Chapter Five

Optimal Position of Sacroiliac Screws for Fixation of Unstable Pelvic Ring Fractures

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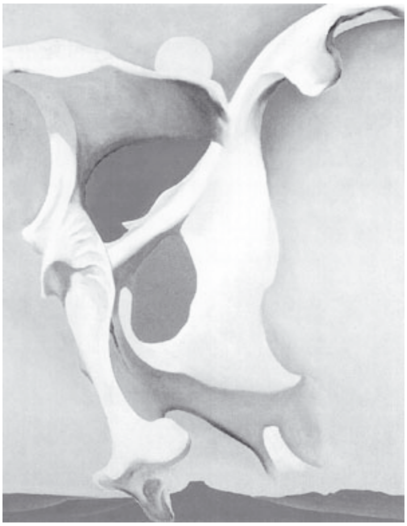

Summary

Objective.

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

Design.

Randomized comparative cadaveric study.

Materials and Methods.

In 12 specimens we created a symphysiolysis and sacral fractures on both sides. Each was fixed with one of the following methods: one sacroiliac screw in the first sacral vertebral body, two screws convergingly in this vertebral body or one screw in the first and one in the second sacral body. The pubic symphysis was not fixated. Using an infrared 3-dimensional videosystem we measured the translation and rotation stiffness of the fixations and the load to failure.

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 the first sacral vertebral body. The techniques with two screws showed no differences.

Conclusions.

The addition of a second screw seems to prevent rotation and improves the load to failure. Therefore we recommend the use of two screws in completely unstable pelvic fractures. In clinical studies both screws in the first sacral body seems to be safer than two parallel screws in the first and the second vertebral body. Given the biomechanical similarity the first technique may be preferable.

INTRODUCTION

Conservative treatment of unstable pelvic fractures has a significant chance of long-term complications, like malunion and nonunion, pain, and neurological dysfunction[1-4]. 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[1-3]. Greater stability can be achieved by internal fixation, consisting of a combination of posterior and anterior fixation[3,4]. Ideally the fixation will provide enough stability to allow early mobilisation of the patient thus avoiding complications associated with prolonged bed rest[2,3,5].

Several authors tried to quantify the stabilizing effect of different internal fixation methods of the pelvic ring. A wide variety of injuries were studied. Furthermore the loading techniques differed: one-leg stance[1,6-10], bilateral stance[10-16] or lateral compression[17]. 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[1,3,6,8-10,12,14,16-18]. Some, however, only did an anterior[3,7,13,14] or posterior fixation[10,11,14,15]. For fixation of the sacroiliac joint one, two or three sacroiliac screws were used, a ventral sacroiliac plate or sacral bars[1,3,6,8-12,14-18]. The pubic symphysis was fixed using one or two plates or a metal or PDS banding[1,3,6-10,12-14,16-18]. Some also used an isolated external frame[1,3,10,12,18,19].

In most cases the displacement of the fracture was measured in one direction[10,11,17,18], sometimes at several points in the pelvis[1,3,6,7,12-16]. Most often shear or diastase of the pubic symphysis or the sacroiliac joint was measured[1,6,7,12-16]. In only a few cases 3-dimensional measurements were done of the movements in the fracture plane[1,3,8,9]. However, 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 sacroiliac screws show biomechanically equal results[9,15]. However, no study has compared different positions of these screws.

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

Materials and methods

We used 12 embalmed cadaveric pelves, which were dissected, leaving the ligamentous structures intact, including ischiosacral ligaments. The femora, lumbar vertebrae and all muscles were removed. Average age of the specimens was 78.3 years. In one pelvis a Girdlestone was present and in another a hemisacralisation of the fifth lumbar vertebra on the left side was found.

In each pelvis we created a Tile C1 pelvic ring injury with a symphysiolysis and a sacral fracture. In order to obtain a similar injury in all pelves we created a vertical sacral fracture through the lateral mass using a saw.

Every sacral fracture was fixated with one of the following methods: one sacroiliac screw in the vertebral body of the first sacral vertebral body (technique S1), two screws convergingly in the first sacral vertebral body (technique S1-S1) or technique with one screw in first sacral vertebral body and one parallel to the first in the second vertebral body (technique S1-S2). In order to compare both sides of the pelvis the pubic symphysis was not fixated.

We used 70 mm cannulated partially threaded, cancellous lag screws (Biomet®, Warsaw, In, U.S.A.) with washers. The screws were inserted through the posterior ilium and into the vertebral body across the sacral fracture, according to the technique of Matta and Saucedo[4]. The drilling was started two to three cm anterior to the posterior superior iliac spine and at the midpoint between the iliac crest and the sciatic notch. Drilling was directed to the center of the vertebral body.

