylmethacrylate-polymer resin (Demotec®, Demotec Siegfried Demel, Nidderau, Germany). The pelvis was oriented with anterior superior iliac spines and the symphysis in the frontal plane, which is approximately comparable to the physiological position during standing.[24;30] The ilium was loaded by a force acting through a rope on a plate with an extension device, which was attached to the ilium in such a way that the line of action of the load passed in a vertical direction through the fracture plane (Figure 1 and 2)[35;36]. This approximates the direction of the forces during weight bearing.[4] The load applied to the ilium was increased in steps of 100 N to a maximum of 400 N[30;32]. In the intact situation each specimen was loaded 400 times as a baseline measurement. After a unilateral Tile C1 fracture was created and the pelvis was fixated with combined anterior and posterior fixation, it was loaded 2000 times. The number of cycli was chosen in order to constrain the total experimental time to prevent dehydration of the specimens. The pelves were randomized in two groups: six were posteriorly fixated with one sacroiliac screw and six with two screws. If the pelves were intact after cyclic loading, the load to failure, which was defined as the force required to produce 5 mm displacement at the sacral fracture or as 10 mm at the symphysis, was determined.[9;24]

Motion measurements

During loading of the pelves, displacements were measured simultaneously between the pubic bones, at the sacroiliac joint or sacral fracture, and between the sacrum and the ilium. With a three-dimensional video system, displacements were measured in all six degrees of freedom (three dislocations and three rotations). To enable the computerized video registration of bone displacements, clusters of four infrared light reflecting markers were attached to the cranioventral edge of the first sacral vertebral body and to both anterior superior iliac spines. Two markers were placed bilaterally, approximately 2 cm from the sacroiliac joint and two markers were positioned on both superior rami of the pubic bone close to lateral edges of the plate (figure 1 and 2). Using a technique similar to that of Keemink et al[34], these markers were illuminated by infrared light sources mounted to two video cameras[37]. Infrared filters in front of the camera lenses ensured good contrast in the video images. With the help of a video image processing board (Vision Dynamics VCS512-II) in a personal computer, the coordinates of the centers of the markers on the camera images were determined. The coordinates from the two cameras were combined to three-dimensional spatial coordinates using Direct Linear Transformation[38]. The algorithms described by Spoor and Veldpaus were used to calculate displacements between the ilium and the sacrum, at the fracture plane and at the pubic symphysis[39]. The resolution of the system proved to be about 0.1 mm, based on previous tests.

Data analysis

We investigated the stiffness of the fixation, the load to failure, and the number of cycles until failure. We defined the translation stiffness (in N/mm) of the fixation as the slope of the load displacement curves of the ilium with respect to the sacrum. The rotation stiffness was defined as the applied load divided by the observed rotation in N/degree because the exact moment was not known. For the statistical calculations we used SAS version 6.12 of the SAS Institute Inc. (Cary, NC, USA.) and SPSS version 9.0 of SPSS Inc. (Chicago, IL, USA). To compare the translation stiffness, the rotation stiffness, and the load to failure of the two fixation methods, we performed both univariate and multivariate analyses. As baseline we examined the translation and rotation stiffness of the intact pelvis. As co-variables we used the fixation technique, bone quality, and fixation quality. Because the distribution was skewed we applied a log transformation to the data and median and range were provided instead of mean and standard deviation. The log rank test was used to calculate the difference in cycles until failure.

Results

Displacement at the sacroiliac joint/sacral fracture

In the intact pelves in most cases less than 1 mm displacement was seen at the sacroiliac joint (median 0.7 mm, range 0.3 - 4.3 mm) when loaded to 400 N. Movements mainly occurred in the direction of the applied force: median cranial displacement was 0.5 mm. Mobility at the sacroiliac joint in dorsoventral and mediolateral direction was less than 0.5 mm. No significant effect of the damage of sacrotuberal ligaments was observed. After fixation most displacement at the sacral fracture was seen in cranial direction (median 6.5 mm), lesser movement was found in ventral and lateral direction (median 0.6 mm and 0.9 mm respectively).

Displacement at the symphysis pubis

In the intact situation generally a median displacement of 0.7 mm was observed between the two pubic rami at a load of 400 N. The the ipsilateral pubic bone moved mostly in ventral (median 0.6 mm) and to a lesser degree in cranial direction (median 0.3 mm). After fixation, most displacement at the symphysis was seen in cranial and dorsal direction (median 2.7 mm and 1.4 mm respectively). Diastasis was less prominent (median 0.4 mm).

Translation and rotation stiffness

The median and range of the translation and rotation stiffness of the ilium with respect to the sacrum, when loaded up to 400 N, are summarized in table 1. Generally, rotation was seen around an axis that ran approximately through the symphysis and the medial tip of the sacroiliac screws. The loaded hemipelvis rotated upwards and medially around this axis. No significant differences were observed for translation or rotation stiffness between the techniques with one or two sacroiliac screws. The intact situation was significantly superior to the fixated situation ($p < 0.022$). In multivariate analysis the effect of the fixation

	Translation stiffness			Rotation stiffness	
	Median	Range		Median	Range
Intact	270	74-18585		966	206-15368
One sacroiliac screw	41	13-5847		284	33-1691
Two sacroiliac screws	160	35-715		426	140-3615

Table 1 Movements of the ilium versus the sacrum: translation and rotation stiffness

quality was significant for the translation stiffness (p = 0.047). The other covariables (fixation technique and bone quality) were not significant (p > 0.1). There was no significant difference in fixation quality and bone quality between the two experimental groups (p > 0.35).

Load to failure

The load to failure as defined previously is shown in table 2. The technique with two sacroiliac screws was significantly superior when measured at the symphysis (p = 0.047) and showed a strong trend at the sacral fracture (p = 0.088).

Figure 3 shows a survival curve for the number of cycles that could be completed without failure. In the group with two screws five specimens completed to loading cycles compared to only one in the group with one screw. Failure occurred significantly later for the technique with two sacroiliac screws for both definitions of failure. Furthermore all failures occurred within the first 700 cycles. With a log rank test the number of cycles at which load to failure occurred at the sacral fracture and at the symphysis differed significantly for the two techniques (p = 0.027 and p = 0.017 respectively). Quality of the fixation was a significant covariable for longer endurance (p = 0.018 and p = 0.026).

For the six pelves that completed the entire loading protocol without failure the stiffness during the first and the last 250 measurements were compared to examine weakening of the osteosynthesis with time. Although the difference between the initial stiffness and the final stiffness was not significant (p = 0.067), the median overall decrease in stiffness was 23.1 %

Load to failure	**At sacroiliac joint**			**At symphysis**	
	Median	**Range**		**Median**	**Range**
One sacroiliac screw	255	147-840		398	201-857
Two sacroiliac screws	710	249-1005		757	401-1005

Table 2 Load to failure

measured as 5 mm displacement at the sacral fracture or 10 mm displacement at the symphysis.

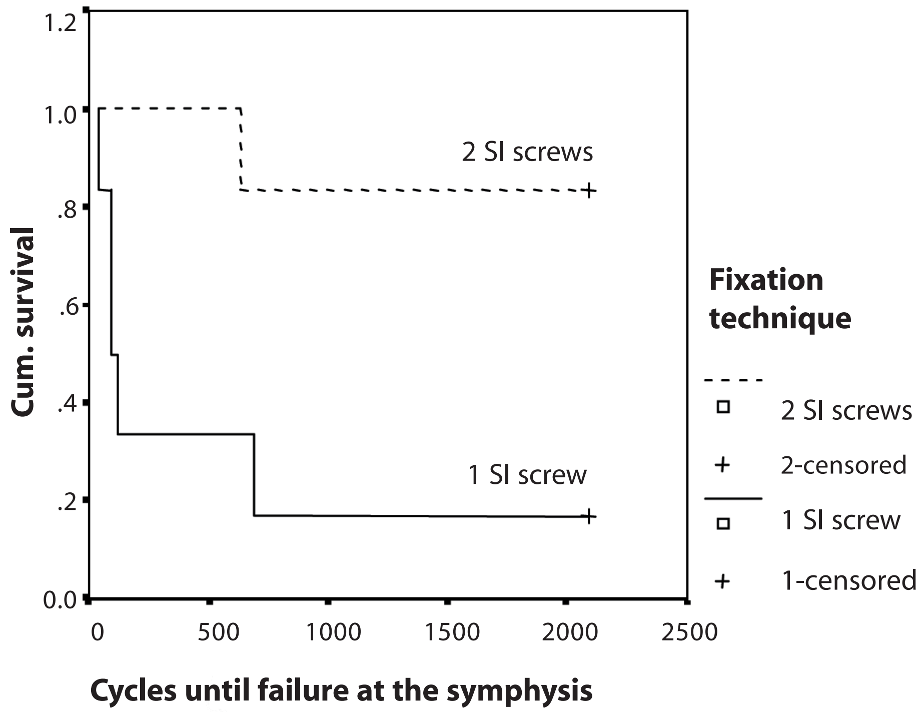

Figure 3 Endurance of fixation until failure
Kaplan-Meier survival curve of the endurance of the fixation until failure measured as 10 mm displacement at the symphysis.

Discussion

Several authors studied the effect of various methods of (internal) fixation for unstable pelvic ring fractures, but only a few reports have studied cyclic loading[1;4;6-9;16-27]. Pohlemann et al. loaded one specimen in which a sacral fracture was fixated with small fragment AO plates 10,000 cycles with 60% of the body weight, after which it showed no sign of loosening of the implants.[24] Meissner et al. loaded isolated symphyses fixated by plate and PDS or wire loop banding techniques with a force equalling 50% of the physiological load over 55,500 cycles.[33] Plate fixation showed better stability provided adequate grip of the screws could be obtained initially. Loading with 100% of the body weight caused early failure. More recently, Schildhauer et al. used dynamic loading with 10,000 cycles to test one sacroiliac screw and triangular osteosynthesis in a model of a sacral fracture in combination with pubic rami fractures. One sacroiliac screw with lumbopelvic fixation showed greater initial stability than an isolated sacroiliac screw and less macroscopic fixation failure at 10,000 cycles.

Because of technical problems they could not quantify the rotation and the displacement at 10,000 cycles.[27]
Although many authors have used sacroiliac screws, only one study has examined the sacroiliac screw fixation under cyclic loading conditions.[8;16;17;19;21;24;25;27-29;32] Literature shows that all methods of pelvic ring fixation were inferior compared to the intact pelvis.[4;8;16;17;19;25;30] In a sacroiliac joint disruption, some authors reported transiliac bars and a tension band plate to be the weakest fixations and ventral sacroiliac plates were found to be less resistant to torsion than sacroiliac screws[1;19;26;28]. Others found no significant difference in stiffness and strength between sacroiliac screws, plates and sacral bars[8;9;18;20;29;32]. For a sacral fracture no significant differences in the load to failure were found between sacral bars, sacroiliac screws and posterior small-fragment posterior plates, but a posterior small-fragment plate showed lower stiffness than sacral bars[23;24]. Simonian found no difference in stiffness between sacroiliac screws, dorsal tension band reconstruction plate and transiliac bars[16]. Simonian and Sagi could not discover a significant difference between one and two sacroiliac screws for a transforaminal sacral fracture[16;25]. For a sacroiliac disruption in artificial pelves Yinger found that one sacroiliac screw was the least stiff of the fixations tested and two sacroiliac screws showed much greater stiffness[28]. In one of our previous studies two sacroiliac screws showed a significantly higher load to failure than one screw when using isolated posterior fixation for a sacral alar fracture[35].

The aim of this study was to compare the stability of completely unstable pelvic fractures, fixated with a symphyseal plate and one or two sacroiliac screws, versus the intact situation under cyclic loading conditions. In twelve embalmed pelves we determined the stiffness, the load to failure and the endurance using a three dimensional video system measuring displacement of the fracture parts.
Three-dimensional measurements have been performed in a limited number of studies[1;4;23;24;27]. Most studies used the vertical displacement at the point of load application representing the total displacement of the entire structure[6;8;18-21;26] or displacement transducers in one or more directions[1;4;7;9;16;17;22;25;28-32]. However, the multiaxial nature of the loads and displacement in the pelvis require three-dimensional description of translations and rotations of the fracture parts. In the application of the force we did not try to simulate physiological conditions during one leg stance as closely as possible and therefore chose a more abstract experimental setup with a better defined loading direction. Several authors simulated one leg stance[1;4;6;9;22-25;27-30], bilateral stance[6;7;16;17;19;20;31;32] by applying an axial load to the lumbar vertebrae and using the femoral shafts[7;16;19;30-32] or a hip prosthesis to support the pelvis[8;17;20;22-24;27;28]. When using single limb stance as an experimental model, a significant moment is intro-

duced at the fracture site by the force applied at the vetebrae and the simulated weight of the contralateral leg. It is very difficult to calculate the exact moment and to keep it constant in different specimens. Like two other authors[18;26] we used a load in a purely cranial direction without the 7.5 degrees medial tilt and 2.9 degrees posterior tilt described by Stocks et al[4]. A smooth fracture surface, created by the use of a saw, and the lack of muscle support was used in order to ensure reproducibility.[6;16;23;27] Even in this worst case scenario, the use of combined anterior single plate and posterior sacroiliac screw fixation allowed us to apply a physiological force (representing the upper body mass) repeatedly.
We observed that the translation and rotation stiffness of the intact pelvis were superior to the fixated pelvis. No difference in stiffness was found between the techniques with one or two sacroiliac screws. However a significantly higher load to failure and significantly more loading cycles before failure could be achieved using two sacroiliac screws compared with one screw. The fact that all failures occurred within the first 700 cycles was in accordance with the observations of Schildhauer[27] The grip of the screws proved to be a significant covariable in longer endurance of the fixation. In the pelves that completed the protocol a decrease of 23% between the initial and final stiffness was seen, although this was not significant. In all outcome measurements a wide variation between specimens was observed similar to other studies[6;16;20;23-25;30-32]

The extrapolation of the results to the clinical situation should be done with caution, because of the fact that we used aged embalmed specimens, which are the only human pelves available. For young trauma patients absolute values of both stiffness and load to failure are expected to be much greater because of a better bone density. Although 2000 loading cycles equals the steps made in only two days[27;33], the results of this study can help to give clinicians a better understanding of the behaviour of pelvic fixations techniques under dynamic loading conditions. This is relevant to make decisions about the choice of fixation technique and the postoperative weightbearing regimen.

This study again shows that the intact pelvis is superior to any method of fixation. The combination of anterior plate fixation and two sacroiliac screws is superior to plate fixation and one sacroiliac screw in Tile C fractures. Even the usually osteoporotic bone of aged embalmed pelves can withstand cyclic loading up to 400 N. The quality (or grip) of the fixation was a significant covariable for longer endurance of the fixation. Although our results suggest that in the average (young) trauma patient with both anteriorly and posteriorly fixated Tile C fractures direct postoperative weight bearing seems safe, we recommend further biomechanical research into prolonged dynamic loading using preferably non-osteoporotic pelves.

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6

Biomechanical Analysis of Sacro-iliac Screw Fixation in Pelvic Pain

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Abstract

Objective

In order to make an estimation of the biomechanical properties of surgical stabilization of the sacroilac joint in pregnancy related low back and pelvic pain patients, we investigated the influence of sacroiliac screw fixation on the stiffness of an anatomically intact sacroiliac joint.

Design

Comparative cadaveric study.

Materials and Methods

In 12 hemipelves baseline measurements of the intact sacroiliac joint without fixation were obtained, after which all sacroiliac joints were fixated with one and with two sacroiliac screws. We compared the baseline situation to fixation with one or two sacroiliac screws. In 10 cycli each hemipelvis was loaded to a maximum of 400N. The translation and rotation stiffness and the displacements of the sacroiliac joint were calculated using a three-dimensional video system.

Results

For the technique with two screws a significantly higher translation and rotation stiffness and less displacement of the sacroiliac joint were found compared to the baseline. The difference between one screw and the non fixated sacroiliac joint situation was less marked, but still significant for the translation stiffness. The rotation stiffness however showed no difference between one sacroiliac screw and the baseline. No significant difference could be found between the two screw techniques.

Conclusions

In isolated sacroiliac joints a higher stiffness and less displacement was found in sacroiliac joints which were fixated with screws. Using one screw only demonstrated better translation stiffness. In the technique with two screws both translation and rotation stiffness improved. Although the difference between the two fixation methods was not significant, the technique with two screws seems to be superior for stabilization of the sacroiliac joint.

Introduction

Pain in the pelvic ring may develop during or after pregnancy and after trauma[1-3]. Approximately 50 % of all women suffer from pelvic pain during their pregnancy[4-9]. One-third of these patients has severe complaints which interfere with normal activities[6-12]. Our previous studies suggest the involvement of sacroiliac joint mechanics in pregnancy related low back and pelvic pain (PLBP)[13-16]. In most patients complaints decrease spontaneously or with conservative treatment[7;9;17-23]. In a minority of patients the pain persists and may cause severe disability[18;22;24-26]. If even a multidisciplinary rehabilitation program has failed, the only remaining treatment for these patients seems to be surgical fixation of the pelvic ring. In our department some experience has been gained with internal fixation of the pubic symphysis and the sacroiliac joints (SIJ) in patients who remained severely disabled by PLBP after all other conservative treatment had failed. For this highly selected group the preliminary results seem promising[27].
Fixation of the sacroiliac joint with screws is commonly used in pelvic fractures[28-32]. A number of studies have been performed to determine the biomechanical properties of sacroiliac screw fixation in pelvic fractures[33-49]. MacAvoy and Tile reported that a fixed symphysis can maintain reduction of the sacroiliac joint in a partially unstable Tile B injury[39;47]. This is in contrast with the findings of Dujardin and Simonian, who described that fixation of the symphysis alone did not reduce displacement of the sacroiliac joint and that the combination of anterior and posterior fixation yielded the greatest decrease in movements[34;45]. In Tile B fractures fixated with an anterior plate and sacroiliac screws Dujardin found that sacroiliac micromotion decreased to the level of the intact pelvis[34].
In order to make an estimation of the biomechanical properties of surgical stabilization of the sacroilac joint in PLBP patients, we investigated the influence of sacroiliac screw fixation on the stiffness of an intact sacroiliac joint. In our patientgroup the degree of mobility of the pelvic joints varied, but usually no mechanical hypermobility could be demonstrated anymore after years of complaints. Therefore no attempt was made to simulate hypermobility in a cadaveric model, but intact sacroiliac joint was used in this study.

Materials and methods

Specimens and fixation method

In this study we measured the sacroiliac joints of 12 embalmed cadaveric hemipelves, which were left sacroiliac joint was still intact after the contralateral side was used for an earlier experiment. The pelves were dissected, leaving the ligamentous structures intact, including the ischiosacral ligaments. The femora, lumbar vertebrae and all muscles were removed. The average age of the specimens was 78.9 years.

Sacroiliac fixation was done with one or two 70 mm cannulated partially threaded, cancellous lag screws (Biomet®, Warsaw, Indiana, U.S.A.) with washer. The screw(s) were placed through the posterior ilium and into the vertebral body of S1 across the sacroiliac joint, according to the technique of Matta and Saucedo[28].

