Chapter Seven

Cyclic Loading of Sacroiliac Screws in Tile C Pelvic Fractures

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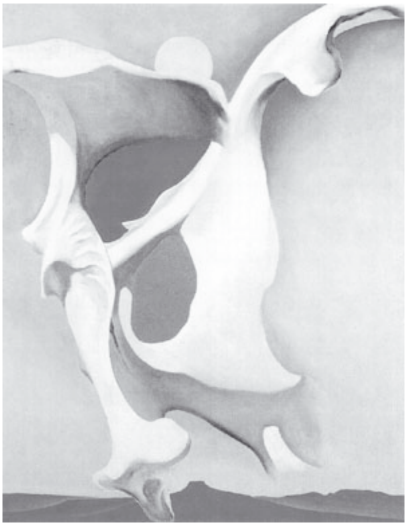


Summary

Objective.

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

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 stiffness, the number of cycles before failure and the load to failure of the fixations were measured using a 3-dimensional video system.

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, this suggests that further clinical research into direct postoperative weight bearing can be undertaken safely.

INTRODUCTION

In Tile C fractures both anterior and posterior pelvic ring are disrupted which leads to both translation and rotation instability. Because conservative treatment leads to a high percentage of complications and long term disability, operative treatment is advocated. However, with external fixation 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]. Despite the superior stability obtained by internal fixation several institutions still limit weight bearing after internal fixation for considerable time[5-10]. Although ideally internal fixation would provide enough stability to allow early mobilisation of the patient, most biomechanical studies have shown inferior stability compared to the intact situation[1,11,12].

Although several authors studied the effect of various methods of (internal) fixation for unstable pelvic ring fractures, only a few reports have studied cyclic loading. Pohlemann 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[13]. Meissner loaded isolated symphyses fixated by plate and banding techniques with a force equalling 50% of the physiological load over 55,500 cycles[14]. Banding techniques led to early failure. 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. They concluded that patients with open book fractures treated by plate fixation could tolerate early half weight bearing, although no information was obtained about the role of the injury to the posterior pelvic ring.

In this study we investigated the combination of an anterior plate with posterior sacroiliac screw fixation in Tile C fractures. In order to simulate weight bearing the pelvis was loaded 2000 times with a maximum of 400N, which equals the upper body weight in adults[15]. A 3-dimensional video system was used to measure the displacement between the various fracture parts in order to determine the stiffness, strength and endurance of the fixation[16].

MATERIALS AND METHODS

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

All pelves were stabilised anteriorly with a 4-hole self compression plate (3.5 mm x 50 mm) across the symphysis (Biomet®, Warsaw, In., U.S.A.). Posteriorly one or two 70 mm canulated partially threaded, cancellous lag screws (Biomet®, Warsaw, In., U.S.A.) with washer 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[4]. The fixation quality 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

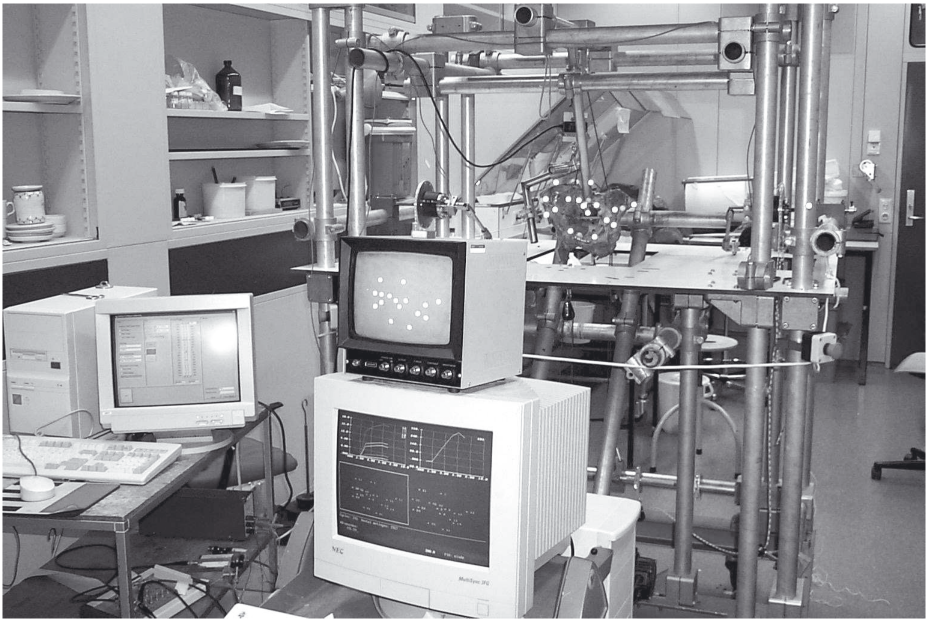


Figure 1. Laboratory setting for loading pelves. On the foreground right the computer required for measuring displacements with on top the view from the camera. On the left the computer required for loading the pelvis. In the middle the pelvis mounted in the frame. Clearly visible on the pelvis are the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

which is approximately comparable to the physiological position during standing[13,15]. 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 sacroiliac joint. This approximates forces 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 (figure 1). The markers were illuminated by an infrared light source mounted on the cameras. The image coordinates from the two cameras 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 each pelvis baseline measurements of the intact situation were obtained. After a unilateral Tile C1 fracture was created and the pelvis was fixated with combined anterior and posterior fixation, it was loaded 2000 times with a maximum load of 400N and with an increment of 100 N[11,15,19]. The pelves were randomized in two groups: 6 were posteriorly fixated with one sacroiliac screw and 6 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[13,20].