In order to measure the stiffness and strength of the sacroiliac joint the sacrum was fixed between two plates with screws and methylmethacrylate-polymere resin (Demotec®). This construction was 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[7,9]. The pelvis and the frame can be seen in figure 1. We applied the load by introducing a force to a plate attached to the ilium. The force was directed along a vertical working line passing through the fracture plane. Both sides of the pelvis were loaded to a maximum of 150 N under two conditions: intact and after disruption of the symphysis, the sacrotuberal and sacrospinal ligaments. The load was applied in three cycles to investigate the reproducibility. After these measurements a Tile C1 fracture was created unilaterally, which was fixed with one of the three sacroiliac screw techniques. A load up to 100 N was applied to examine the stiffness. Furthermore the load to failure was determined. After failure the other side was measured. The initial side was replaced in its original position and if necessary fixated additionally to obtain this position. For assignment of the fixation methods a cross-over design was used. The two sacral fractures of one pelvis were fixed with different screw techniques, which yielded six different combinations when sides were reversed. We randomized the order in which these six combinations were used. Furthermore we scored the bone quality and the quality of the fixation on a three-point scale.

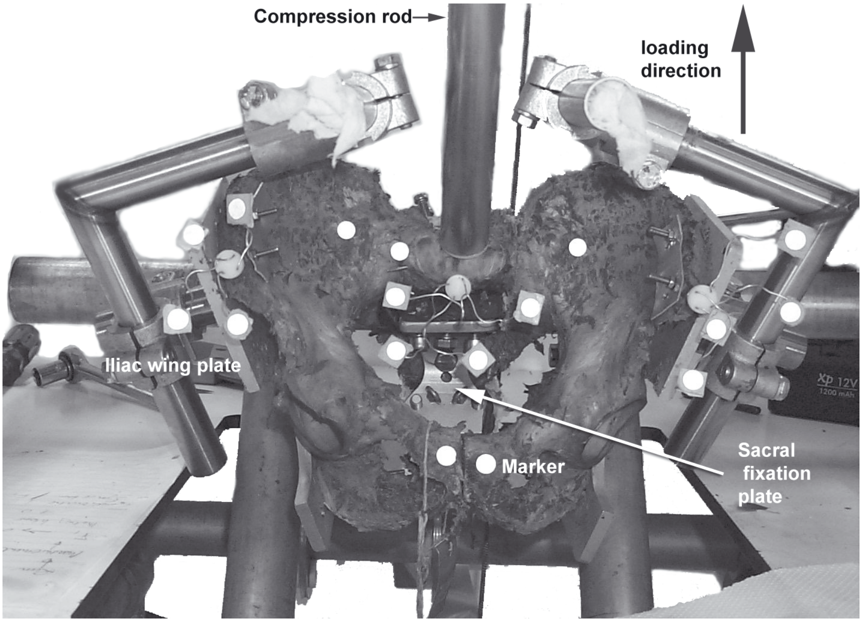

Figure 1. Loading frame with pelvis.

With an infrared 3D videosystem displacements were measured in all 6 degrees of freedom (3 dislocations and 3 rotations). From previous tests the resolution of the system proved to be about 0.1 mm. 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. Similar to the technique used by Keemink et al[20], these markers were illuminated by infrared light sources mounted to the two video cameras[21]. 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. 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[22].

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 pelves and up to 100 N in the fixated pelves. The definition of rotation stiffness was not in Nm/degree, because the main force applied was a translational force. Therefore, the relative rotation stiffness is given in N/degree. In a linear model the slope of the load displacement curves from the 3 cycles was calculated with 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[9] and 10 mm displacement of the pubic symphysis[19]. For the statistical calculations we used SAS 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 three screw methods we performed a MANOVA with the translation/rotation stiffness or load to failure of the fixated pelvis as depending variable. As baseline we examined the translation/rotation stiffness of the intact pelvis and the pelvis with disrupted ligaments. 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 and provided means and ranges.