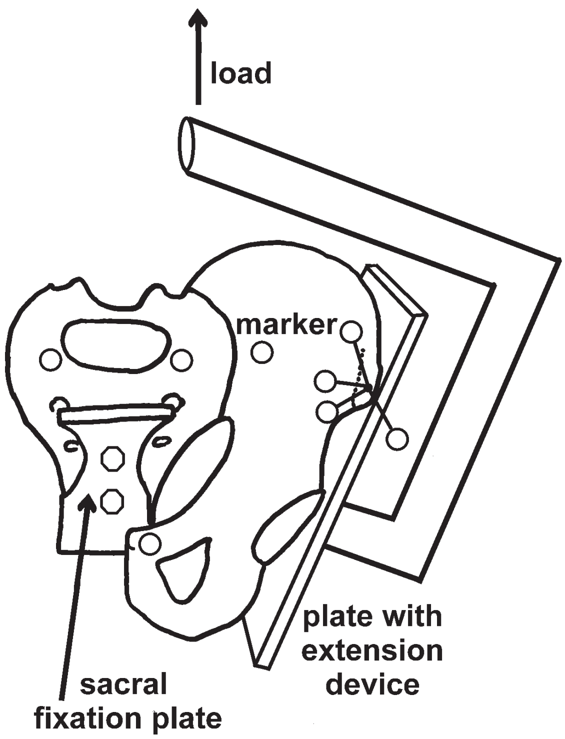

Figure 1 Experimental setup

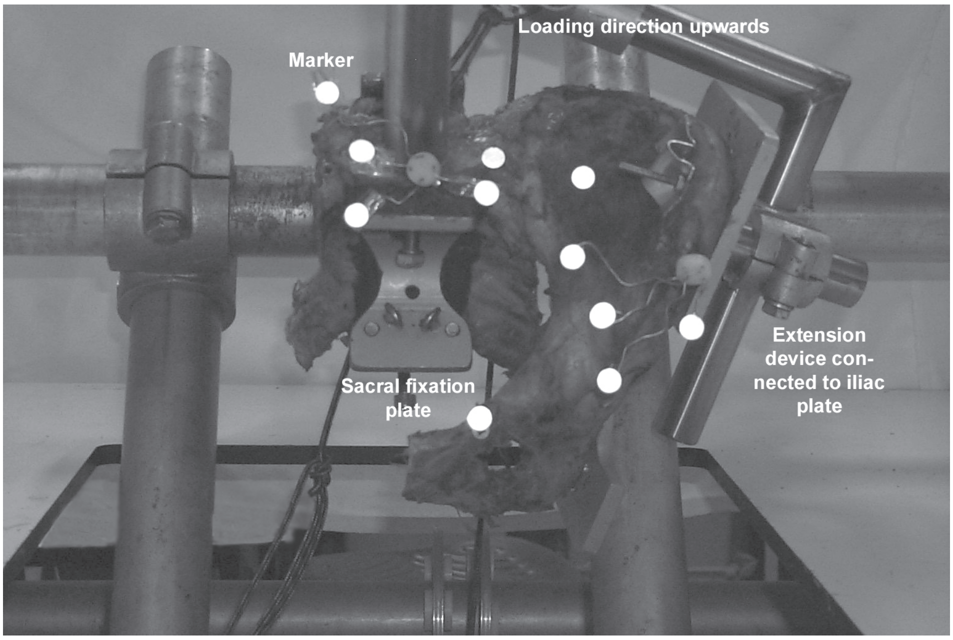

Figure 2 Hemipelvis with markers while fixated in the loading frame

Loading arrangement

To enable the application of load to the sacroiliac joint, the sacrum was fixed between two plates with screws and methylmethacrylate-polymere resin (Demotec®, Demotec Siegfried Demel, Nidderau, Germany) and mounted to a frame. The hemipelvis was oriented with anterior superior iliac spine and the symphysis in the frontal plane which is approximately comparable to the physiological position during standing[39;40]. The ilium was loaded by a force acting through a rope on a plate with an extension device, which was attached to the ilium in such a way that the line of action of the load passed in a vertical direction through the sacroiliac joint (Figure 1 and 2). This enabled us to investigate the resistance of the fixation against shear force, which is an important part of the load during weight bearing.

After baseline measurements of the intact sacroiliac joint without fixation were obtained for each hemipelvis, all sacroiliac joints were fixated successively with one and with two sacroiliac screws in a randomized order. In all three situations (intact, one and two sacroiliac screws) the hemipelves were loaded 10 cycles to a maximum load of 400 N and with an increment of 100 N[34;39;45;46]. In a pilot study this showed to be safe, avoiding failure levels and permanent displacement.

Motion measurements

With a three-dimensional video system displacements were measured in all six degrees of freedom (three dislocations and three rotations). To enable the computerized video registration of bone displacements, clusters of four infrared light reflecting markers were attached to the cranioventral edge of the first sacral vertebral body and to the superior anterior iliac spine. Two markers were placed bilaterally, about two cm from the sacroiliac joint and one marker was positioned on the superior ramus of the pubic bone. The markers were illuminated by an infrared light source mounted to the two video cameras. Infrared filters in front of the camera lenses ensured good contrast in the video images. With the help of a video image processing board (Vision Dynamics VCS512-II) in a personal computer, the image coordinates of the centers of the markers were determined. The image coordinates from the two cameras were combined to three-dimensional spatial coordinates using Direct Linear Transformation[50]. The algorithms described by Spoor and Veldpaus were used to calculate displacements between the ilium and the sacrum, and at the sacroiliac joint[51]. From previous tests the resolution of the system proved to be about 0.1 mm.

Data Analysis

As outcome measures, we investigated the stiffness of the fixation, and the displacements at the sacroiliac joint. We defined the translation stiffness (in N/mm) of the fixation as the slope of the load displacement curves of the ilium with respect to the sacrum. Although we tried to apply the force exactly in the fracture plane, inadvertently a small lever arm will be present between the force and the fracture plane. Since the magnitude of the resulting moment is unknown, the rotation stiffness (moment divided by observed angular displacement) could not be calculated. Therefore we determined the applied load divided by the observed rotation as an indication of rotation stiffness. In a linear model, the slope of the load displacement curves from the three cycles was calculated using the least squares method.

For the statistical calculations we used SAS version 6.12 of the SAS institute inc, Cary, NC, USA. A MANOVA was performed to compare the translation stiffness, the rotation stiffness and the displacements at the sacroiliac joint of the two fixation methods with the intact baseline situation. Because the distribution was skewed we applied a log transformation to the data, therefore median and range were provided instead of mean and standard deviation.

Results

The median and range for the displacements between the two markers at the sacroiliac joint are described in table 1. Without fixation displacement of the ilium ocurred mainly in cranial direction (median 0.85 mm) and to a lesser degree in dorsal direction (median 0.4 mm). Median diastasis was 0.2 mm. Fixation of the intact sacroiliac joint with screws resulted in a decrease of movement in craniocaudal and dorsoventral direction. In lateral direction no difference was seen. For fixation with two sacroiliac screws median displacements were 0.75, 0.3 and 0.2 mm, respectively. The fixation with one screw showed less marked differences (medians 0.8, 0.5 and 0.1 mm). For comparison of the displacement at the sacroiliac joint between the three situations the overall p value of the MANOVA was 0.008. Significantly less displacement was seen in the fixation with two screws compared with the baseline measurements (p = 0.002). The method with one sacroiliac screw also differed from the baseline, but this decrease did not reach significance (p = 0.055). No significant difference was found between the two techniques when measuring displacements at the sacroiliac joint (p = 0.425).

Displacement in mm						
		X	**Y**	**Z**	**Total**	**p value**
Intact	**median**	-0.4	0.2	0.85	0.9	
	range	-1.5 - 0.5	-0.2 - 0.8	0.1 - 5.1	0.4 - 5.4	
One SI screw	**median**	-0.5	0.1	0.8	0.85	0.055
	range	-1.0 - -0.2	-0.1 - 0.7	0.3 - 3.8	0.3 - 3.9	
Two SI screws	**median**	-0.3	0.2	0.75	0.8	0.002
	range	-1.5 - 0.7	-0.2 - 0.9	0.2 - 5.2	0.2 - 5.4	

Table 1 Displacement measured between the two markers at the sacroiliac joint when loaded up to 400 N

The X-axis is the ventrodorsal axis with the ventral direction being positive
The Y-axis is the mediolateral axis with lateral movement of the ilium being positive
The Z-axis is the craniocaudal axis with the cranial direction being positive
The screw techniques are compared with the intact situation without fixation.

When movements from the ilium with respect to the sacrum are calculated a median translation of 5.7mm (range 1.0 - 17.0 mm) was found in the intact situation. For the technique with two and one sacroiliac screw median translations were 4.4 mm (range 0.9 - 17.0 mm) and 4.7 mm (range 0.7 - 15.3 mm) respectively. Median rotation was 2.6 degrees (range 0.6 - 5.3 degrees) in the non-fixated situation, 2.0 degrees (range 0.5 - 5.4 degrees) with two and 2.2 degrees (range 0.4 - 4.7 degrees) with one sacroiliac screw.
The median and range of both translation and rotation stiffness are summarized in table 2. For the translation stiffness the overall p value of the model was 0.0007. Fixation with two screws showed a significantly higher stiffness than the not fixated situation ($p = 0.0002$). The difference between one sacroiliac screw and the baseline situation was less marked, but significant ($p = 0.041$). The screw techniques did not differ significantly ($p = 0.123$).
Although the overall model of the rotation stiffness was not significant ($p = 0.088$), rotation stiffness was significantly higher for the fixation with two screws than in the baseline situation ($p = 0.030$). However no differences were found between one screw and the non- fixated sacroiliac joint and between the two techniques. ($p = 0.32$).
No significant effect was found for the order in which the two screw techniques were applied.

Translation stiffness (N/mm)				
	median	**minimum**	**maximum**	**p value**
Intact without fixation	188	33	593	
One sacroiliac screw	225	32	746	0.041
Two sacroiliac screws	240	33	776	0.0002
Rotation stiffness (N/degree)				
	median	**minimum**	**maximum**	**p value**
Intact without fixation	435	105	1109	
One sacroiliac screw	452	102	1449	0.32
Two sacroiliac screws	1535	104	13014	0.030

Table 2 Movements of the ilium versus the sacrum: translation and rotation stiffness

The screw techniques are compared with the intact situation without fixation.

Discussion

In this study we investigated the biomechanical properties of screw fixation on the intact sacroiliac joint. With this model we tried to estimate the effect of sacroiliac screws fixation on the stiffness of the sacroiliac joint of PLBP patients after surgical fixation. Although a number of studies report about the effect of sacroiliac screw fixation in partially and completely unstable pelvic fractures[33-49;52-55], these results cannot be extrapolated to the situation of PLBP patients who do not suffer major alterations of the pelvic anatomy. Some authors have described an association between increased mobility in the pelvic joints and pelvic pain[24;56].

However, others found no correlation between either sacroiliac mobility or the degree of symphyseal distension and the severity of pelvic pain in pregnancy or after childbirth[3;6;17;57]. Moreover, after years of complaints usually no mechanical hypermobility can be demonstrated anymore, whereas the pain persists[2;3;17]. Based on our own biomechanical modelling, we assume that small movements in the sacroiliac joints, even if the mobility is not larger than normal, may cause stress in the joint capsule and ligaments and thus cause pain. Internal fixation is thought to eliminate the loading of vulnerable and injured soft tissue structures surrounding the sacroiliac joint, which can result in relief of pain and improvement of functional impairment.

Because there is no suitable model of the sacroiliac joint in PLBP available, intact sacroiliac joints were used in this study. If an increase in stiffness after sacroiliac screw fixation could be demonstated in an intact joint, the stabilizing effect could only assumed to be larger in a joint with any residual hypermobility. We used an isolated sacroiliac joint without any muscular support in order to create a reproducible situation with as little interference as possible from other factors.

The results of this study show a significantly higher translation and rotation stiffness and less displacement of the sacroiliac joint for the technique with two screws compared to the baseline, of which the rotation stiffness showed the least prominent effect. The difference between one screw and the non fixated sacroiliac joint situation was less marked, but still significant for the translation stiffness. For the displacement at the sacroiliac joint the p value just exceeded 0.05. The rotation stiffness however showed no difference between one sacroiliac screw and the baseline. This confirms the assumption that two sacroiliac screws would be more resistant to rotation. However, no significant difference could be found between both screw techniques for rotation stiffness as was the case for the other two outcome measures. In all outcome measurements a wide variation between specimens was observed similar to other studies[35;39;40;42;45;46;52;54;58]

The results are consistent with earlier investigations in which two sacroiliac screws were found to be superior to one screw in rotation stiffness and load to failure for Tile C pelvic fractures[59].

The abstract design of this study made comparison between the two screw fixations and the intact situation easier. However, this limits extrapolation of the results to the clinical situation. In our population with people severely disabled from PLBP, the use of aged specimens may not be as far from reality as in trauma patients, because disuse osteopenia is frequently encountered in our patients. To draw conclusions about the biomechanical properties of the sacroiliac joint fixation used clinically in PLBP patients, in vivo measurements should be done in future investigations. Because all reliable methods to measure sacroiliac joint displacements require invasive procedures, we are currently developing a non-invasive way to determine sacroiliac joint stiffness.

Based on the results of this study we can conclude that in isolated sacroiliac joints a higher stiffness and less displacement was found in sacroiliac joints which were fixated with screws. Using one screw only demonstrated better translation stiffness. In the technique with two screws both translation and rotation stiffness improved. Although the difference between the two fixation methods was not significant, the technique with two screws seems to be superior for stabilization of the sacroiliac joint.

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7

Triple Pelvic Ring Fixation in Patients with Severe Pregnancy Related Low Back and Pelvic Pain

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Abstract

Study design
Single-group prospective follow-up study

Objectives
To assess the functional outcome of internal fixation of the pelvic ring in patients suffering from severe pregnancy-related low back and pelvic pain (PLBP) in whom all other treatments failed.

Background data
More than half of all pregnant women experience PLBP. In most cases the pain disappears after childbirth. In some, however, the pain becomes chronic and patients may be wheelchair bound or bedridden. After failure of all conservative treatment, surgical fixation of the pelvic ring seems to be the only remaining option for those severe cases.

Methods
The post-surgical functional outcome of 58 severe PLBP patients was evaluated with the Majeed score, and endurance of walking, sitting and standing. Inclusion criteria were serious disability and failure of all conservative treatment. The surgical technique consisted of a symphysiodesis and bilateral percutaneous placement of two sacroiliac screws under fluoroscopic guidance.

Results
With a follow-up of on average 2.1 years, the difference between pre- and post-operative Majeed score indicated that an improvement of over 10 points was achieved in 69.8 % and 89.3% of the patients at 12 and 24 months respectively. The most important complications were irritation of nerve roots (8.6 %), non-union of the symphysis (15.5 %), failure of the symphyseal plate (3.4 %) and pulmonary embolism (1.7 %).

Conclusions
In this preliminary study surgical fixation of the pelvic ring yielded satisfactory results in severe PLBP patients in terms of pain relief, and improvement in ADL functions. These results should be confirmed in a randomized clinical trial.

Introduction

Low back pain is common during pregnancy. The reported prevalence ranges from 42 to 81 %[1-8] and 20 to 30 % of the pregnant women describe their back pain as severe or disabling[2;4;5;9]. Östgaard et al.[5;6] differentiate low back pain from posterior pelvic pain, which is experienced by 14 to 30 % of all pregnant women[3;5;6;10]. However, for such differentiation no uniform definitions and diagnostic criteria are available. A wide variety of nomenclature is used: insufficientia pelvis[11], symptom giving pelvic girdle relaxation[9;10], posterior pelvic pain[6;7], peripartum pelvic pain[12], pelvic instability[13;14], and sacroiliac joint (SIJ) dysfunction[1]. Since a clear distinction based solely on the localization of the pain is difficult to make we suggest a more descriptive term: pregnancy-related low back and pelvic pain (PLBP). The etiology of PLBP is still unknown, but several theories are described: hormonal (relaxine)[15;16], enzymatic (hyaluronidase), metabolic (calcium)[11], mechanical (pelvic instability)[14;17-21], and traumatic[2;13;20]. In our previous studies on PLBP we determined a measure for SIJ stiffness by means of color Doppler imaging of vibrations at both sides of each sacroiliac joint. In women with pregnancy-related low back and pelvic pain a significant difference in stiffness of the left and right SIJ was found[22]. This supports the involvement of SIJ mechanics in PLBP[21;23].
After childbirth low back pain disappears in most cases within six months[3;7;8;10;17]. Some patients (circa 2 %), however, develop a chronic pain pattern[10]. The most common symptoms and signs are summarized in Table 1. Several diagnostic tests have been described of which the posterior pelvic pain provocation test (PPPP)[6] and the active straight leg raising test (ASLR)[24] are most commonly used. In the PPPP[6] the hip is flexed to 90 degrees when the patient is lying in supine position. Gentle pressure is applied to the knee along the longitudinal axis of the femur. Pain deep in the gluteal area on the ipsilateral side indicates SI involvement. For the ASLR[24-26] the patient is asked to actively raise the extended leg five to 10 cm above the underground, left and right leg separately.
Conservative treatment includes physiotherapy with muscle strengthening exercises and a pelvic belt[6;11;12;21], which contribute to the stability of the SIJ. In some patients even therapy in a specialized rehabilitation clinic remains unsuccessful and surgical fixation of the symphysis and sacroiliac joints seems to be the only remaining treatment option for patients seriously disabled by PLBP. Internal fixation of the pelvic ring is commonly used in unstable pelvic fractures[27-32]. For PLBP, surgical fixation of the symphysis and sacroiliac joints has only been described in a few case reports and small series[17-20;33-36]. Objective of the present study is to determine whether in very severe cases of PLBP, in whom all conservative treatments failed, internal fixation of the pelvic ring relieves pain and reduces disability. Furthermore, the safety of the technique is evaluated and an attempt made to identify characteristics which may predict the outcome of the intervention.

complaints (1-4, 6, 9, 12-14, 17, 20)
- pain around the sacroiliac joints uni- or bilaterally, the pubic symphysis
and sometimes in the inguinal region
- symptoms started in pregnancy or after partus
- pain frequently radiates to the upper legs
- pain becomes worse during ADL activities and exercise
physical examination (6, 13, 14, 17, 24-26)
- pain SIJ or symphysis on palpation
- pain SIJ during "posterior pelvic pain provocation test"
- "active straight leg raising test" positive
- Trendelenburg's sign positive
- waddling gait, short steps
- inguinal pain at contraction adductors
radiological (13, 14, 17, 20, 24, 39)
- symphyseolysis (> 4 mm)
- sclerosis SP or SIJ
- vertical shift on Chamberlain stress radiographs (> 2 mm)
- exophytes
- soft tissue calcifications
- irregular articular surfaces
- gapping SIJ

Table 1 Symptoms in pregnancy related low back and pelvic pain

Materials and methods

Patient series and selection

Between March 1996 and August 1999, 58 women with severe PLBP were operated by the senior author (ABvV), and follow-up took place until December 2000. The study was designed as single-group prospective follow-up study for a very selected group of women. Patients were only accepted if they had already completed all conservative treatment options, including a multidisciplinary rehabilitation program and showed no significant improvement to these measures over the years. The following criteria were obligatory for the diagnosis PLBP[6;9;12;24]: pain in one or both sacroiliac joints which originated during the pregnancy or directly after the delivery and increased during ADL activities and exercise. Both provocation tests (ASLR[24-26] and PPPP[6]) had to be positive. In addition, from the physical examination section in Table 1 two additional points had to be present and at least 3 points from the radiology section. Furthermore the patient had to be severely disabled in mobility and self-care. The Barthel Index[37] which assesses ADL on a scale from 0 to 20 should be less than 20. The last delivery had to be at least twelve months ago and informed consent should be given. Exclusion criteria were the presence of radiculopathy, and pathology in spine or hip. The study was approved by the institutional review board.

At intake a physical examination was performed by the senior author, including an evaluation of hypermobility by means of the Biro score[38]. For the ASLR [25;26]impairment was scored on a five-point scale: 0 (no restriction), 1 (slight weakness), 2 (weak), 3 (severe weakness), and 4 (impossible). The scores for both legs were added. Pre-operatively, plain X-rays and stress radiographs according to Chamberlain[39] were made, if necessary completed with a CT or MRI scan to exclude low back origin of the complaints. Postoperatively a CT scan is made to check whether the screws are placed correctly. With X-rays the development of bony union of the symphysis is monitored. Follow-up appointments are scheduled at three, six and twelve months and yearly thereafter. A visit at eighteen months was optional.

Surgical intervention

From March 1996 to March 1998 we fixed the symphysis in 22 patients, as described by Tile[32]. After resection of the joint surfaces of the symphysis and approximation of the pubic bones, two DC plates were placed. Because this resulted in six (27.3 %) non-unions we modified the technique. From April 1998 to August 1999 (35 patients) a wedge-shaped block from the upper half of the symphyseal joint was removed and a bone graft from the iliac crest similar in shape, but a fraction larger in size, was fitted between both pubic bones. We positioned one reconstruction plate over the symphysis and the graft[19]. In one patient no symphysiodesis was performed, because this had already been done. For the approach of the SIJ the patient lay in prone position. Fixation of both sacroiliac joints was accomplished with two percutaneously placed cannulated titanium screws on each side. From March 1996 to January 1998 one screw in the vertebral body of S1 and one in S2 (25 patients) and afterwards both in the body of S1 (29 cases). In four cases the screws were positioned in S1 and S2 on one side, and both in S1 on the contralateral side. Using fluoroscopy (inlet and outlet view) the screws were inserted into the vertebral body reaching the mid-sagittal line of the sacrum[27;29]. One day after surgery mobilization and full weight bearing was gradually started.

Outcome parameters

The functional outcome of the operation is assessed by completing the following methods of evaluation during intake and at each follow-up visit: an adapted version of the Majeed score[40], and endurance of walking, sitting and standing. All outcome measures were scored by the senior author.

The Majeed score[40] originally devised to grade the functional result after pelvic trauma, is divided into seven categories: pain, work, sitting, sexual intercourse, walking aids, gait unaided and walking distance. Each of these items is scored and the total ranges from 0 (completely bedridden) to a maximum of 100 points (no complaints) for patients who were working before the onset of the complaints and 80 for those who were not. We employed the Majeed score because it is easy to use and is the only scoring system specifically related to the pelvis, as well as assessing functions such as sitting and sexual intercourse. A good correlation between the Majeed score items and the SF-36 was found by Van den Bosch et al[41]. The difference between pre- and postoperative Majeed score was divided into four categories: < 10 points, 10-25 points, 26-40 points and > 40 points improvement.

Furthermore, the patient was asked to give an estimation of the distance she could walk and of the time she was able to sit and stand without considerable increase of the pain[26;42]. Because in most cases this was recorded as a range, we divided the answers in categories. The categories ranged from '0 meter' to 'no restriction' for walking distance and from 0 min to > 60 min for endurance of sitting and standing.

Data analysis

The functional status of the patients before the operation was compared with the situation after surgery. Because the data were reasonably normally distributed, the differences between pre- and postoperative Majeed scores were compared with parametric tests. For ordinal data (walking distance, endurance of sitting and standing, and the Majeed score items) a Wilcoxon's matched pair signed rank test was used. Both univariate and multivariate regression analysis was used to determine whether any pre-operative characteristics are significantly related to surgical outcome. Two-tailed p-values were calculated and a $p < 0.05$ was considered to be significant. All calculations were performed using the SPSS 9.0 computer package.

Hypermobility	none	40	(69.0%)
	yes	11	(19.0%)
	missing	7	(12.1%)
Housework	nothing at all	13	(22.4%)
	hardly anything	12	(20.7%)
	only light work	20	(34.5%)
	all except heaviest tasks	9	(15.5%)
	everything	3	(5.2%)
	missing	1	(1.7%)
Medication	none	14	(24.1%)
	paracetamol	8	(13.8%)
	NSAID	14	(24.1%)
	opiate	18	(31.0%)
	other	3	(5.2%)
	missing	1	(1.7%)
Walking aids	bedridden	8	(13.8%)
	wheelchairbound	20	(34.5%)
	rollator walker	2	(3.4%)
	crutches	16	(27.6%)
	none	12	(20.7%)
Chamberlain stress radiographs	0-2 mm	21	(36.2%)
vertical shift of the pubic bones	3-5 mm	28	(48.3%)
	6-9 mm	4	(6.9%)
	missing	5	(8.6%)

Table 2 Preoperative patient characteristic
the data are expressed as the number of patients, with the percentage in parentheses

Results

Clinical outcome

Average age of the patients was 33.5 (SD 4.64) years. Mean duration of the complaints when patients first visited the outpatient clinic was 3.9 (SD 2.57) years. All women were severely impaired in normal daily functioning due to pain in the pelvic region. The Barthel Index[37] was on average16.5 (SD 3.04). A number of patients indicated that sitting and standing caused more complaints than walking. Eleven patients (19.0 %) were primiparae, 47 (81.0 %) were multiparae. In 32 cases (55.2 %) the first complaints originated in the last pregnancy, in 26 (44.8 %) less severe symptoms were present during an earlier pregnancy. In these patients complaints had not resolved after the delivery and were aggravated in each subsequent pregnancy. The pain usually developed during the third or fourth month of pregnancy; however, in 17 (29.3 %) of the women complaints started during or after delivery. The pain was localized at the left and right SIJ region in 48 (82.8 %) and 51 cases (87.9 %) respectively and at the symphysis in 50 patients (86.2 %); 53 women experienced radiation of the pain to one (41.4 %) or both (50.0 %) legs. Further characteristics of the patient group are given in Table 2. None of the patients showed improvement of their complaints during the time they were on the waiting list for the operation, which was on average 0.94 years (SD 0.46). Duration of the follow-up period was on average 2.1 years (range 1.0 to 4.2 years, SD 0.84). Follow up at 12 and 24 months was available for 58 and 32 patients respectively. None of the patients were lost to follow-up.

Figure 1 shows the Majeed scores obtained before and after surgery. The mean Majeed score was 36.6 (SD 12.0) preoperatively, and postoperatively 60.6 (SD 21.6) and 68.5 (SD 17.0) at 12 and 24 months respectively. We compared the postoperative scores at 12 and 24 months respectively with the preoperative score: the mean difference was 24.1 (range -19 to 72) at 12 months and 33.3 (range 3 to 64) at 24 months. No Majeed score was available in 3, 4 and 3 patients at baseline, 12 and 24 months respectively. Therefore the difference between pre- and postoperative score could not be calculated in five patients. Using a paired t-test both differences were significant, $p < 0.001$. Between 12 and 24 months postoperatively some further improvement was seen ($p = 0.035$). Based on the difference between the pre- and 12 months postoperative Majeed score 16 (30.2%) of our patients improved less than 10 points, 11 (20.8%) 10 to 25 points, 18 (34.0%) 26 to 40 points, and 8 (15.1%) improved over 40 points. At 24 months the figures were 3 (10.7%), 5 (17.9%), 14 (50.0%) and 6 (21.4%) respectively. Of the 16 patients with a poor result at 12 months one showed a difference of –19, due to the development of back pain; for the remaining 15 patients the scores ranged from –5 to 10, and their complaints were unchanged after the operation.

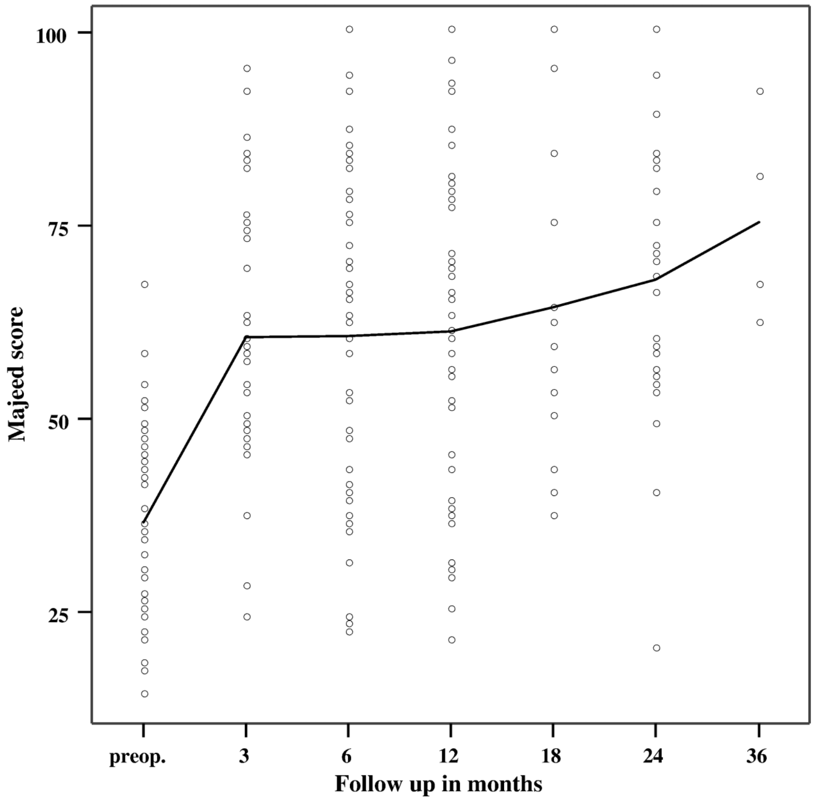

Figure 1 Pre- and postoperative Majeed score
The dots show the Majeed score for individual patients and the line represents the mean.

With a Wilcoxon's matched pair signed rank test a significant difference was found between the preoperative and postoperative values for walking distance, endurance of sitting and standing, and all Majeed score items (figure 2), all $p < 0.001$. The Majeed score items for pain and sexual functioning showed a significant improvement between 12 and 24 months postoperatively ($p = 0.025$ and $p = 0.001$).

Improvement in mobility implied that of the 20 women who were wheelchair bound and of the eight that were bedridden before the operation, after surgery only four of the first group and four of the latter were using a wheelchair. At 12 and 24 months the ASLR showed improvement in 81.6% and 100% of the patients, for the PPPP improvement was seen in 54.7% and 64.3% respectively. Pre- and postoperative scores for walking distance and provocation tests are shown in table 3. Furthermore, 11 patients returned to work after the operation.

Walking distance (meter)	preoperatively		12 months post		24 months post	
	N		N		N	
0	7	(14.3%)	0	(0%)	0	(0%)
< 50	15	(30.6%)	11	(20.4%)	2	(6.7%)
<200	16	(32.7%)	13	(24.1%)	6	(20.0%)
< 500	9	(18.4%)	6	(11.1%)	6	(20.0%)
> 500	2	(4.1%)	14	(25.9%)	9	(30.0%)
no restriction	0	(0%)	10	(18.5%)	7	(23.3%)
Total	49	(100%)	54	(100%)	30	(100%)
Missing	9		4		2	

Active Straight Leg Raising test	preoperatively		12 months post		24 months post	
	N		N		N	
0	0	(0%)	35	(61.4%)	20	(71.4%)
1 - 2	9	(18.0%)	7	(12.3%)	4	(14.3%)
3 - 4	19	(38.0%)	9	(15.8%)	4	(14.3%)
5 - 6	21	(42.0%)	5	(8.8%)		
7 - 8	1	(2.0%)	1	(1.8%)		
Total	50	(100%)	57	(100%)	28	(100%)
Missing	8		1		4	

Posterior pelvic provocation test	preoperatively		12 months post		24 months post	
	N		N		N	
both sides positive	49	(84.5%)	19	(35.8%)	7	(25.0%)
one side positive	9	(15.5%)	24	(45.3%)	11	(39.3%)
both sides negative	0	(0%)	10	(18.9%)	10	(35.7%)
Total	58	(100%)	53	(100%)	28	(100%)
Missing	0		5		4	

Table 3 Difference between pre- and postoperative scores

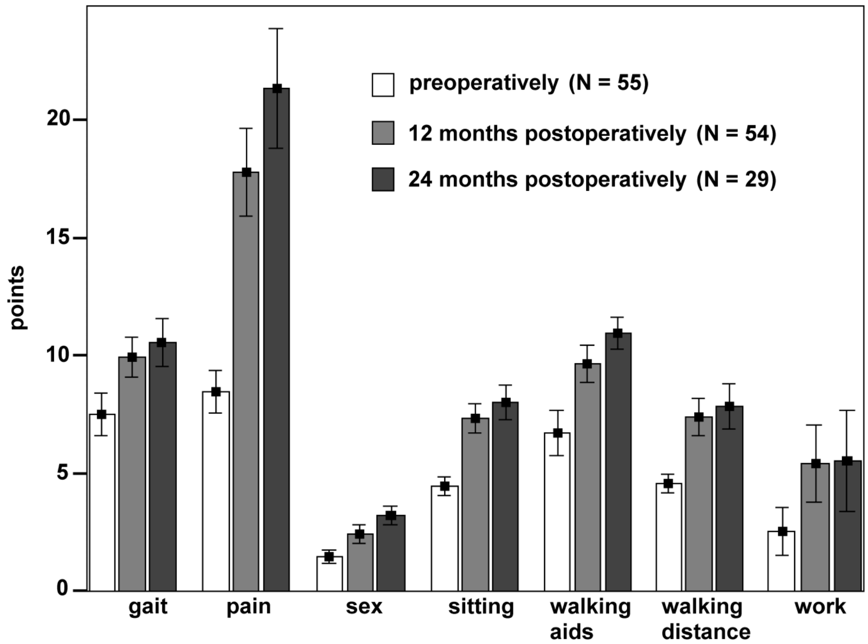

Figure 2 Majeed score items

The bars show the mean and the error bars represent the 95% CI of the mean
The Majeed score item for gait unaided ranges from 0 to 12, pain 0 - 30, sexual intercourse 0 - 4, sitting 0 - 10, walking aids 0 - 12, and walking distance 0 – 12, work 0 – 20

Predictive factors

We tried to identify preoperative characteristics that might help to predict the outcome of the operation. With univariate regression we analyzed whether any of the following factors was related to the outcome: preoperative Majeed score, walking distance, duration of the complaints, Quetelet index, parity, age, preoperative ASLR, Barthel Index, Chamberlain radiographs, date of the operation, hypermobility, earlier operations on pelvis or low back, anterior and posterior operation technique and the presence of complications. The pre-operative Majeed ($p < 0.001$), the duration of the complaints ($p = 0.049$) and the preoperative walking distance ($p = 0.018$) were associated with the 12 month postoperative Majeed score. We included those factors in the multivariate regression and also included parity and the operation date, which were borderline significant. Only the preoperative Majeed score (ß 0.743, $p = 0.002$) and the duration of the complaints (ß –2.237, $p = 0.047$) proved to be independant predictors of the 12 month postoperative Majeed score. R^2 (variation explained by regression) of the overall model was 0.285. Only the duration of complaints ($p = 0.049$) correlated with the change in Majeed score.

Complications

Complications were encountered in 27 patients (Table 4) of whom 23 underwent a reintervention, six of them twice (Table 5). Using the first technique of symphysiodesis six non-unions out of 22 patients (27.3 %) were seen. The second technique resulted in three non-unions out of 35 cases (8.6 %). In eight patients a resymphysiodesis was done: in six cases of non-union and three times in two patients because of failure of the plate. Material failure occurred twice in a patient who weighed 135 kilograms. Symphysiodesis was achieved in all eight patients.

Five patients (8.6 %) experienced radiating pain and a subjective sensory loss, in three cases in segment S1 and in two in S3-4. Of the 25 patients in whom the lower SI screw was placed in S2, nerve root irritation was found in four cases (16.0 %); of the 29 patients with the lower screw in S1 only one showed nerve irritation (3.4 %). One patient also suffered a motor deficit of S3-4. Percutaneous repositioning of the screws with a parallel device resulted in a complete recovery of all patients. In one case the complaints resolved spontaneously.

The other revisions of the SI screws were carried out because of pain fitting residual SI instability, due to non-optimal placement or loosening of the SI screws. A serious general surgical complication was pulmonary embolism in one patient after discharge from the hospital. Four patients developed a haematoma and one a wound infection at the pfannenstiel incision.

Discussion

In 58 patients with severe pregnancy-related low back and pelvic pain we applied surgical treatment, with an improvement of over 10 points on the Majeed score in 69.8% and 89.3% of the cases at 12 and 24 months postoperatively. This result was remarkable considering the highly selected patient population with a severe disability and failure of all earlier conservative treatment over the years. Possible explanation of this result is that the primary cause of the complaints was eliminated, i.e. the patients inability to stabilize the SIJ, which in the longer term resulted in a complex pain pattern.

There is much discussion on the pathogenesis of PLBP. Several authors describe hypermobility of the pelvic joints to be a causative factor[13;14;17;19;20]. After years of complaints usually no mechanical hypermobility can be demonstrated, whereas the pain persists[13;14;17]. In 36.2% of our patients movement of the symphysis did not exceed two mm on the Chamberlain stress radiographs. Based on our own biomechanical modeling[21;23] we assume that the pain is related to the mechanics of the SIJ and surrounding ligamentous structures. Internal fixation is thought to eliminate the loading of vulnerable and injured soft tissue structures.

	No. of patients	Percentage
irritation of nerve roots	5	(8.6%)
non-union of the symphyse	9	(15.5%)
failure of the plate	2	(3.4%)
hematoma	4	(6.9%)
wound infection	1	(1.7%)
other locoregional	3	(5.2%)
other systemic	3	(5.2%)
Total	27	(46.6%)

Table 4 Postoperative complications

	No. of operations
resymphysiodesis	5
revision SI screws	7
resymphysiodesis + revision SI screws	4
open SI arthrodesis	2
removal SI screws	4
removal symphyseal plate	1
drainage hematoma	1
drainage abcess	1
correction cicatrial hernia	2
removal protruding screw symphyseal plate	1
resection neurinoma	1
Total	29

Table 5 Reinterventions

In all patients the symphysis and both sacroiliac joints were fixed. The complete pelvic ring fixation prevents shear deformation of the symphysis and rotation in the sacroiliac joints. From experience with unstable pelvic fractures it is known that isolated fixation of the anterior complex results in failure because of the remaining mobility in the posterior complex. A few biomechanical studies support the concept that posterior fixation adds most to the stability of the pelvis[32;43;44].
Recent advances in imaging and operating techniques have allowed percutaneous placement of sacroiliac screws[28-31], which reduces the complications of the procedure: less tissue damage, limited blood loss, and decreased infection rates[29;30]. Screws can be placed under either fluoroscopic[29-31] or CT guidance[28]. During the study the SI screw fixation technique was modified: instead of two parallel screws in the body of S1 and S2, we placed both screws tapering in S1. The vertebral body of S1 is larger, so the risk of intrusion of a SI screw into the sacral canal is reduced.
Initially we only used plates for fixation of the symphysis, but after six cases of non-union a bone graft was added in the subsequent patients. We took care that the bone graft was not inserted under strain in the wedge-shaped defect between the pubic bones; this would cause tension in the thin ventral SIJ ligaments and slackening of the dorsal interosseous SIJ ligaments.
Surgical intervention in PLBP patients is described in only a few small series. Some authors did an isolated symphysiodesis[18;34], others did only a SIJ arthrodesis[20;36], or used various combinations of operations[17;19;33]. Sacroiliac screws were applied only in two small series of PLBP patients[33;35], and in one case the SI screws reached only in the lateral mass of the sacrum[35]. More often the SIJ was fixated through an anterior[17;20] or open posterior approach[36]. Our results are at least as good as the 52 to 75% recovery described in literature[17;19;20;33;36], but with percutaneous placement of the SI screws less extensive surgery was required. Complications were consistent with literature[29-31]. Permanent nerve damage did not occur.