Results

The median rotation of the iliac wing was 0.5 degree in the intact situation, 0.7 degree when the pubic symphysis was disrupted and 2.1 degree for the fixated sacral fracture. In all three situations the rotation axis of the loaded ilium was directed mainly along the transversal axis (figure 1). When the pubic symphysis was disrupted the ilium rotated upwards in all cases. At the pubic symphysis this rotation showed as movement of the loaded pubic bone upwards and forwards. In some fixated pelves, however, the ilium rotated in the opposite direction with the pubic bone moving downwards and backwards. When comparing the rotation stiffness of the different screw methods the overall p value was 0.026. The fixation

Rotation Stiffness (N/degree)			
	S1	**S1-S2**	**S1-S1**
Median	58	224	163
Range	11- 323	16 - 1654	22 - 724
Translation Stiffness (N/mm)			
Median	30	51	71
Range	7 - 264	6 - 185	6 - 214

Table 1. Rotation and translation stiffness for various screw techniques.

5mm displacement fracture (N)			
	S1	S1-S2	S1-S1
Median	107	168	192
Range	28 - 279	95 - 346	97 - 371
10mm displacement symphysis (N)			
Median	97	150	158
Range	28 - 248	85 - 265	77 - 363

Table 2. Load to failure: loading force required to achieve failure level.

with one screw in the first sacral body was significantly inferior compared to the techniques with two screws ($p = 0.015$ and $p = 0.018$ for technique 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.

Descriptive statistics of the load to failure (10mm displacement at the pubic symphysis and 5 mm displacement at the sacral fracture) for various fixation methods are shown in table 2. 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 ($p < 0.02$).

Discussion

Purpose of this study is to determine which sacroiliac screw technique is from biomechanical point of view the best for completely unstable pelvic ring fractures. We therefore fixated a sacral fracture in 12 embalmed pelves with various sacroiliac screw techniques and using a infrared 3D videosystem measured displacement of the fracture parts. In the literature several authors have used sacroiliac screws[6,9,11,14-17]. No study has examined the optimal technique for sacroiliac screw positioning. Although various authors simulated muscle forces of the abductor muscles[6,9] or the hip flexors and extensors[14,15] we dissected all muscles and made no attempt to simulate the additional stability of these muscles in order to exclude any forces which might influence the measurements. For the same reason we did not add anterior fixation in order to compare the various sacroiliac screw techniques with each other. The sacral fracture was created with a saw, the smooth fracture surface representing a worst case scenario. Although this might not allow us to reach physiological forces the use of a more abstract model gives less confounding. Overall this resulted in a situation in which the stability of the fixed fracture depended entirely on the stiffness of the osteosynthesis.

In only a few cases 3-dimensional measurements were done[1,8,9]. Most studies used the vertical displacement at the point of load application representing the total displacement of the entire structure[11,17,18] or displacement transducers in one[10] or more directions[1,3,6,7,12-16]. 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 showed that no method of fixation came close to the stability of the intact pelvis[1,15,16]. In a sacroiliac joint disruption sacral bars were inferior to sacroiliac screws and a sacroiliac plate[11], which have similar results[9,15]. Fixation with sacroiliac screws however has the additional benefit that they can be inserted percutaneously without the complications of an open procedure which is required for plate fixation.

The translation and rotation stiffness of the intact pelvis were, as could be expected, clearly superior to the solely posteriorly fixated pelvis. Even after dissection of the pubic symphysis and the sacrotuberal 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 pubic symphysis some diastase was seen, combined with cranial and ventral displacement. In pelves fixated with only one screw in some cases dorsal displacement was seen. In the fixated situation rotation occurred in the same direction in most cases, which means that the ilium tended to rotate upward around the sacroiliac screws. 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 the first sacral body. No difference was found for the translation stiffness. 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 difference was found between the techniques with two screws. Although these techniques may seem biomechanically similar, the positioning of the lower screw in the second vertebral body is more difficult clinically. It also carries a higher risk of intrusion into the sacral foramina and therefore neurological damage[23]**.** No significant differences were found for the bone quality and the fixation quality (grip of the screws).

Limitations of our study include the use of elderly embalmed specimens and denuded pelves lacking soft tissue support and muscle activity. Also fatigue of the fixation is not examined. Future experiments should be conducted to investigate the stability of the osteosynthesis during dynamic 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 we recommend the addition of a second sacroiliac screw in completely unstable pelvic fractures. Based on clinical studies the combination of both screws in the first vertebral body of the sacrum seems to be safer than two screws parallel in the first and second body and may be preferable given the biomechanical similarity.