Our results support the notion that satisfactory stabilization of the pelvic ring can be achieved by symphysiodesis with a plate and bone graft and sacroiliac screw fixation. Because the surgical intervention at the symphysis is the most extensive, it will be appropriate to investigate whether this can be omitted in the future by proving that isolated SI screw fixation of the posterior complex is also sufficient. To achieve this, perfect SIJ fixation with screws is a prerequisite. Limitation of the present study is the absence of a control group. Our results should therefore be confirmed in a randomized controlled trial. The patient population consisted of a highly selected group of women, who failed to respond to all conservative treatment during the years. Therefore our results should not be generalized to the entire population of PLBP patients. In our selected group of severely disabled patients for whom no other treatment option was left, 12 months postoperatively 69.8% showed improvement of ADL functions of more than 10 points on the Majeed score after surgical fixation of the pelvic ring, despite the substantial number of complications which we encountered. To improve selection of individuals who will benefit, factors which may predict surgical outcome should be identified in future studies. For the excluded patients however no alternative treatment is present.

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8

Fluoroscopic Positioning of Sacroiliac Screws in 88 Patients

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Abstract

Introduction

Fluoroscopic placement of guided sacroiliac screws is a well-established method of fixation of the posterior pelvic ring, leading to biomechanical results similar to an intact pelvic ring. The main problem still remains the risk of neurological injury due to the penetration of the intervertebral root or the vertebral canal.

Material and Methods

88 patients, in whom the posterior pelvic ring was stabilized for several indications, were reviewed retrospectively. On peroperative and direct postoperative radiographs and postoperative CT scan positioning was scored for 285 screws and compared to clinical results.

Results

Depending on the type of imaging (X-ray or CT scan) only 2.1% to 6.8% of the screws showed malpositioning. In several cases the malpositioned screws did not cause any complaints. Postoperative radiographs did not show to have any additional value above peroperative radiographs, in predicting malpositioning. 7 out of 88 patients had neurological complaints and were re-operated. All complaints resolved completely, and no permanent neurological damage occurred. Positioning both sacroiliac screws in the first vertebral body had a significantly lower rate of neurological complaints compared to the lower screw in the second vertebral body. CT scan was able to predict neurological complaints most accurately.

Discussion

Percutaneous sacroiliac screws can be positioned safely, in experienced hands, using peroperative fluoroscopic techniques. A position in the first vertebral body had a significantly lower incidence of neurological injury compared to a position in the second. In case of postoperative neurological deficit only CT scan can predict the clinical outcome. Further research towards improving the peroperative imaging technique must be undertaken.

Introduction

Nonoperative treatment of unstable pelvic ring fractures has a significant long-term morbidity, including pain, leg length difference, difficulty walking and sexual impairment. Internal fixation has shown to reduce mortality, morbidity and hospital stay[1-3]. Better anatomical reduction of the posterior dislocation can also be achieved which leads to a lower rate of malunion[4]. The biomechanical stability of internal fixation through sacroiliac screws approaches that of an intact pelvic ring and the period of nonweight bearing can therefore be minimized[5;6].

Open reduction and internal fixation of the posterior pelvic ring is traditionally associated with a high complication rate of which peroperative hemorrhage and postoperative infection are the most common. Neurological deficit is the most feared because of its severely disabling effects. Although it seems technically easier to position sacroiliac screws correctly through an open procedure, advantages of percutaneously placed screws include a minimal invasion of usually severely compromised soft tissue, limited blood loss and a decreased number of postoperative infections[7-9]. The disadvantage might be a possibly higher percentage of neurological injury.

Computed tomography guided fixation of the posterior pelvic ring is a new technique on which several small studies have been published[10-14]. Despite the advantage of a very precise imaging of the osseous structures of the pelvis, malpositioning is still possible[15]. Fluoroscopy, on the other hand, allows real-time imaging during positioning. Fluoroscopic placement of percutaneous sacroiliac screws requires a high degree of "three-dimensional thinking" and thorough knowledge of pelvic anatomy by the surgeon. The advantage of using a canulated screw technique is that a guide wire is drilled, which allows the surgeon to determine the position of the screw prior to definitive placement minimizing the risk of nerve injury.

In most patients the procedure was started by stabilization of the anterior pelvic ring through a Pfannenstiel incision using one or two plates or, in lateral pubic fractures, screw fixation. After the anterior approach the patient was turned over to prone position for the posterior surgical approach. In some unilateral cases the supine position was retained during the positioning of sacroiliac screws. Intra-operatively the posterior pelvic ring is evaluated through both inlet and outlet view by C-arm fluoroscopic radiographs. After peroperative marking with ink a small incision is made. Through this incision a 3-millimeter guide-wire is inserted. Using in- and outlet views and since 1999 the true lateral view for direction the guide-wire is inserted in the first or second vertebral body, aiming towards the center part of the body. After correct positioning has been confirmed by inlet, outlet and later lateral radiographs the canulated screw is positioned over the guide-wire. Most patients are mobilized several days

postoperatively, depending on the indication for stabilization and, in trauma patients, the fracture type and concomitant injuries.
In this study we present the results of 88 patients in whom the posterior pelvic ring has been stabilized using fluoroscopically positioned sacroiliac canulated screws.

Material and Methods

Retrospectively the charts and radiographs were reviewed of all patients in which the posterior pelvic ring was stabilized using canulated sacroiliac screw fixation between 1 January 1994 and 1 June 1999. From 1994 to January 1998 the lower screw was most frequently positioned in the second vertebral body parallel to the first screw. From 1998 onwards upper and lower screws were both positioned convergingly with their tip into the first vertebral body. The technique of positioning of the lower screws was changed because on inlet radiographs it was not always possible to determine the exact contour of the second sacral body and it therefore resulted in misplacement of the lower screw in some patients.
The indications for fixation were trauma patients with unstable pelvic ring fractures, Tile B or C type[16]. Other indications related to permanent disabilities were patients with posttraumatic nonunion or posttraumatic pain syndrome and post partum pelvic pain. These patients were included in a study of which the long-term results are submitted for publication[17].
All available radiographs were scored by the investigators separately. The inlet view was used to score screw placement in dorsoventral direction i.e. the relation to the vertebral body and the sacral canal . The outlet view was used to score screw placement in craniocaudal direction i.e. the relation to the sacral foramina (Figure 1a+b). On both per- and postoperative outlet views the position of the screw in relationship to the sacral foramina was scored. Because of the variation in angle at which these views can be made no attempt was made to measure the distance exactly, only whether it was "adequately positioned", defined as no indication of protrusion into the sacral canal or into the sacral foramina, or "malpositioned" defined as clearly showing intrusion into either the sacral canal or the sacral foramina or a position extra-osseous ventrally (figure 1+2). If either inlet or outlet view showed signs of malpositioning the screw was scored as malpositioned. An additional CT scan was made routinely starting 1 June 1998. Prior to this date CT scan was only made if there was suspicion of malpositioning, either clinically or on postoperative radiographs. On CT scan the relationship with both vertebral body and sacral foramina was scored using the same categories (figure 2). All data were analyzed with SPSS using Student t-test and Chi square test.

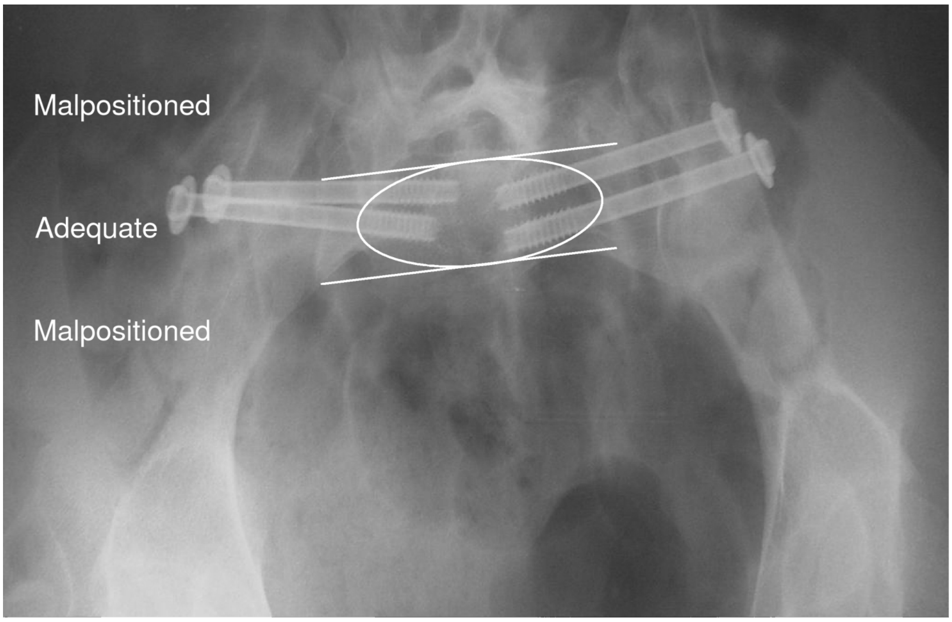

Figure 1a inlet view
the position of the vertebral body of the sacrum is highlighted

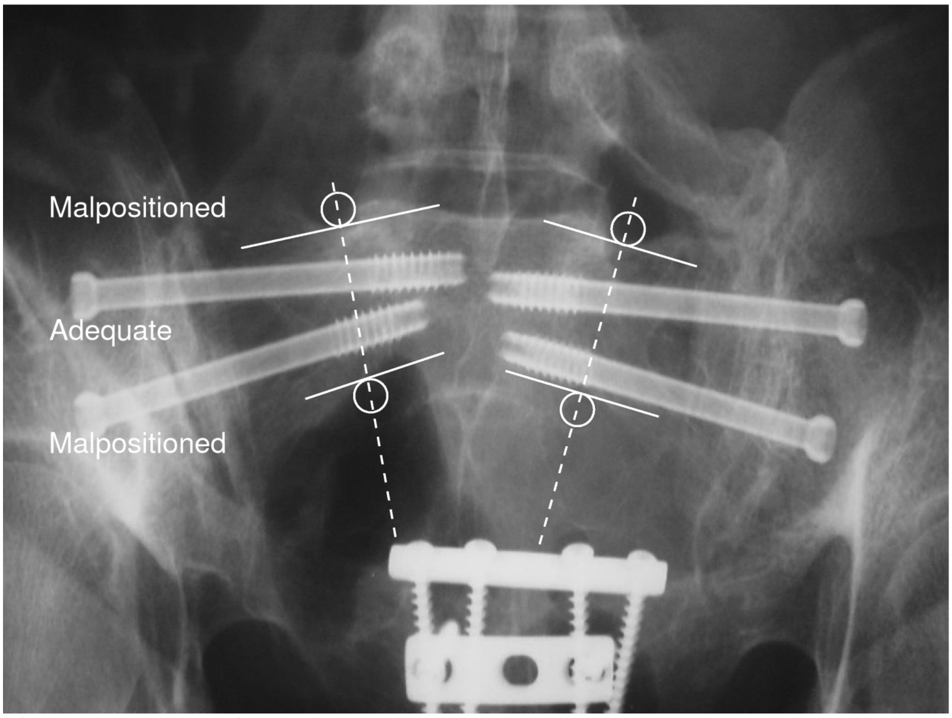

Figure 1b outlet view
the position of the intervertebral foramina and the body of the sacrum are highlighted

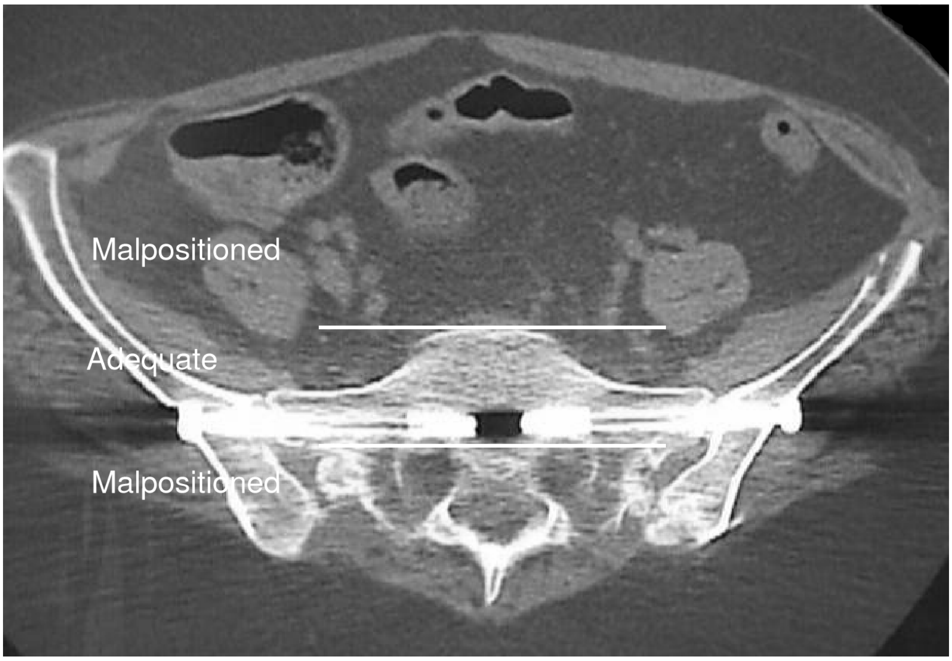

Figure 2 relationships between the tip of the screw with the vertebral body scored on CT scan

Type of stabilization	1 unilat. SI screw	2 unilat. SI screws	1 screw bilateral.	2 screws bilateral.	Total (% male)
Tile-B pelvic ring fracture	4	1	0	0	5 (60%)
Tile-C pelvic ring fracture	3	12	1	1	17 (71%)
Nonunion	0	7	0	8	15 (53%)
Post partum pelvic pain	0	2	0	49	51 (0%)
Total	7	22	1	58	88 (26%)

Table 1 Indications for and type of stabilization (number of patients)

Results

In 88 patients (65 women and 23 men) the posterior pelvic ring was stabilized using canulated screws. The average age was 38,6 (16-75). The indications and the technique of the posterior pelvic ring stabilization are shown in table 1. According to Tile classification five patients had a type-B fracture, which was most often stabilized with one sacroiliac screw and 17 patients had a totally unstable type-C fracture, in which case two sacroiliac screws were used. In all but three trauma patients, in whom sufficient reduction could not be acquired through closed reduction, the sacroiliac screws were positioned percutaneously. In patients with post partum pelvic pain the posterior pelvic ring was stabilized with two sacroiliac screws bilaterally in almost all cases.
Average time to weightbearing mobilization was 10.2 days (1-77) for trauma-patients and 1.8 (1-14) days for nontrauma patients. Average hospital stay was 19.2 days for trauma and 5.0 for nontrauma. One patient died after developing a multi organ failure. Average follow-up was 11.6 months (3-45 months).
There were no posterior wound infections or haematomas. Nine patients needed re-operation of the posterior pelvic ring. Two for technical complications (one in which a screw was positioned too deeply protruding the cortex of the os ileum and one in which the screw loosened and worked its way out). Pain and a positive test of Laseque was present in five patients, one patient had pain and sensory deficit of S1 and in the last patient a sensory and motor deficit of S1 was noticed. CT showed malpositioning in four out of seven patients. In these seven patients re-intervention was carried out during which the screws were repositioned parallel to the old screws using a guidewire system. All complaints resolved completely and there was no permanent neurological damage.
A significantly higher number of patients (6 out of 31) with the lower screw positioned in the second vertebral body had neurological complaints when compared to patients with both screws in the first vertebral body (1 out of 49, $p < 0.01$, using Chi-square test (eight patients with only one screw were excluded)). In retrospect, our change of technique to positioning both screws in the first vertebral body seems therefore justified. There was no significant effect of the addition of the lateral view to peroperative fluoroscopy.
Overall 285 sacroiliac screws were positioned in 88 patients. For 188 screws (53 patients) both per- and postoperative radiographs and postoperative CT scan were available. Peroperative radiographs were not retrieved in 12 patients because no hard copies were made peroperatively, direct postoperative were not available for 10 patients, most often because no adequate in- and outlet views were made, and in the early period no routine CT was made in 21 patients.
On the inlet view radiological scoring showed 72% of the screws in the center of the vertebral body on peroperative and 83% on postoperative radiographs.

The remaining screws were positioned more ventral or more dorsal in about equal percentages (respectively, 11% and 17% peroperatively and 8% and 9% postoperative). On CT only 58% scored in the center while 32% of the cases showed a more ventral position and only 10% a more dorsal positioning. When the peroperative positioning was thought to be exactly in the center, the CT scan confirmed this positioning in only 66.6% of the cases, in total 3.5% (5 cases) severe malpositioning either into the sacral canal or extra-osseus ventrally was seen.
On the outlet view the relationship between screw and sacral root canal was scored. Peroperatively 99.2% (242 screws) scored adequate, while in 0.8% (2 screws) the screw seemed to penetrate the foramen. Postoperative percentages were similar. On CT scans 99.0% (218 screws) was positioned safely in relationship to the sacral root canal and in 1% (2 screws) there was definite intrusion of the sacral canal.
The relationship between radiological scoring and clinical outcome is shown in table 2. In about 2.0% to 6.8% of cases the overall positioning was inadequate. Despite the fact that the 94% of the screws (176 screws of 188 screws) scored similar on peroperative views and postoperative CT, there was a significantly higher risk of neurological complaints in patients in which the CT showed a malpositioned screw ($P<0.01$, using Chi-square test). Eleven screws were malpositioned on CT scan, but did not cause any neurological symptoms in these patients.
No correlation was found for neurological symptoms and score on per- or postoperative radiographs ($p>0.1$). Although the quality of peroperative fluoroscopic images might be poorer than postoperative radiographs there was no additional value of postoperative conventional radiographs in this series. No additional malpositioned screws were discovered on postoperative radiographs in patients with neurological complaints who had scored optimal peroperatively.

	Peroperative		Postoperative		CT scan	
	Without complaints	With complaints	Without complaints	With complaints	Without complaints	With complaints
Adequate	232 (95.1%)	7 (2.9%)	242 (94.2%)	5 (2.0%)	200 (90.9%)	5 (2.3%)
Malposit-ioned	5 (2.0%)	0 (0%)	10 (3.8%)	0 (0%)	11 (5.0%)	4 (1.8%)

Table 2
overall radiological scores divided into patients with or without complaints

Discussion

Positioning sacroiliac screws percutaneously using fluoroscopic guidance is a difficult procedure because of the risk of damage to sacral nerves. Several studies have investigated the risk of neurological injury after sacroiliac screw positioning, the percentage neurological injury is between 0.5% and 7.7%[3;7;8;10;12;15]. In this study we tried to evaluate not only the clinical results but also the radiological results by scoring per- and postoperative in- and outlet views and CT results. Clinically we followed 88 patients, 22 after acute trauma and 66 with chronic pain or nonunion, for an average follow-up of almost 12 months. There were no posterior infections or haematomas, in one patient a screw was positioned too far into the os ilium and in one patient the screw loosened and worked its way out, both requiring re-operation.
Complications due to sacroiliac screw malpositioning were seen in seven patients with neuralgia. In two patients neuralgia was combined with motor or sensor deficit. All complaints resolved completely after re-operation and no permanent neurological damage was seen.
Although there might be a bias from the learning curve, we believe that there is a significantly lower risk of neurological complaints in patients with both sacroiliac screws in the first vertebral body compared to the earlier technique with the lower screw in the second vertebral body.
Using the criteria for accurate screw positioning used in this article it seems possible to position sacroiliac screws quite safely fluoroscopically with less than 7% malpositioned screws on both peroperative radiographs and postoperative CT. Although CT shows some variation of the exact position of the screw in the vertebral body compared to peroperative fluoroscopy, the overall positioning is similar in 94% of the cases. Despite this high number of similar results between peroperative radiographs and CT scan, CT scan is able to predict the clinical outcome more accurately with a significantly higher chance of neurological complaints when a screw is malpositioned on CT. Since the additional value of postoperative conventional radiographs is absent, we recommend that a CT is made to determine the exact position more precisely.
To prevent neurological injuries we changed our technique from only bidirectional views (inlet and outlet) to tridirectional fluoroscopy as described by Matta and Routt[10;18]. We hope that the addition of a true lateral radiograph can determine the antero-posterior positioning of the distal part of the screw in the vertebral body more precisely. Research into the added value of this radiograph, especially combined with peroperative computer guidance systems, is currently undertaken.
Despite the fact that computed tomography guided placement of sacroiliac screws seems to offer the advantage of more precise information of the posi-

tion of the screw due to the greater accuracy of CT above conventional radiographs, there are several disadvantages to CT. Besides the logistical demands of a CT suite with sufficient space for the required monitoring equipment for trauma-patients, it is also necessary to have an operating room located quite close to the CT in case the reduction requires operative intervention or when surgical debridement of the wound is necessary. In non-trauma patients, when the patient is seldom in a critical condition and therefore requires less intensive monitoring computed tomography guided placement could become the option of first choice.

However, currently, sacroiliac screw positioning can be carried out with a high degree of safety using conventional fluoroscopy. More research whether CT guided positioning can improve this fluoroscopic technique, with such a low frequency of permanent neurological complications, requires further investigation into the accuracy and practicality of CT guided positioning versus fluoroscopic guided positioning of sacroiliac screws.

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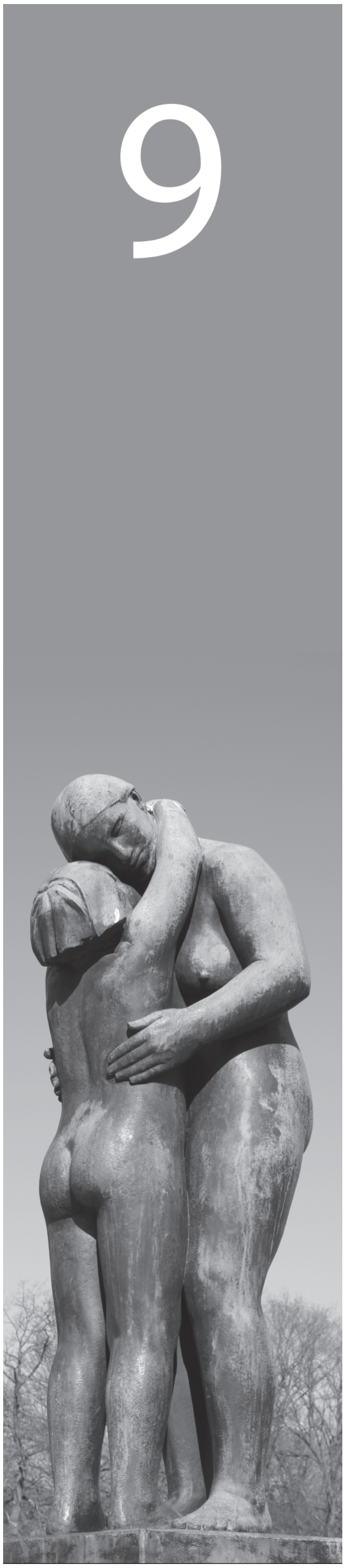
9

Pregnancy Related Low Back and Pelvic Pain: Histopathological Findings of the Pubic Symphysis



Abstract

Background

Traumatic and degenerative changes of the pubic symphysis during and after pregnancy have been described in a few autopsy studies. The relation of these changes with pelvic pain has never been described.

Objective

To analyse the histological findings of the symphysis pubis of patients with severe pregnancy related low back and pelvic pain.

Materials and Methods

A group of 15 women, who were seriously disabled by pregnancy related low back and pelvic pain, underwent surgical fixation of the symphysis and sacro-iliac joints after all other conservative treatment had failed. The histological changes of the pubic symphysis of these patients were compared to the symphysis from five women of comparable age, without complaints who died of unnatural causes.

Results

In patients vascular proliferation, callus formation, rupture of fibres, disturbance in the orientation of the fibres, and deposition of fibrinous material were seen. No significant correlations could be detected between any of the pre- and postoperative outcome measures and individual or total histological characteristics. A significant difference between the patients and the control group was found for rupture of fibres, and disturbance in the orientation of the fibres.

Conclusions

In our study degenerative changes of the symphysis pubis were found more often in patients with severe pregnancy related low back and pelvic pain than in control women.

Introduction

Low back and pelvic pain during or after pregnancy is a common complaint and has already been described in 1849 by Cederschjöld[15]. Since a clear distinction based solely on the localisation of the pain is difficult, we have suggested a more descriptive term: pregnancy-related low back and pelvic pain (PLBP)[46]. The reported nine-month prevalence ranges from 32 to 81 %[3;6;8;23;29;37-40]. Fifteen to 36 % of the pregnant women describe their back pain as severe or disabling[8;17;23;29;37].
After childbirth low back pain disappears in most cases within six months spontaneously or after conservative treatment [2;12;16;23;24;32;37-40]. Some patients (circa two percent), however, develop a chronic pain pattern and in a minority the pain persists even after a multidisciplinary rehabilitation program and may cause severe disability[2;5;24;35;36]. Surgical fixation of the pubic symphysis and sacroiliac joints seems to be the only remaining treatment option for these patients.
In our department a study has been conducted to evaluate the results of internal fixation of the pelvis in patients who remained seriously disabled by PLBP after all other conservative treatment had failed. For this highly selected group the preliminary results in terms of pain relief and increased walking distance seem promising[46].

Using radiographs and ultrasound several authors have described a physiological increase in the width and vertical mobility of the pubic symphysis during pregnancy and a decrease after delivery[1;4;7-9;14;20;21;27;34;44]. Some authors reported a relationship between the severity of the pelvic pain and the amount of separation and movement of the symphysis, but this correlation varied widely in literature[1;5;7;11;14;15;22;43;49]. In women with persistent pelvic pain originating from pregnancy or childbirth usually no signs of hypermobility can be found after years of complaints[16;47;48].
Histological changes of the symphysis during and after pregnancy have been described in a number of autopsy studies from the first half of the twentieth century, when mortality during pregnancy and labour was not exeptional[41;42]. During pregnancy oedema of the cartilage, connective tissue hypertrophy and increased vascularisation in the ligaments of the pubic symphysis are reported[13;18;19;25;26;41]. After delivery mechanical damage such as haemorrhage in the symphyseal ligaments or clefts and tears in cartilage and ligaments were seen. In the long term all these traumatic lesions contribute to degenerative changes[13;19;25;41;42]. In these cases, vascular proliferation, callus formation, rupture of fibres, disturbance in the orientation of the fibres, and deposition of fibrinous material have been described[13;19;41]. The relation of these changes with pelvic pain has never been described.

Because the aetiology and pathogenesis of pregnancy related low back and pelvic pain remain unclear and radiological signs are often absent we investigated whether any pathological changes would be present in the tissues of the pubic symphysis. Therefore we analysed the histological findings of the symphysis pubis of patients who underwent surgical fixation of the symphysis and sacroiliac joints for severe pregnancy related low back and pelvic pain.

	Preoperatively		12 months postop		24 months postop	
	mean	SD	mean	SD	mean	SD
Majeed score	37,5	9,6	68,9	12,7	72,8	12,6
VAS for pain	7,4	1,5	3,6	2,1	2,8	1,5
walking distance	N	%	N	%	N	%
0	1	(6.7)	0		0	
< 50	5	(33.3)	0		0	
< 200	7	(46.7)	5	(38.5)	4	(28.5)
< 500	2	(13.3)	2	(15.4)	3	(21.4)
> 500	0		4	(30.1)	5	(35.7)
No restriction	0		2	(15.4)	2	(14.3)
Total	15	(100)	13	(100)	14	(100)
missing	0		2		1	

Table 1 Results of pre- and postoperative tests

Materials and Methods

Between April and December 1997, 15 women with severe PLBP were operated by the senior author (ABvV). Duration of the follow-up period was on average 2.8 years (range 2.0 to 3.5 years, SD 0.48). These were the first patients in a study of which the clinical results are reported earlier[46]. The study was designed as single-group prospective follow-up study for a very selected group of women. Patients were only accepted after failure of all conservative treatment options, including a multidisciplinary rehabilitation program and showed no significant improvement to these measures over the years. The following criteria were obligatory for the diagnosis PLBP[17;32;33;40]: pain in one or both sacroiliac joints which originated during the pregnancy or directly after the delivery and increased during ADL activities and exercise. Two pain provocation tests, posterior pelvic pain provocation test (PPPP) [40] and the active straight leg raising test (ASLR)[33], [30;31]had to be positive. Furthermore the patient had to be severely disabled in mobility and self-care and the last delivery should be at least twelve months ago. Informed consent was obtained. Exclusion criteria were the presence of radiculopathy, and pathology in spine or hip. The study was approved by the institutional review board.
We fixed the symphysis as described by Tile[45]. After an en bloc resection of the joint surfaces of the symphysis with an osteotome and approximation of the pubic bones, two DC plates were placed at 90 degrees. Fixation of both sacroiliac joints was accomplished with two percutaneously placed cannulated titanium screws on each side with one screw in the first and one in the second sacral vertebral body. The clinical outcome of the operation was assessed by completing the following methods of evaluation during intake and follow-up: an adapted version of the Majeed score[28], a visual analogue scale for pain and endurance of walking, sitting and standing.

The histological changes of the pubic symphysis of patients with severe pregnancy related low back and pelvic pain were compared to the symphysis of healthy women. As controls, 5 symphyseal specimens of women who died from unrelated, unnatural causes were obtained from the Netherlands Forensic Institute. These women were of comparable age, and did not have complaints.
The resected pubic symphysis specimens were formalin-fixed, formic acid-decalcified, and paraffin wax-embedded, in accordance with standard laboratory practice and examined following haematoxylin and eosin (H&E) staining.
In the specimens the existence of vascular proliferation, callus formation, rupture of fibres, disturbance in the orientation of the fibres, and deposition of fibrinous material was recorded. We scored only the presence or absence of an item and made no attempt to quantify the appearance.

Results

Average age of the patients was 32.2 (SD 4.03) years. Mean duration of the complaints when patients first visited the outpatient clinic was 3.3 years (SD 1.99). All women were severely impaired in normal daily functioning due to pain in the pelvic region. Three patients (20%) were primiparae, 12 were multiparae (80%).

Table 1 shows the Majeed scores obtained before and after surgery. The mean Majeed score was 37.5 (SD 9.6) preoperatively, and postoperatively 68.9 (SD 12.7) and 72.8 (SD 12.6) at 12 and 24 months respectively. The preoperative and postoperative values for the Majeed score, the visual analogue scale for pain and walking distance are presented in table 1.

Pre-operatively, plain X-rays and stress radiographs according to Chamberlain[10] were made. The width of the symphysis exceeded 5 mm in only one patient. In 10 out of 15 patients movement of the symphysis was more than two millimetres on the Chamberlain stress radiographs. The mean width of the symphysis was 4.2 mm (SD 1.1), the mean vertical mobility was 2.9 mm (SD 1.6).

Macroscopically in one patient a complete pseudo-arthrosis was found. On Chamberlain stress radiographs she had the highest vertical mobility (6 mm). In four other cases an abnormal mobility of the pubic symphysis was described during surgery, all in patients who had more than 2 mm vertical mobility radiographically.

In PLBP patients vascular proliferation was seen in four patients, callus formation in three, rupture of fibres in eight, disturbance in the orientation of the fibres in 13, and deposition of fibrinous material in six out of 15 patients. (Table 2) In figures 1 to 5 the symphyses of five patients are shown with degenerative findings. No significant correlations could be found between any of the pre- and postoperative outcome measures and individual or total histological characteristics.

	No. of patients
vascular proliferation	4
callus formation	3
rupture of fibres	8
disturbance in the orientation of the fibres	13
deposition of fibrinous material	6

Table 2 Histological findings in the symphysis of severe PLBP patients

Mean age of the five control women was 34.8 (SD 6.8) years. The parity was unknown. In the control women disturbance in the orientation of the fibres was seen in one case, and deposition of fibrinous material in another subject. No vascular proliferation, callus and rupture of fibres were found. Figure 6 shows an overview of a completely normal pubic symphysis. Using a Chi-square test a significant difference between the PLBP patients and the control group was found for rupture of fibres ($p = 0.035$), and disturbance in the orientation of the fibres ($p = 0.005$).

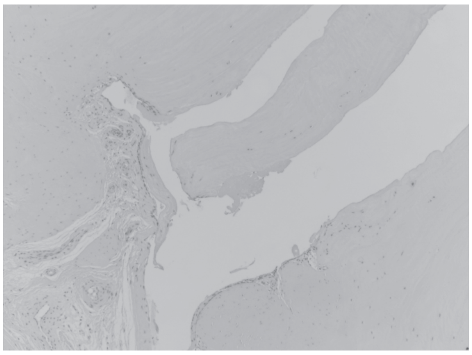


Figure 1 Vascular proliferation

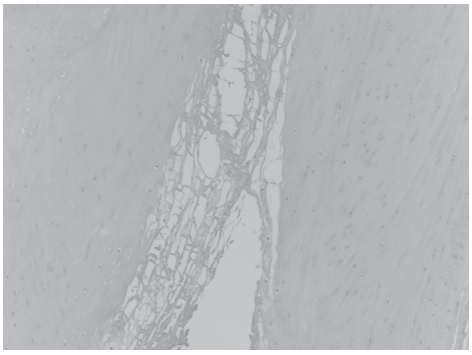


Figure 2 Rupture of fibres

Figure 3 Callus formation

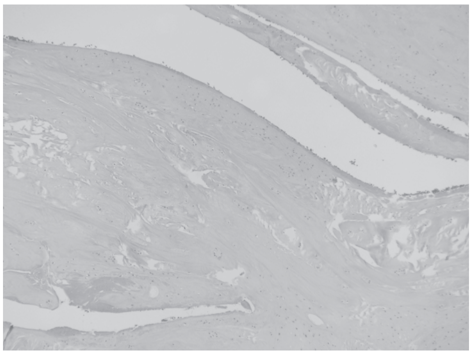


Figure 4 Deposition of fibrinous material

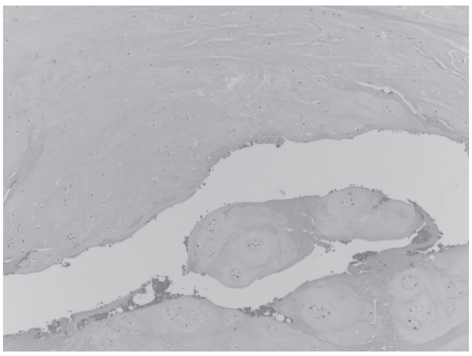


Figure 5 Disturbance in the orientation of the fibres

Discussion

Most of our knowledge about the histological changes of the symphysis and the sacroiliac joint during or after pregnancy dates from the first half of the twentieth century, when mortality during pregnancy and labour was not exceptional. Loosening of the ligaments and cartilage in the pelvic joints during pregnancy and after delivery were already described by Luschka (1854) and Loeschcke (1912)[25;26]. Characteristic changes include oedema and irregular cavities in the cartilage, connective tissue hypertrophy and increased vascularisation in the ligaments in the symphysis[13;18;19;25;26;41]. Loeschcke found these changes as early as the second month of pregnancy and noted that they disappeared shortly after birth[25]. In a comprehensive monograph Putschar considered the most characteristic pregnancy change to be the resorption and remodelling of the posterior margin of the pubic facette in combination with ligamentous hypertrophy, which contributes to the formation of a retropubic eminence[41;42]. According to his observations delivery of a mature infant always causes traumatic damage to the symphysis pubis. The formation of irregular fissures of the fibrous and hyaline cartilage of the symphysis are described[13;18;19;25;41;42]. Furthermore haemorrhage or serosanguineous transsudation into symphyseal ligaments and into the cavity of the cartilage tears are usually present. Ruptures of the bony endplate are also seen[19;25;41;42]. All these traumatic cartilage changes contribute to the disruption, attrition and expulsion of the disc cartilage into the ligaments. Disruption of the continuity of the osteocartilaginous border with herniation of cartilage into the underlying bone, formation of proliferating cartilage nodules, cyst formation, fibrous transformation of the bone marrow and reactive, sometimes sclerotic bone formation is observed[13;19;25;41;42]. Eymer and Haslhofer interpreted these changes in the osteochondral junction as osteo-arthritis deformans[13;18;19]. Degenerative changes are not specific to women who have borne children. There is no sharp border between post-partum changes and early arthritic manifestations seen in men and women without children. However, in women who have been pregnant, the prevalence and the extent of degenerative changes is larger[19;41;42].

In our study, vascular proliferation, callus formation, rupture of fibres, disturbance in the orientation of the fibres, and deposition of fibrinous material were seen more often in PLBP patients than in healthy control women. For rupture of fibres, and disturbance in the orientation of the fibres a significant difference was found. No significant correlations could be detected between any of the pre- and postoperative outcome measures and histological characteristics. One of the limitations of this study is the small number of patients and healthy controls. However, the presence and severity of histological changes in patients with pregnancy related low back and pelvic pain has never been described. In conclusion, degenerative changes of the symphysis pubis were found more often in patients with severe pregnancy related low back and pelvic pain than in control women.

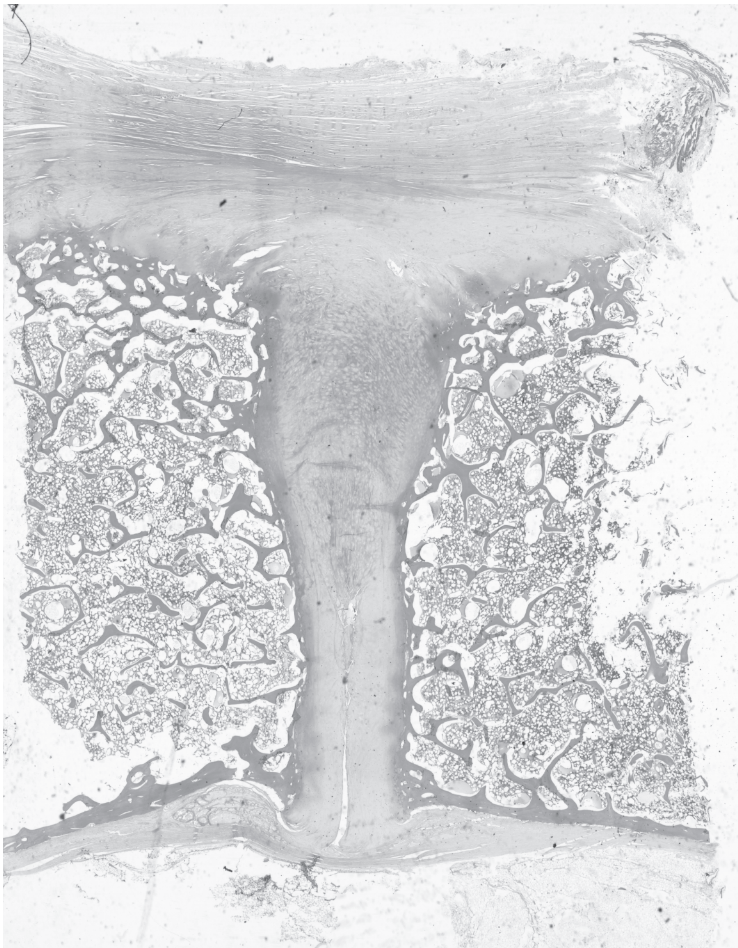


Figure 6 Overview of a completely normal pubic symphysis

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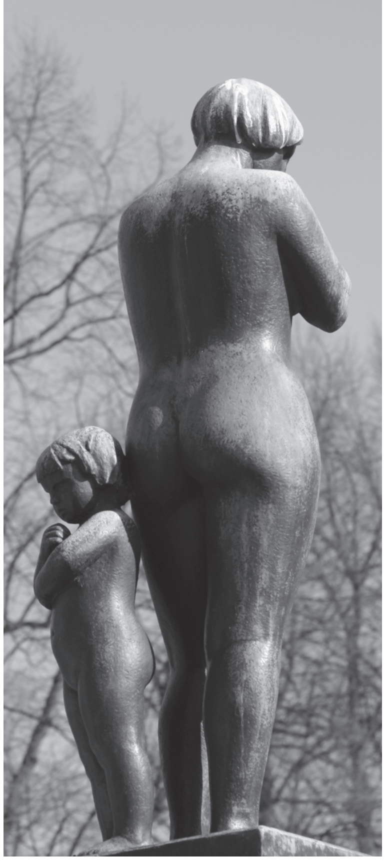
General Discussion



General Discussion

Pain in the pelvic ring during pregnancy or after delivery has already been described in the nineteenth century and approximately 50 % of all pregnant women suffer from pregnancy related low back and pelvic pain. In literature the nomenclature varies widely and no uniform criteria and definitions exist to categorise the complaints. Therefore, the diagnosis pelvic pain is controversial and frequently the complaints are believed to be of psychological origin.