REFERENCES

1. Stocks GW, Gabel GT, Noble PC, Hanson GW, Tullos HS. Anterior and posterior internal fixation of vertical shear fractures of the pelvis. *J Orthop Res*. 1991;9:237-45.
2. Tile M. Pelvic ring fractures: should they be fixed? *J Bone Joint Surg Br*. 1988;70:1-12.
3. Tile M. *Fractures of the pelvis and actabulum.* Baltimore: Williams & Wilkins; 1995.
4. Matta JM, Saucedo T. Internal fixation of pelvic ring fractures. *Clin Orthop*. 1989;242:83-97.
5. Routt MLJr, Meier MC, Kregor PJ, Mayo KA. Percutaneous iliosacral screws with the patient supine technique. *Operative Techniques Orthop*. 1993;3:35-45.
6. Kraus E, Schlickewei W, Cordey J, Wahl D, Kuner EH, Perren SM. [Method for measuring the comparative stability of osteosynthesis in the dorsal pelvic ring] Methode zur vergleichenden Messung der Stabilitat von Osteosynthesen am dorsalen Beckenring. *Unfallchirurgie*. 1998;24:25-31.
7. MacAvoy MC, McClellan RT, Goodman SB, Chien CR, Allen WA, van der Meulen MC. Stability of open-book pelvic fractures using a new biomechanical model of single-limb stance. *J Orthop Trauma*. 1997;11:590-3.
8. Pohlemann T, Angst M, Schneider E, Ganz R, Tscherne H. Fixation of transforaminal sacrum fractures: a biomechanical study. *J Orthop Trauma*. 1993;7:107-17.
9. Pohlemann T, Culemann U, Tscherne H. [Comparative biomechanical studies of internal stabilization of trans-foraminal sacrum fractures] Vergleichende biomechanische Untersuchungen zur internen Stabilisierung der transforaminalen Sakrumfraktur. *Orthopade*. 1992;21:413-21.
10. Shaw JA, Mino DE, Werner FW, Murray DG. Posterior stabilization of pelvic fractures by use of threaded compression rods. Case reports and mechanical testing. *Clin Orthop*. 1985;240-54.
11. Comstock CP, van der Meulen MC, Goodman SB. Biomechanical comparison of posterior internal fixation techniques for unstable pelvic fractures. *J Orthop Trauma*. 1996;10:517-22.
12. Rubash HE, Brown TD, Nelson DD, Mears DC. Comparative mechanical performances of some new devices for fixation of unstable pelvic ring fractures. *Med Biol Eng Comput*. 1983;21:657-63.
13. Simonian PT, Routt ML, Jr., Harrington RM, Tencer AF. Internal fixation of the unstable anterior pelvic ring: a biomechanical comparison of standard plating techniques and the retrograde medullary superior pubic ramus screw. *J Orthop Trauma*. 1994;8:476-82.
14. Simonian PT, Routt ML, Jr., Harrington RM, Mayo KA, Tencer AF. Biomechanical simulation of the anteroposterior compression injury of the pelvis. An understanding of instability and fixation. *Clin Orthop*. 1994;245-56.
15. Simonian P, Routt C, Harrington R, Tencer A. Internal fixation for the transforaminal sacral fracture. *Clin Orthop*. 1996;323:202-209.

16. Varga E, Hearn T, Powell J, Tile M. Effects of method of internal fixation of symphyseal disruptions on stability of the pelvic ring. *Injury*. 1995;26:75-80.

17. Hofmann D. [Comparative study of various stabilization procedures in dislocation of the pelvic half joint]Vergleichende Untersuchung verschiedener Stabilisierungsverfahren bei der Luxation der Beckenhalbgelenke. *Unfallchirurgie*. 1991;17:247-52.

18. Leighton RK, Waddell JP, Bray TJ et al. Biomechanical testing of new and old fixation devices for vertical shear fractures of the pelvis. *J Orthop Trauma*. 1991;5:313-7.

19. Rieger H, Winckler S, Wetterkamp D, Overbeck J. Clinical and biomechanical aspects of external fixation of the pelvis. *Clin Biomech (Bristol, Avon)*. 1996;11:322-327.

20. Keemink CJ, Hoek van Dijke GA, Snijders CJ. Upgrading of efficiency in the tracking of body markers with video techniques. *Med Biol Eng Comput*. 1991;29:70-74.

21. Faber FW, Kleinrensink GJ, Verhoog MW et al. Mobility of the first tarsometatarsal joint in relation to hallux valgus deformity: anatomical and biomechanical aspects. *Foot Ankle Int*. 1999;20:651-656.

22. Spoor CW, Veldpaus FE. Rigid body motion calculated from spatial co-ordinates of markers. *J Biomech*. 1980;13:391-393.

23. Van Den Bosch EW, Van Zwienen CM, Van Vugt AB. Fluoroscopic positioning of sacroiliac screws in 88 patients. *This thesis.*