There is much discussion on the pathogenesis and aetiology of pregnancy-related low back and pelvic pain. Some authors reported a general correlation between the severity of the pelvic pain and the amount of separation and movement of the symphysis, but this relationship was not directly proportional. In women with persistent pelvic pain originating from pregnancy or childbirth usually no signs of hypermobility can be found after years of complaints. In our patient population, movement of the symphysis on the Chamberlain stress radiographs did not exceed two mm in 36.2% of the patients. Based on our own biomechanical modelling, we assume that small movements in the sacroiliac joints, even if the mobility is not larger than normal, may cause stress in the joint capsule and ligaments and thus cause pain. Internal fixation is thought to eliminate the loading of vulnerable and injured soft tissue structures surrounding the sacroiliac joint, which can result in relief of pain and improvement of functional impairment.

Surgical fixation of the pubic symphysis and the sacroiliac joints has been developed for pelvic fractures, but in this thesis we investigate the use of these techniques in women suffering from severely disabling pregnancy related low back and pelvic pain after failure of all conservative treatment.

From our biomechanical experiments we can conclude that in completely unstable pelvic (Tile C) fractures the techniques with two screws bridging the sacroiliac joint and the sacral fracture, showed a significantly higher load to failure and rotation stiffness than a single screw in the first sacral vertebral body. As expected the single screw technique was more susceptible to rotation. It can be assumed that the addition of a second screw plays an important part in the prevention of rotation and the overall load to failure. No differences were found between the two techniques utilising two sacroiliac screws (two screws convergingly in the first sacral vertebral body or one screw in the first and one screw parallel in the second vertebral body).
This is in contrast with the results of Simonian and Sagi, who could not discover a significant difference between one and two sacroiliac screws. A possi-

ble explanation is the fact that both authors used different fixations subsequently in one pelvis. On the other hand, in artificial pelves Yinger found that one sacroiliac screw was the least stiff of the fixations tested and two sacroiliac screws showed much greater stiffness.

In the pelvic specimens, we dissected all the muscles and made no attempt to simulate the additional stability of these muscles in order to exclude any unpredictable forces which might influence the measurements. For the same reason the sacral fracture was created with a saw, the smooth fracture surface representing a worst case scenario. We did not simulate the interdigitations seen in sacral fractures, because this would yield a much less reproducible model. Overall this resulted in a situation in which the stability of the fixed fracture depended entirely on the stiffness of the osteosynthesis. In this model, physiological forces could not be reached, however it allowed a biomechanical comparison of the different posterior fixation techniques. In the application of the force we did not try to simulate physiological conditions during one leg stance as closely as possible, but chose an approximation with a better defined (purely cranial) loading direction, which was reproducible.

Significantly more loading cycles before failure could be achieved using two sacroiliac screws compared to one screw. Although 2000 loading cycles equals the steps made in only two days, the results of this study can help to give clinicians a better understanding of the behaviour of pelvic fixations techniques under dynamic loading conditions. This is relevant to make decisions about the choice of fixation technique and the postoperative weightbearing regimen. In a recent study of Schildhauer loaded pelves during 10,000 cycles and reported that failure mainly occurred within the first 1000 cycles, which was in accordance with our own observations. Completely unstable pelvic fractures in the usually osteoporotic bone of embalmed aged pelves could be loaded repeatedly with physiological forces. The fact that the quality (or grip) of the fixation was a significant covariable for longer endurance of the fixation suggests that in the average (young) trauma patient with both anteriorly and posteriorly fixated Tile C fractures direct postoperative weight bearing could be possible if these results are confirmed in prolonged dynamic loading studies using preferably non-osteoporotic pelves. The extrapolation of the results to the clinical situation should be done with caution because of the fact that we used aged embalmed pelves, lacking muscle activity and soft tissue support, loaded in an experimental setting. Unfortunately aged specimens are the only human pelvises available. For young trauma patients absolute values of both stiffness and load to failure are expected to be much greater because of a much better bone density. Although this may alter the absolute data, the relative difference between the techniques is likely to remain the same.

No significant difference could be found between symphyseal plate fixation with or without a sacroiliac screw and the intact pelvis in partially unstable Tile B1 fractures. Forces equal to the upper body weight could be applied. Although we did not examine the fatigue of the fixation, the observed biomechanical stability seems sufficient to examine direct postoperative weight bearing in Tile B fractures in a clinical study. A single sacroiliac screw did not give significant additional stability to anterior plate fixation in Tile B1 fractures. This is in contrast with the findings of Dujardin and Simonian, who described that fixation of the symphysis alone did not reduce motion of the sacroiliac joint and that the combination of anterior and posterior fixation yielded the greatest decrease in movements. On the other hand, MacAvoy and Tile reported that a fixed symphysis can maintain reduction of the sacroiliac joint in a Tile B injury.

Sacroiliac screw fixation has been tested in a biomechanical model representing partial and completely unstable pelvic fractures. For pregnancy-related low back and pelvic pain even a partially stable pelvic fracture is not a suitable model, because the structural integrity of the pelvic ring is intact in PLBP. In a model with an isolated intact sacroiliac joint higher stiffness and less displacement were seen for the technique with two sacroiliac screws compared to the intact non fixated sacroiliac joint. The difference between one screw and the non fixated situation was less marked, but still significant for the translation stiffness. No significant difference could be found between the two screw techniques. This is in contradiction with our findings in *chapter four* in which a sacroiliac screw did not provide additional stability to anterior plate fixation in a partially unstable (Tile B) pelvic injury. An explanation could ben that either the anterior fixation of a complete pelvis prevents posterior displacements exceeding the detection limits of our measuring equipment or that in a Tile B fracture two sacroiliac screws should have been used instead of one to prevent posterior movement sufficiently.
The use of an isolated sacroiliacjoint as a model made comparison between the two screw fixations and the intact situation easier. However, this limits extrapolation of the results to the clinical situation in which the pelvic ring is complete and surrounded by muscles. In our population with people severely disabled from PLBP, the use of aged specimens may not be as far from reality as in trauma patients, because disuse osteopenia is frequently encountered in our patients. To draw conclusions about the biomechanical properties of the sacroiliac joint fixation used in PLBP patients, in vivo measurements should be done in future investigations. Because all currently available, reliable methods to measure sacroiliac joint displacements require invasive procedures, we are developing a non invasive way to determine sacroiliac joint stiffness.

The clinical results of surgical fixation of the complete pelvic ring in severe pregnancy related low back and pelvic pain were described. An improvement was found in terms of pain relief and an increase in Majeed score, walking distance, and ADL functions. This result was remarkable considering the negatively selected patient population with a severe disability and failure of all earlier non-surgical treatment over the years. Possible explanation of this result is that the primary cause of the complaints was eliminated, i.e. the patients inability to stabilise the sacroiliac joint, which in the longer term resulted in a complex pain pattern. The patient population consisted of a highly selected group of women, who were severely disabled and failed to respond to all conservative treatment during the years. Therefore our results should not be generalised to the entire population of PLBP patients. Despite the substantial number of complications which we encountered, reasonably good results were found in this study. These results should be confirmed in a randomised controlled trial, because of the absence of a control group, which is one of the limitations of the study. To improve selection of individuals who will benefit, factors which may predict surgical outcome should be identified in future studies. Only the preoperative Majeed score (a higher preoperative score correlated with a higher postoperative score) and the duration of the complaints (longer duration correlated with a lower postoperative score) proved to be independent predictors of the postoperative Majeed score. Which means that a large improvement did not occur significantly more often in the most disabled women.

When reviewing the complications of sacroiliac screw fixation, none of the patients suffered permanent neurological damage. Positioning both sacroiliac screws in the first sacral vertebral body had a significantly lower risk of nerve injury compared to positioning the lower screw in the second vertebral body. Since no significant biomechanical differences could be found between the two techniques and more complications were encountered with the second method, we advise to place both screws in the first sacral vertebral body. In a few cases anatomical variations such as (hemi)sacralisation or lumbalisation of a vertebra make it impossible to position both screws in the upper sacral vertebral body.

The addition of a lateral radiograph may help to determine the location of the screw in the vertebral body more accurately. Recent computer guided navigation techniques offer the additional advantage of simultaneously displaying all views with decreased fluoroscopy time. In the future CT guided navigation and robotic insertion might give a better three-dimensional understanding of the sacroiliac anatomy combined with more accurate insertion. This may finally result in a lower risk of peroperative neurological damage of the fifth lumbar or first sacral root due to more accurate positioning.

In the symphyseal specimens removed during surgical fixation of the pelvis in these patients with severe pregnancy related low back and pelvic pain, degenerative changes were found more often than in healthy control women. In literature pregnancy related low back and pelvic pain has never been correlated to histological changes. However, histology is only available after definitive fixation of the pubic symphysis and cannot be used as a preoperative diagnostic test.

The aim of this thesis was to investigate the biomechanical properties and safety of different fixation techniques of the pelvic ring and describe the results of surgical fixation of the pubic symphysis and the sacroiliac joints in patients severely disabled by pregnancy related low back and pelvic pain. For a highly selected group of women the preliminary results in terms of pain relief and increased walking distance seem promising. The results should be confirmed in a randomised controlled trial, although ethically it will be difficult to compare conservative treatment and surgical intervention in end-stage disease. Furthermore, clinical research is required to implement the results of the biomechanical investigations in the postoperative regimen for patients with unstable pelvic fractures.

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Summary

Summary

More than half of all pregnant women experience low back and/or pelvic pain of whom one-third has severe complaints. In most cases the pelvic pain disappears within a few months after delivery, either spontaneously or after conservative treatment. In a minority of patients the pain persists even after a multidisciplinary rehabilitation program and may cause severe disability. Some patients may even be wheelchair bound or bedridden. After failure of all conservative treatment, surgical fixation of the pelvic ring may prove one of the last remaining options for those women. Internal fixation of the pelvic ring is commonly used in unstable pelvic fractures. For pregnancy related low back and pelvic pain (PLBP), surgical fixation of the symphysis and sacroiliac joints (SIJ) has only been described in a few case reports and small series.
In this thesis the biomechanical properties of different fixation techniques of the pelvic ring are investigated. Main subject of this thesis is surgical fixation of the pubic symphysis and the sacroiliac joints in patients severely disabled by pregnancy related low back and pelvic pain.

In literature different nomenclature, definitions and classifications are used for pregnancy related low back and pelvic pain. Therefore in *chapter two* the complaints, diagnostic tests and criteria for the diagnosis pregnancy related low back and pelvic pain are discussed to establish the diagnosis pregnancy related low back and pelvic pain. The following criteria were the most constant for the diagnosis PLBP: pain in one or both sacroiliac joints which originated during pregnancy or directly after delivery. The pain may radiate into the legs and is frequently accompanied by pain in the symphyseal region and pain in the groins especially at adduction of the hips. Usually complaints increase during exercise, which may impair Activities of Daily Life (ADL), like walking, climbing stairs, lifting objects and turning over in bed. In severe cases, patients walk with short steps and a waddling gate. The best validated pain provocation tests are the posterior pelvic pain provocation test (PPPP) and the active straight leg raising test (ASLR). The aetiology and pathogenesis of pregnancy-related low back and pelvic pain (PLBP) are subject of debate. Hormonal influences (relaxine) and mechanical effects (pelvic instability, postural changes and trauma) have been proposed as causative factors. A physiological increase in the width and vertical mobility of the pubic symphysis during pregnancy and a decrease after delivery is described. Some authors reported a relationship between the severity of the pelvic pain and the amount of separation and movement of the symphysis, but the strength of the correlation varied widely in literature. Furthermore, a review is given of the conservative and operative treatment options and the different surgical fixation techniques of the pelvic ring.

In *chapter three to six* the results of our in vitro studies into the biomechanical properties of sacroiliac screw fixation are described. In unstable pelvic fractures, sacroiliac screws are one of the most commonly used methods for internal fixation of the posterior pelvic ring and have the advantage of percutaneous placement. In order to determine the stability of different configurations and combinations of sacroiliac screw fixations, cadaveric pelves were loaded in a standardised way. Translation and rotation stiffness of the fixation and the load to failure were measured using a three-dimensional video system. In *chapter three to five* sacroiliac screw fixation was tested in a biomechanical model representing partial and completely unstable pelvic fractures, because in this model the stability of the fixed fracture depended largely on the stiffness of the osteosynthesis, which allowed a better comparison of the different fixation techniques. In pregnancy-related low back and pelvic pain, the structural integrity of the pelvic ring is intact. Therefore we used an intact isolated sacroiliac joint as a model in *chapter six*.
In *chapter three* we compared different configurations of sacroiliac screws in order to find the optimal number and positioning in the sacral vertebral body. In 12 embalmed human pelvises a Tile C pelvic fracture was created, consisting of a symphysiolysis and sacral fractures on both sides. After cutting the pubic symphysis, the left and right sacroiliac joint were loaded separately as baseline measurements. Each of the sacral fractures was fixed with one of the following methods: one sacroiliac screw in the first sacral vertebral body, two screws convergingly in the first sacral vertebral body or one screw in the first and one in the second sacral vertebral body. The pubic symphysis was not stabilised, to limit the influence of the anterior fixation on the comparison of the screw techniques. The stiffness of the intact posterior pelvic ring was superior to any screw technique. The techniques with two screws showed a significantly higher load to failure and rotation stiffness than the moethod with one single screw in the first sacral vertebral body. There were no differences between the two techniques utilising two screws. The addition of a second screw seems to prevent rotation and improves the load to failure.

In *chapter four* we studied whether the stability of partially unstable pelvic fractures can be improved by combining plate fixation of the symphysis with a posterior sacroiliac screw. In 6 specimens a Tile B1 (open book) pelvic fracture was created, by cutting the pubic symphysis and the anterior sacroiliac ligaments. The pelves were loaded intact and after fixation of the fracture to 300 N, avoiding failure levels, and subsequently up to 700 N. The results showed no significant difference between isolated plate fixation and combined plate and sacroiliac screw fixation in either absolute displacements of the symphysis or sacroiliac joints or the stiffness. In addition, movements and stiffness of the fixated pelves were similar to the intact situation. Load to failure was only reached in one of the six cases. In all other cases the fixation of the pelvis to the frame failed before failure of the fixation itself. In these cases a load of about 1000 N or more could be applied. This suggests that the fixation could withstand even higher forces. Generally this is well above the force exerted by the upper body under physiological conditions. The addition of a sacroiliac screw in a Tile B1 fracture does not give significant additional stability and we recommend isolated plate fixation in Tile B1 fractures.

Chapter five describes the stiffness and strength of combined anterior and posterior fixation under dynamic loading conditions in order to see if stability can be maintained in completely unstable (Tile C1) pelvic fractures. In 12 pelvic specimens a symphysiolysis and sacral fracture were created. We compared the intact situation to anterior plate fixation combined with one or two sacroiliac screws. Each pelvis was loaded 2000 times, with a maximum of 400N, in the intact situation and after fixation with one of the two techniques. Furthermore the load to failure and the number of cycles before failure were determined. Translation and rotation stiffness of the intact pelvis were superior to the fixated pelvis. No difference in stiffness was found between the techniques with one or two sacroiliac screws. However a significantly higher load to failure and significantly more loading cycles before failure could be achieved using two sacroiliac screws compared to one screw. A better grip of the screws was a significant predictor of longer endurance of the fixated pelvis during loading. In this study embalmed aged pelves could be loaded repeatedly with a force which equals the upper body weight in adults. The fact that the average trauma patient is younger, suggests that direct postoperative weight bearing could be possible if these results are confirmed in further research.

In *chapter six* we investigated whether 1 or 2 sacroiliac screws supply additional stiffness to the intact sacroiliac joint, in order to make an estimation of the biomechanical properties of surgical stabilisation of the sacroiliac joint in PLBP patients. In 12 hemipelves baseline measurements of the intact sacroiliac joint without fixation were obtained, after which all sacroiliac joints were fixated sequentially with one and with two sacroiliac screws. In 10 cycli each hemipelvis was loaded to a maximum of 400N. For the technique with two screws a significantly higher translation and rotation stiffness and less displacement of the sacroiliac joint were found compared to the baseline. The difference between one screw and the non fixated sacroiliac joint situation was less marked, but still significant for the translation stiffness. The rotation stiffness however showed no difference between one sacroiliac screw and the baseline. No significant difference could be found between the two screw techniques.

In *chapter seven* we report on the functional outcome of internal fixation of the pelvic ring in a group of 58 patients suffering from severe pregnancy-related low back and pelvic pain in whom all conservative treatment has failed. Results were prospectively evaluated with the Majeed score, and endurance of walking, sitting and standing. The surgical technique consisted of a symphysiodesis and bilateral percutaneous placement of two sacroiliac screws under fluoroscopic guidance. With a follow-up of on average 2.1 years, the difference between pre- and postoperative Majeed score indicated that an improvement of over 10 points was achieved in 69.8 % and 89.3% of the patients at 12 and 24 months respectively. Furthermore, a significant increase was found in walking distance, endurance of sitting and standing and all Majeed score items (pain, work, sitting, sexual intercourse, walking aids, gait unaided and walking distance). Improvement in mobility implied that of the 20 women who were wheelchair-bound and of the eight women who were bedridden before the operation, only four of the first group and four of the latter were using a wheelchair. The most important complications were irritation of nerve roots (8.6 %), non union of the symphysis (15.5 %), failure of the symphyseal plate (3.4 %) and pulmonary embolism (1.7 %). In this preliminary study surgical fixation of the pelvic ring yielded satisfactory results in severe PLBP patients in terms of pain relief, and improvement in ADL functions, although these results should be confirmed in a randomised clinical trial.

Malpositioning of sacroiliac screws may lead to serious neurological complications due to intrusion of the screws in the sacral foramina or vertebral canal. In *chapter eight* the safety of sacroiliac screw positioning using peroperative inlet and outlet fluoroscopy is assessed. We compared the correlation between screw position on peroperative fluoroscopy, postoperative radiographs and postoperative CT scan. The radiographs, CT scan and charts from 88 patients, in whom the posterior pelvic ring was stabilised for several indications, were reviewed retrospectively. Seven of the 88 patients had neurological complaints and were reoperated. All complaints resolved completely and no permanent neurological damage occurred. Positioning both sacroiliac screws in the first vertebral body had a significantly lower rate of neurological complaints compared to positioning the lower screw in the second vertebral body. Malpositioning on CT scan correlated most accurately with neurological complaints, while no correlation between peroperative position and neurological deficit was found. 285 screws were reviewed and, depending on the type of imaging (X-ray or CT scan) 2.1% to 6.8% of the screw showed malpositioning. In several cases the malpositioned screws did not cause any complaints. Postoperative radiographs did not show to have any additional value above peroperative radiographs. In conclusion, percutaneous sacroiliac screws can be positioned safely, in experienced hands, without permanent neurological injury.

In *chapter nine* the histological findings of the symphysis pubis of patients with severe pregnancy related low back and pelvic pain are analysed. Traumatic and degenerative changes of the pubic symphysis during and after pregnancy have been described in a few autopsy studies from the first half of the twentieth century, when mortality during pregnancy and labour was not exceptional. The relation of these changes with pelvic pain has never been described. A group of 15 women, who were seriously disabled by pregnancy related low back and pelvic pain, underwent internal fixation of the pubic symphysis and sacroiliac joints after all other conservative treatment had failed. These were the first patients of the study described in chapter seven. The histological changes of the symphyseal specimens removed during surgical fixation of these patients were compared to the symphysis of five healthy women. Vascular proliferation, callus formation, rupture of fibres, disturbance in the orientation of the fibres, and deposition of fibrinous material were seen in patients. A significant difference between the patients and the control group was found for rupture of fibres, and disturbance in the orientation of the fibres. No significant correlations could be detected between any of the pre- and postoperative outcome measures and individual or total histological characteristics. In conclusion, degenerative changes of the symphysis pubis were found more often in patients with severe pregnancy related low back and pelvic pain than in control women.

Finally, recommendations for further research are given in *chapter ten*. For a highly selected group of women, severely disabled by pregnancy related low back and pelvic pain, the results of surgical fixation of the pelvic ring seem promising in terms of pain relief and increased walking distance. However, these results should be confirmed in a randomised controlled trial. Furthermore, tests with prolonged dynamic loading and clinical studies are required to implement the results of the biomechanical investigations in the postoperative weight bearing regimen for patients with unstable pelvic fractures. In the future, CT guided navigation and robotic insertion may result in a lower risk of peroperative neurological damage due to more accurate positioning of sacroiliac screws.

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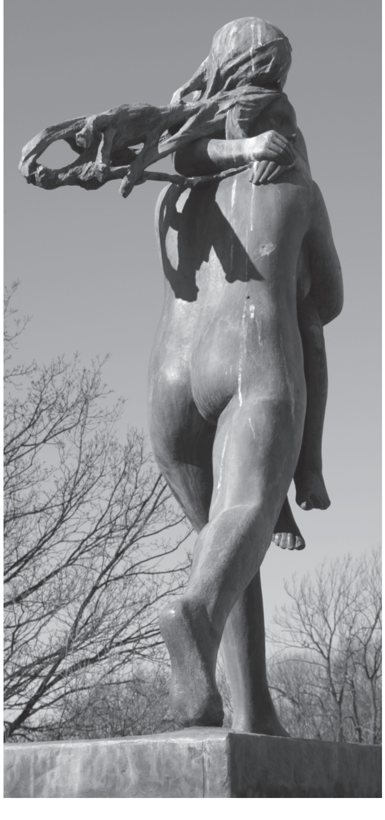
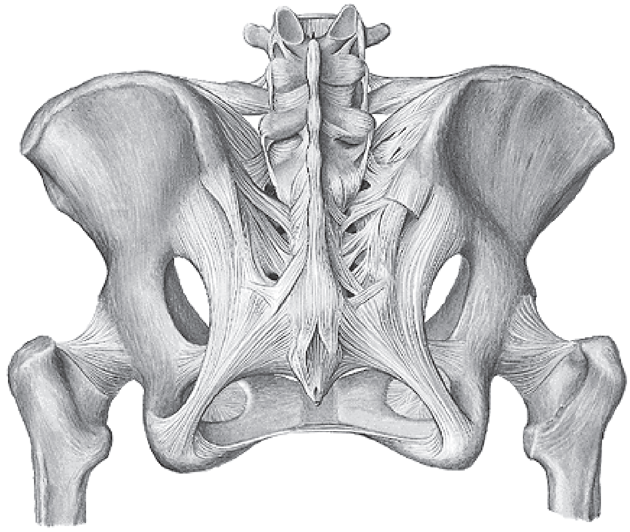
Nederlandse samenvatting



Nederlandse samenvatting

Pijn in het bekken tijdens de zwangerschap of na de bevalling werd al beschreven in de verloskundige literatuur van de negentiende eeuw. Meer dan de helft van alle vrouwen heeft last van zwangerschapsgerelateerde pijn in de lage rug en/of het bekken, van wie ongeveer een derde ernstige klachten heeft, die interfereren met de dagelijkse activiteiten. In de meeste gevallen verdwijnt de bekkenpijn binnen een paar maanden na de bevalling, spontaan of na behandeling met een bekkenband en/of fysiotherapie. Een minderheid van de patiënten houdt klachten zelfs na een multidisciplinair revalidatie programma. Sommige van deze patiënten zijn rolstoelgebonden of bedlegerig. Wanneer bij ernstig geïnvalideerde patiënten geen verbetering optreedt na alle conservatieve behandelingsmogelijkheden, lijkt operatieve fixatie van de gewrichten in het bekken de enige overgebleven optie. Interne fixatie van de bekkenring wordt gewoonlijk toegepast bij bekkenbreuken. Voor zwangerschapsgerelateerde pijn in lage rug en bekken, is deze operatie alleen beschreven in een paar kleine patiëntenseries.
Gezien de sterke variatie in naamgeving, criteria en definities in de literatuur, is de diagnose controversieel en beschouwen sommigen de klachten als psychologisch van origine. Gebaseerd op het biomechanisch model van het bekken dat uit eerder onderzoek ontwikkeld is, nemen we aan dat de pijn gerelateerd is aan de mechanica van het sacroiliacale gewricht en omringende gewrichtsbanden en -kapsels. Door middel van interne fixatie wordt de belasting van kwetsbare en beschadigde banden en weke delen verminderd. Het onderwerp van dit proefschrift betreft de resultaten van chirurgische fixatie van de symphyse en de sacroiliacale gewrichten bij patiënten die ernstig geïnvalideerd zijn door zwangerschapsgerelateerde pijn in lage rug en bekken en niet gereageerd hebben op conservatieve behandeling. Verder worden de biomechanische eigenschappen van verschillende fixatie technieken van de bekkenring beschreven.

Anatomisch bestaat het bekken uit een benige ring die de beide benen met de romp verbindt. De bekkenring wordt gevormd door het heiligbeen (sacrum) dat aan de achterkant met de twee darmbeenderen (ilium) verbonden is door middel van het sacroiliacale gewricht. De twee darmbeenderen zijn aan de voorkant met elkaar verbonden bij de symphyse. Om de gewrichten heen zit een gewrichtskapsel en diverse bindweefselbanden (ligamenten) die voor stevigheid zorgen.
Botbreuken (fracturen) van het bekken worden ingedeeld in verschillende klassen, geordend naar de mate van stabiliteit van het bekken. De classificatie volgens Tile onderscheidt drie typen. Bij een type A letsel is de ring die de

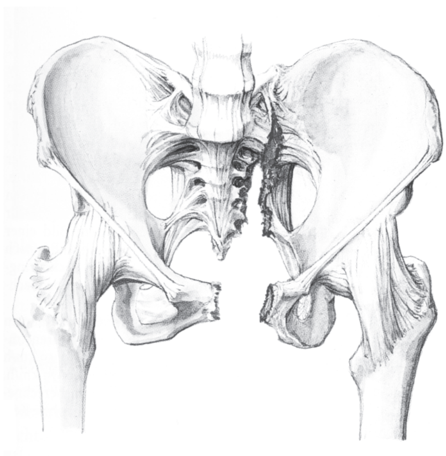


Figuur1 De anatomie van het bekken in een achteraanzicht

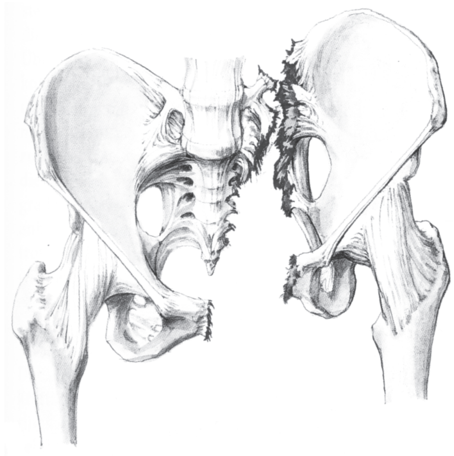
stevigheid van het bekken bepaalt, niet onderbroken. Bij type B is door een botbreuk of het afscheuren van banden bij de symphyse (symphysiolyse) sprake van beperkte instabiliteit in het horizontale vlak. Een veel voorkomende verwonding is het "open boek" letsel waarbij het bekken als een boek aan de voorzijde geopend kan worden. Bij type C is er niet alleen instabiliteit in het horizontale, maar ook in het verticale vlak. De verschillende botstukken kunnen door een botbreuk of schade aan de banden in alle richtingen ten opzichte van elkaar bewegen.

Er zijn veel verschillende operatietechnieken voor de behandeling van bekkenbreuken. De techniek die in dit proefschrift wordt onderzocht bestaat uit een operatie waarbij aan de voorzijde van het bekken de symphyse bij elkaar wordt gehouden door een plaat met schroeven. Dit wordt gecombineerd met één of meerdere schroeven die aan de achterzijde door het ilium in het wervellichaam van het sacrum worden gebracht. Onder geleide van röntgenfoto's voor nauwkeurige positiebepaling worden deze schroeven percutaan geplaatst, dat wil zeggen door een kleine snee in de huid van de bilregio. Allereerst wordt een dunne geleidedraad geboord om de positie te bepalen en vervolgens wordt hier overheen een holle schroef gedraaid. Het grootste gevaar van het inbrengen van de schroeven aan de achterzijde is beschadiging van de zenuwen die aan het ruggenmerg ontspringen, in het wervelkanaal liggen, uit het heiligbeen naar buiten komen en naar de benen toe lopen. Het raken van deze zenuwen kan pijn, gevoelsverlies of krachtsverlies tot gevolg hebben.

In de literatuur worden verschillende nomenclatuur, definities en classificaties gebruikt voor zwangerschapsgerelateerde pijn in lage rug en bekken. In *hoofdstuk twee* wordt eerst een beschrijving gegeven van de klachten en onderzoeken die nodig zijn om de diagnose te kunnen stellen. Pijn in één of beide sacroiliacale gewrichten, ontstaan tijdens de zwangerschap of vlak na de bevalling wordt meestal genoemd als belangrijkste kenmerk. De pijn kan uitstralen in de benen en gaat vaak gepaard met pijn in de regio van de symphyse en in de liezen, met name bij het naar elkaar toe bewegen van de benen. Meestal verergert de pijn bij inspanning, hetgeen de activiteiten van het dagelijks leven kan bemoeilijken, zoals lopen, de trap op gaan, iets optillen en omdraaien in bed. In ernstige gevallen lopen de patiënten met kleine stapjes en een waggelende gang. De best onderzochte en meest valide diagnostische onderzoeken zijn de tests waarbij geprobeerd wordt de pijn met een bepaalde manoeuvre op te wekken. Bij de "*posterior pelvic pain provocation test*" drukt de onderzoeker bij een liggende patiënt op het in de heup en knie gebogen bovenbeen om spanning over te brengen op het bekken. Voor de "*active straight leg raising test*" wordt aan de patiënte gevraagd de benen na elkaar gestrekt op te tillen van de onderzoeksbank.



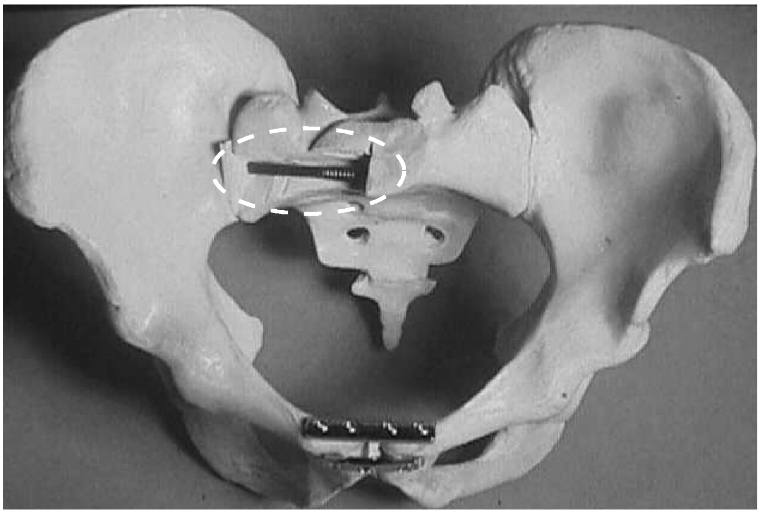
Figuur 2a Tile B (open boek) letsel
de banden van de symphyse en aan de voorzijde van het sacroiliacale gewricht zijn gescheurd. Doordat de achterste sacroiliacale ligamenten nog intact zijn, is er alleen instabiliteit in het horizontale vlak, waarbij het bekken aan de voorzijde "openklapt".



Figuur 2b Tile C letsel
alle banden van de symphyse en het sacroiliacale gewricht zijn afgescheurd. Er is niet alleen instabiliteit in het horizontale, maar ook in het verticale vlak, waarbij de botstukken alle richtingen ten opzichte van elkaar kunnen bewegen.

De oorzaak van zwangerschapsgerelateerde pijn in lage rug en bekken is onderwerp van discussie. Hormonale invloeden tijdens de zwangerschap (relaxine) en mechanische effecten (instabiliteit van het bekken, houdingsveranderingen en traumatische beschadigingen van de gewrichten van het bekken) zijn genoemd als oorzakelijke factoren. Gedurende een normaal verlopende zwangerschap wordt een toename in de breedte en beweeglijkheid van de symphyse gevonden. Sommige auteurs beschrijven een verband tussen de ernst van de pijn in het bekken en de mobiliteit van de symphyse, maar dit is geen sterke correlatie. Bij vrouwen met persisterende bekkenpijn ontstaan tijdens de zwangerschap kan meestal geen vergrote beweeglijkheid van de bekkengewrichten meer gevonden worden als de klachten al jaren bestaan. In onze eigen patiëntengroep was de beweeglijkheid van de symphyse bij ooievaarsopnamen (röntgenfoto's waarbij de patiënt op één been staat) in 36.2% van de patiënten niet groter dan 2 mm.
Tenslotte wordt een overzicht gegeven van de diverse conservatieve en operatieve behandelingsmogelijkheden en de verschillende chirurgische fixatietechnieken van de bekkenring.

In *hoofdstuk drie tot zes* worden de resultaten van de laboratoriumonderzoeken beschreven naar de biomechanische eigenschappen van schroeffixatie van de sacroiliacale gewrichten. Sacroiliacale schroeven zijn één van de meest gebruikte methoden voor fixatie van de achterzijde van het bekken in instabiele bekkenfracturen en hebben als grote voordeel dat ze percutaan, via een klein sneetje geplaatst kunnen worden. Om de stabiliteit van verschillende configuraties en combinaties van sacroiliacale schroeffixaties te bepalen, werden kadaverbekkens belast op een gestandaardiseerde manier. De stijfheid (weerstand tegen verschuiving en draaiing) en sterkte van de fixatie werden driedimensionaal gemeten met een videosysteem. Van de bekkens werden alle spieren verwijderd en vervolgens werden ze met een klem vastgemaakt aan een buizenframe waarin een verticale kracht door middel van een touw over een katrolsysteem werd aangebracht. De breuk werd met een zaag gemaakt omdat het nabootsen van de gekartelde rand van een botbreuk een veel minder goed reproduceerbare situatie op zou leveren. In *hoofdstuk drie tot vijf* testten we sacroiliacale schroeven in een model waarin geheel en gedeeltelijk instabiele bekken fracturen gesimuleerd werden. Aangezien in dit model de stabiliteit grotendeels afhing van de stijfheid van de fixatie, konden de verschillende technieken onderling beter vergeleken worden. Bij zwangerschapsgerelateerde pijn in de lage rug en/of het bekken is de bekkenring anatomisch gezien intact. Daarom hebben we in *hoofdstuk zes* een geïsoleerd intact sacroiliacaal gewricht als model gebruikt.
Het extrapoleren van de resultaten naar de klinische situatie moet heel voorzichtig gebeuren, aangezien we gebalsemde preparaten van ouderen



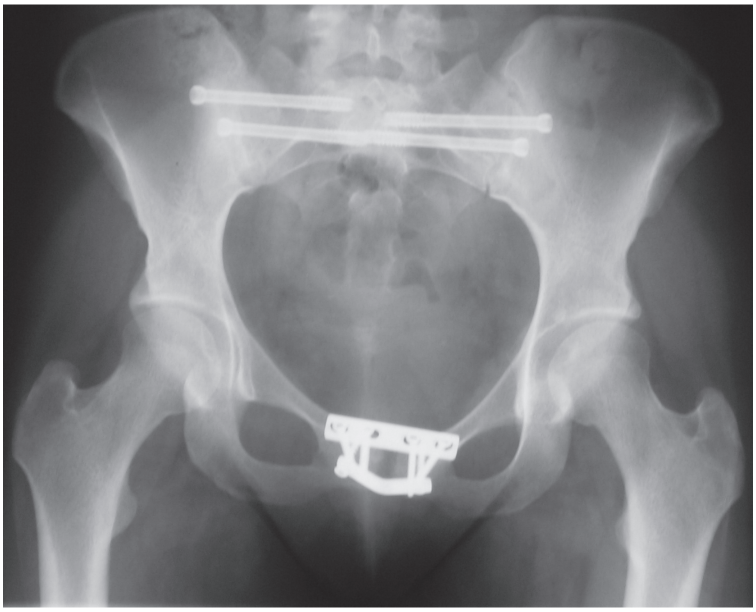
Figuur 3
In dit kunststof bekkenmodel is aan de voorzijde de symphyse gefixeerd met twee platen. Aan de achterzijde is in het sacrum (heiligbeen) een luikje gemaakt om de omcirkelde sacroiliacale schroef te tonen.

hebben gebruikt zonder simulatie van de spierkracht. Voor experimenten zijn alleen de bekkens van ouderen beschikbaar die vrijwel allemaal in meer of mindere mate last hebben van botontkalking. Bij jongere patiënten is te verwachten dat zowel de stijfheid als de sterkte van de fixatie groter zouden zijn door een grotere botdichtheid. Dit kan de absolute waarden van de data veranderen, maar het relatieve verschil tussen de technieken blijft zeer waarschijnlijk hetzelfde.

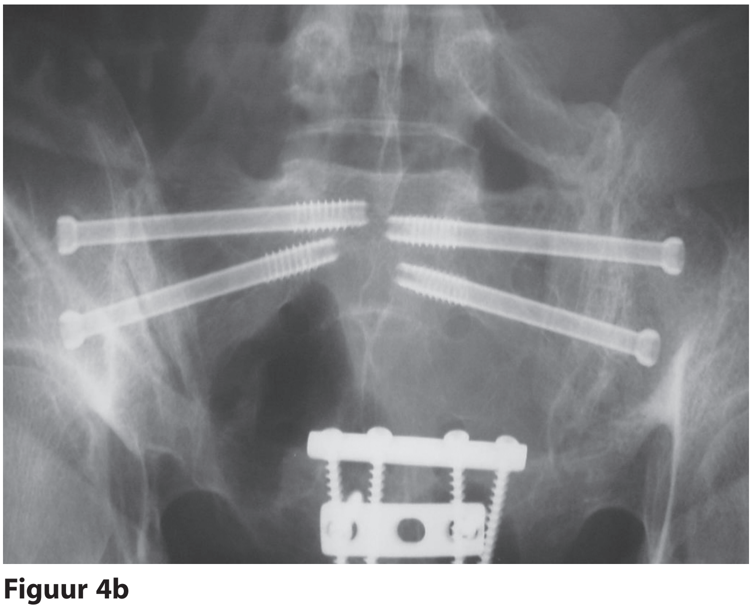
In *hoofdstuk drie* vergeleken we verschillende configuraties van sacroiliacale schroeven om het optimale aantal en de beste positie in de eerste wervel van het heiligbeen te bepalen. In 12 menselijke kadaverbekkens werd een Tile C bekkenbreuk gecreëerd die bestaat uit een symphysiolyse en breuken van het sacrum aan beide kanten. Bij een Tile C bekkenbreuk zijn zowel de voorzijde als de achterzijde van de bekkenring onderbroken, hetgeen leidt tot instabiliteit waarbij de breukvlakken zowel kunnen schuiven als draaien ten opzichte van elkaar. Na het doorsnijden van de symphyse werden het intacte rechter en linker sacroiliacale gewricht afzonderlijk belast als uitgangsmeting. Elk van de sacroiliacale breuken werd gefixeerd met één van de volgende methoden: één sacroiliacale schroef in het eerste sacrale wervellichaam, twee sacroiliacale schroeven convergerend in het eerste sacrale wervellichaam of één schroef in het eerste en één schroef parallel in het tweede sacrale wervellichaam. De symphyse werd niet gestabiliseerd om de invloed van de fixatie aan de voorzijde van het bekken op de vergelijking van de schroeftechnieken te beperken. De stijfheid van de intacte achterzijde van de bekkenring was groter dan die van alle fixatietechnieken. De methoden met twee sacroiliacale schroeven waren significant sterker en beter bestand tegen draaibewegingen dan de techniek met één schroef. Er konden geen verschillen gemeten worden tussen de twee technieken met twee schroeven. De toevoeging van een tweede schroef lijkt draaiing van de breukvlakken te voorkomen en de sterkte te verbeteren.

In *hoofdstuk vier* bestudeerden we of de stabiliteit van gedeeltelijk instabiele bekkenbreuken verbeterd kan worden door fixatie van de symphyse met een plaat te combineren met sacroiliacale schroeffixatie aan de achterzijde van het bekken. In zes kadaverbekkenpreparaten maakten we een Tile B bekkenbreuk. De Tile B bekkenbreuk is alleen instabiel voor draaiing zonder verticale instabiliteit en staat ook bekend als "open boek" breuk, waarbij het bekken door druk van de voorzijde als het ware opengeklapt is. De breuk werd gecreëerd door de symphyse en de banden aan de voorzijde van één sacroiliacaal gewricht door te snijden. De bekkens werden belast, eerst in de intacte situatie en vervolgens na fixatie, met een gewicht van 30 kg, om te voorkomen dat het bekken permanent beschadigd zou worden en later tot 70 kg. De resultaten lieten geen significant verschil zien tussen alleen plaatfixatie van de symphyse en gecombineerde plaat en sacroiliacale schroeffixatie wat betreft de absolute verplaatsingen van de symphyse en de sacroiliacale gewrichten, of de stijfheid van het ilium ten opzichte van het sacrum. Daarbij waren de verplaatsing en stijfheid van de gefixeerde bekkens gelijk aan de beweeglijkheid van het intacte bekken. Slechts in één van de zes bekkens werd de sterkte van de fixatie bereikt. In de andere gevallen kwam het bekken los van het frame waaraan het bevestigd was vóór de fixatie zelf kapot ging, waarbij de bekkens werden belast tot ongeveer 100 kg of meer. Dit suggereert dat de fixatie zelf nog grotere krachten zou kunnen weerstaan. In het algemeen bevindt deze belasting zich boven de kracht die onder normale omstandigheden door het bovenlichaam op het bekken wordt uitgeoefend. De toevoeging van een sacroiliacale schroef in een Tile B1 fractuur geeft geen extra stabiliteit en we adviseren in Tile B1 fracturen alleen de symphyse te fixeren met een plaat.

Hoofdstuk vijf beschrijft de stijfheid en sterkte van gecombineerde fixatie aan de achter- en voorzijde van het bekken onder dynamische belasting om te onderzoeken of de stabiliteit gehandhaafd kan blijven in volledig instabiele (Tile C1) bekkenfracturen. In 12 bekkenpreparaten werden een symphysiolysis en sacrale fractuur gemaakt. We vergeleken de intacte situatie met fixatie door middel van een symphyseplaat gecombineerd met één of twee sacroiliacale schroeven. Elk bekkenpreparaat werd 2000 keer belast, tot een maximum van 40 kg, in de intacte situatie en na fixatie met één van de twee technieken.



Figuur 4a
Röntgenfoto van het bekken van een patïent bij wie de sacroiliacale schroeven parallel aan elkaar in het eerste en tweede wervellichaam van het sacrum geplaatst zijn.



Figuur 4b
Röntgenfoto van het bekken van een patïent bij wie de sacroiliacale schroeven convergerend in het eerste wervellichaam van het sacrum geplaatst zijn.

Daarnaast werden de sterkte en het aantal belastingscycli voor falen van de fixatie bepaald. De stijfheid van het intacte bekken was groter dan die van het bekken na fixatie van de fractuur. Er werd geen verschil in stijfheid gevonden tussen de technieken met één en twee sacroiliacale schroeven. Wel bestond er een significant grotere sterkte en konden meer cycli voor falen van de fixatie bereikt worden bij de techniek met twee sacroiliacale schroeven in vergelijking met de methode met één schroef. Een betere grip van de schroeven in het bot had een significante voorspellende waarde voor langere weerstand tegen belasting. In dit onderzoek konden gebalsemde bekkens van oudere mensen herhaaldelijk belast worden met een kracht die gelijk is aan het gewicht van het bovenlichaam bij volwassenen. Het feit dat de grip van de schroeven in het bot een goede voorspelling gaf van het aantal cycli dat een bekken belast kon worden en dat de gemiddelde traumapatiënt jonger is, suggereert dat directe postoperatieve belasting mogelijk zou kunnen zijn als deze resultaten bevestigd worden in verder onderzoek met langdurige dynamische belasting. Hoewel 2000 belastingscycli ongeveer gelijk staat met het aantal passen dat iemand in twee dagen maakt, geeft het resultaat artsen toch een idee van het gedrag van de bekkenfixatie onder dynamische belasting. Dit is van belang voor het nemen van beslissingen over het postoperatieve mobilisatieschema.

In de vorige hoofdstukken werd sacroiliacale schroeffixatie getest in biomechanische modellen van geheel en gedeeltelijk instabiele bekkenfracturen. Zelfs een gedeeltelijk instabiele bekkenfractuur is geen goed model voor zwangerschapsgerelateerde pijn in lage rug en bekken, omdat bij deze patiënten het bekken anatomisch intact is. In *hoofdstuk zes* onderzochten we of één of twee sacroiliacale schroeven additionele stevigheid geven aan het intacte sacroiliacale gewricht om een schatting te maken van de biomechanische eigenschappen van chirurgische stabilisatie van het sacroiliacale gewricht in patiënten met zwangerschapsgerelateerde pijn in lage rug en bekken. In 12 halve bekkens deden we uitgangsmetingen van het intacte sacroiliacale gewricht zonder fixatie, waarna alle sacroiliacale gewrichten achtereenvolgens gefixeerd werden met één en twee sacroiliacale schroeven. In tien cycli werd elk halve bekkenpreparaat belast tot een maximum van 40 kg. Voor de techniek met twee schroeven werd een significant hogere stijfheid en minder verplaatsing van het sacroiliacale gewricht gezien in vergelijking met de uitgangsmetingen. Het verschil tussen één schroef en het niet-gefixeerde sacroiliacale gewricht was minder groot, maar nog significant voor de weerstand tegen verschuiving. De weerstand tegen draaiing liet geen verschil zien tussen fixatie met één sacroiliacale schroef en de uitgangsmeting. Er kon geen significant verschil gevonden worden tussen de twee verschillende schroeftechnieken. Deze resultaten zijn in tegenspraak met de bevindingen in *hoofdstuk vier* waarin één sacroiliacale schroef geen toegevoegde stabiliteit

gaf aan plaatfixatie van de symphyse in een gedeeltelijk instabiele bekkenfractuur.
Bij patiënten met ernstige zwangerschapsgerelateerde pijn in lage rug en bekken is het gebruik van bekkens van ouderen niet zo ver van de praktijk als bij traumapatiënten, aangezien kalkarmoede van de botten door weinig lichaamsbeweging vaak voorkomt bij deze patiëntengroep. Voor definitieve conclusies over de biomechanische eigenschappen van de sacroiliacale fixatie in patiënten met zwangerschapsgerelateerde pijn in lage rug en bekken moeten metingen gedaan worden bij patiënten. Aangezien alle methoden om verplaatsingen van de sacroiliacale gewrichten te meten invasieve procedures vereisen, wordt er gewerkt aan een manier om de stijfheid van het gewricht te bepalen.

In *hoofdstuk zeven* rapporteren we de functionele resultaten van interne fixatie van de bekkenring in een groep van 58 patiënten met ernstige klachten van zwangerschapsgerelateerde pijn in lage rug en bekken die niet verbeterd waren na conservatieve behandeling. De resultaten werden prospectief geëvalueerd met de Majeed score en met de duur van lopen, zitten en staan zonder ernstige toename van pijnklachten. De chirurgische techniek bestond uit een symphysiodese en het beiderzijds plaatsen van twee percutane sacroiliacale schroeven onder röntgengeleide. Met een follow-up van gemiddeld 2.1 jaar was na respectievelijk 12 en 24 maanden in 69.8% en 89.3% van de patiënten een verbetering te zien van het verschil tussen de pre- en postoperatieve Majeed score. Daarnaast werd een significante verbetering gevonden in de loopafstand, de duur van zitten en staan zonder pijn en alle items van de Majeed score (pijn, werk, zitten, seksueel, hulpmiddelen bij lopen, looppatroon zonder steun en loopafstand). De verbetering in mobiliteit hield in dat van de 20 vrouwen die rolstoelgebonden en van de acht vrouwen die bedlegerig waren voor de operatie, slechts vier uit de eerste en vier uit de tweede categorie nog een rolstoel nodig hadden. De belangrijkste complicaties waren irritatie van de zenuwwortels van het sacrum (8.6%), niet aan elkaar groeien van de botten van de symphyse (15.5%), breuk van de symphyseplaat (3.4%) en longembolie (1.7%). In deze studie werden redelijk goede resultaten verkregen met chirurgische fixatie van de bekkenring bij patiënten met ernstige zwangerschapsgerelateerde pijn in lage rug en bekken wat betreft pijnvermindering en verbetering van de activiteiten van het dagelijks leven. Een beperking van het onderzoek is de afwezigheid van een controlegroep. De resultaten van dit onderzoek moeten daarom nog bevestigd worden in een vergelijkend klinisch onderzoek. De patiënten uit de studie waren een zeer sterk geselecteerde groep vrouwen, die ernstig geïnvalideerd waren en niet verbeterden na alle conservatieve behandeling gedurende de jaren. Daarom mogen deze resultaten niet gegeneraliseerd worden naar de gehele patiëntenpopulatie. De resultaten van de operatie zijn opvallend gezien de negatieve selectie van patiënten. Ter verbetering van de selectie van individuen die baat zullen hebben bij een operatie, moeten in volgende studies factoren geïdentificeerd worden die de chirurgische uitkomst voorspellen.

Verkeerd positioneren van de sacroiliacale schroeven kan leiden tot ernstige neurologische complicaties door plaatsing in de sacrale foramina (openingen in het heiligbeen waar de zenuwen door naar buiten komen) of in het wervelkanaal. In *hoofdstuk acht* wordt de veiligheid van het plaatsen van sacroiliacale schroeven met peroperatieve "inlet en outlet" röntgenfoto's bekeken. We vergeleken de correlatie tussen de schroefpositie op de foto's gemaakt tijdens de operatie, na de operatie en op de CT scan na de operatie. De röntgenfoto's, CT scan en statussen werden nagekeken van 88 patiënten, die chirurgische stabilisatie van de achterzijde van het bekken hadden ondergaan op verschillende indicaties. Zeven van de 88 patiënten hadden neurologische klachten en werden opnieuw geopereerd. Alle klachten verdwenen volledig en er trad geen permanente neurologische schade op. Bij positioneren van beide sacroiliacale schroeven in het eerste sacrale wervellichaam traden significant minder neurologische klachten op dan wanneer de onderste schroef in de tweede sacrale wervel geplaatst werd. Malpositie op de CT scan correleerde het beste met neurologische klachten en er werd geen correlatie gevonden tussen de schroefpositie op de peroperatieve röntgenfoto's en neurologische schade. 285 schroeven werden nagekeken en afhankelijk van het soort foto (röntgenfoto of CT scan) was 2.1% tot 6.8% van de schroeven niet goed gepositioneerd. In verschillende gevallen veroorzaakten de niet goed geplaatste schroeven geen klachten. Postoperatieve röntgenfoto's hadden geen toegevoegde waarde boven peroperatieve röntgenfoto's. Concluderend kunnen percutane sacroiliacale schroeven door een ervaren chirurg geplaatst worden zonder groot risico op permanente neurologische schade. Aangezien bij het plaatsen van beide schroeven in het eerste sacrale wervellichaam minder neurologische klachten optraden dan met de onderste schroef in de tweede sacrale wervel en er biomechanisch geen significant verschil te vinden was tussen beide technieken, adviseren wij beide schroeven in de eerste sacrale wervel te positioneren. De toevoeging van een zuiver laterale röntgenopname zou kunnen helpen de exacte locatie van de schroef in het wervellichaam nauwkeuriger te bepalen. In de toekomst zouden CT-geleide navigatie en plaatsing van de schroeven met een robotarm kunnen bijdragen aan het verlagen van het complicatierisico.

In *hoofdstuk negen* beschreven wij het histologisch onderzoek, waarbij het weefsel van de symphyse bij patiënten met ernstige zwangerschaps-gerelateerde pijn in lage rug en bekken onder de microscoop bekeken werd.

Traumatische en degeneratieve afwijkingen van de symphyse tijdens en na de zwangerschap zijn beschreven in een aantal autopsiestudies uit de eerste helft van de twintigste eeuw, toen overlijden tengevolge van zwangerschap en bevalling niet zeldzaam was. De relatie van deze veranderingen met pijn in het bekken is nog nooit beschreven. Een groep van 15 vrouwen die ernstig geïnvalideerd waren door zwangerschapsgerelateerde pijn in lage rug en bekken, onderging interne fixatie van de symphyse en sacroiliacale gewrichten. Dit waren de eerste patiënten van de studie die beschreven wordt in *hoofdstuk zeven*. De histologische veranderingen in het weefsel van de symphyse dat verwijderd werd tijdens chirurgische fixatie bij deze patiënten werd vergeleken met de symphyse van vijf gezonde vrouwen. In de patiënten werden de volgende kenmerken gezien: vaatproliferatie (uitgroei van kleine bloedvaatjes), vorming van callus (littekenweefsel van het bot), ruptuur (breuk) van vezels, verstoring van het vezelverloop en de afzetting van vezelachtig materiaal. Een significant verschil tussen de patiënten en de controle groep werd gevonden voor ruptuur van vezels en verstoring van het vezelverloop. Er kon geen correlatie worden aangetoond tussen de pre- en postoperatieve effectmaten en histologische kenmerken. Concluderend werden degeneratieve veranderingen van de symphyse vaker gevonden in patiënten met ernstige zwangerschapsgerelateerde pijn in lage rug en bekken dan in controles. De aanwezigheid van herkenbare histologische veranderingen is opvallend aangezien er geen uniforme syndroomcriteria en specifieke radiologische veranderingen bestaan.

Het doel van dit proefschrift was de biomechanische eigenschappen en veiligheid van verschillende fixatietechnieken van de bekkenring te onderzoeken en de resultaten te beschrijven van chirurgische fixatie van de symphyse en de sacroiliacale gewrichten bij patiënten die ernstig geïnvalideerd waren door zwangerschapsgerelateerde pijn in lage rug en bekken. Voor een sterk geselecteerde groep lijken de resultaten wat betreft verlichting van pijn en verbetering van loopafstand en dagelijkse activiteiten veelbelovend.
Uit de biomechanische experimenten kunnen we concluderen dat voor compleet instabiele bekkenfracturen de fixatietechnieken met twee sacroiliacale schroeven sterker zijn en een hogere weerstand tegen draaiing hebben dan één sacroiliacale schroef. De tweede schroef speelt waarschijnlijk een belangrijke rol bij de preventie van rotatie. Daarnaast konden meer belastingscycli voor het falen van de fixatie gehaald worden met twee schroeven. Er werden geen verschillen tussen de twee technieken met twee sacroiliacale schroeven gevonden. Aangezien bij het plaatsen van beide schroeven in het eerste sacrale wervellichaam minder neurologische klachten optraden dan met de onderste schroef in de tweede sacrale wervel en er biomechanisch geen significant verschil te vinden was tussen beide technieken, adviseren wij beide schroeven in de eerste sacrale wervel te positioneren.

Dankwoord

Dankwoord

Uiteindelijk is het er toch van gekomen. Met veel plezier schrijf ik dit hoofdstuk dat het meest gelezen wordt en altijd achteraan in het proefschrift staat. Promoveren doe je nooit alleen en ik ben veel dank verschuldigd aan iedereen die direct of indirect een bijdrage hebben geleverd aan de totstandkoming van dit proefschrift.

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Curriculum Vitae

Curriculum Vitae

Marieke van Zwienen werd op 22 december 1973 te Dordrecht geboren. In 1992 behaalde zij het gymnasiumdiploma aan de C.S.G. Johannes Calvijn te Rotterdam. Aansluitend startte zij met de studie geneeskunde aan de Erasmus Universiteit te Rotterdam. Tijdens haar studententijd was zij als eindredacteur en fotograaf actief bij het faculteitsblad O'Dokter. Vanaf het tweede jaar gaf zij les op de snijzaal van de afdeling Anatomie, aanvankelijk als student-assistent, later ook aan groepen paramedici. Haar interesse in onderzoek werd gewekt door keuze-onderzoek op de afdeling Biomedische Natuurkunde en Technologie (BNT) en afstudeeronderzoek op de afdeling Anatomie en Plastische Chirurgie.

Na haar artsexamen in 1999 keerde zij terug op de afdeling Biomedische Natuurkunde en Technologie (BNT) voor promotieonderzoek in samenwerking met de afdeling Traumatologie. Het onderzoek naar chirurgische fixatie van het bekken bij vrouwen met zwangerschaps-gerelateerde lage rug- en bekkenpijn vormt de basis van dit proefschrift. De experimenten verrichtte zij samen met dr. E.W. van den Bosch. Gedurende dit onderzoek heeft zij een periode gewerkt als arts-assistent op de afdeling Algemene Heelkunde in het AZR Dijkzigt te Rotterdam onder prof.dr. H.J. Bonjer. Daarnaast was ze van 1999 tot 2002 'verbonden' als docent anatomie aan de opleiding voor gipsverbandmeesters (LOGV) in het AZR Dijkzigt.

Het aanstekelijk enthousiasme van de artsen in het ZRTI tijdens haar co-schap Interne Geneeskunde te Vlissingen vormde de basis voor de stap richting de Radiotherapie. Na korte tijd als arts-assistent Radiotherapie in het AMC te Amsterdam gewerkt te hebben, is zij in 2002 gestart met de opleiding tot radiotherapeut in het LUMC te Leiden (opleider: Prof.dr. E.M. Noordijk). In de avonduren schreef zij gestaag door aan dit proefschrift.

Zij is getrouwd met Joost Batenburg.