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. In order 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/rotation stiffness of the intact pelvis. As covariables 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

In the intact situation generally less than 1 mm displacement was observed between the two pubic rami when loaded to 400N. In most pelves the ipsilateral marker moved in ventral and to a lesser degree in cranial direction. At the sacroiliac joint in most cases less than 1 mm displacement was seen. In three cases more than 1 mm was observed with a maximum of 4.3 mm (median 0.7 mm). While hardly any diastases was found, most movement was in cranial direction. No significant effect of the damage of sacrotuberal ligaments was observed.

After fixation most displacement at the symphysis was seen in cranial and dorsal direction (median 2.7 mm and 1.4 mm respectively). Diastases was less prominent (median 0.4 mm). At the sacral fracture most displacement 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).

The median and range of the translation and rotation stiffness of the ilium with respect to the sacrum, when loaded up to 400N, are summarized in table 1. Rotation was generally seen around an axis which 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 found 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 quality was significant for the translation stiffness ($p=0.047$). The other covariables were not significant ($p>0.1$).

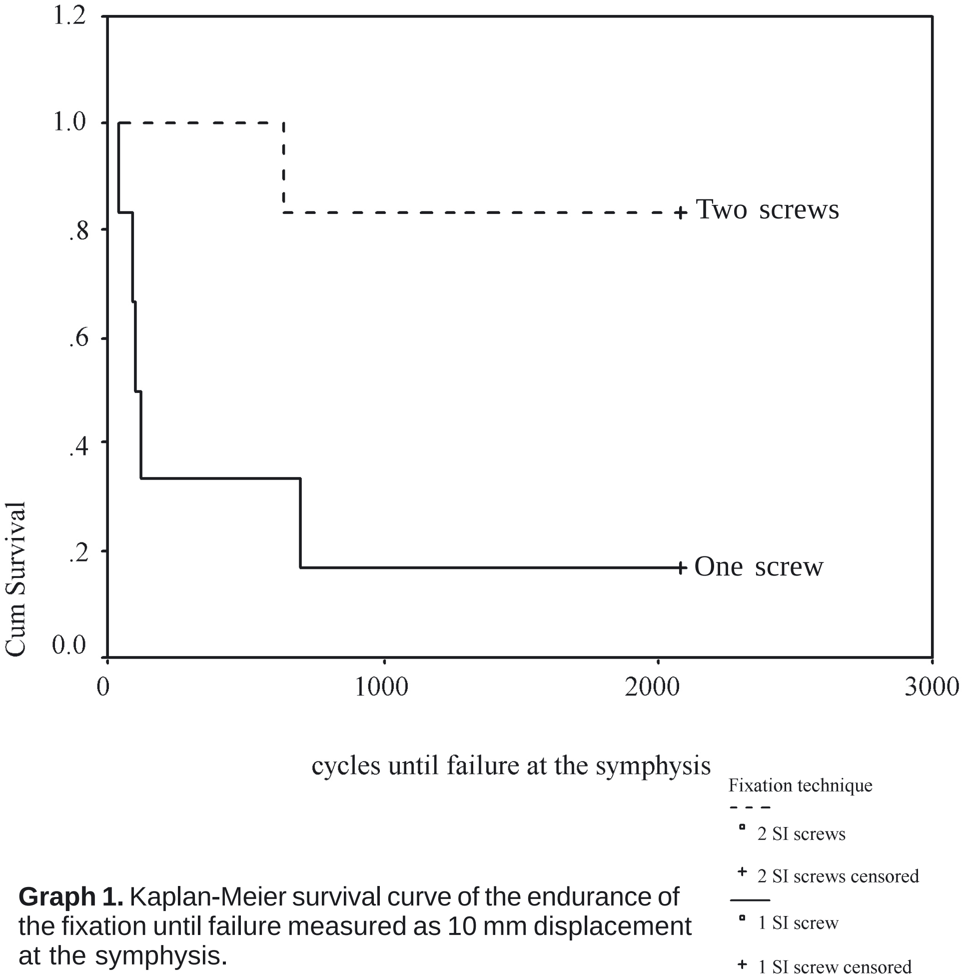
Translation stiffness (N/mm)			
	intact	one sacroiliac screw	two sacroiliac screws
Median	270	41	160
Range	74 - 18585	13 - 5847	35 - 715
Rotation stiffness (N/degree)			
Median	966	284	426
Range	206 - 15368	33 - 1691	140 - 3615

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

The load to failure as previously defined 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).

In graph 1 a survival curve for number of cycles which could be completed without failure is shown. Failure occurred significantly later for the technique with two sacroiliac screws for both definitions of failure. With a log rank test p = 0.027 and p = 0.017 were found for measurement of the load to failure at the sacral fracture and at the symphysis respectively. Quality of the fixation was a significant covariable for longer endurance (p=0.018 and p=0.026).

For the pelves that completed the entire loading protocol without failure the stiffness over the first and the last 250 measurements were compared in order to examine weakening of the osteosynthesis over 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 %.



Graph 1. Kaplan-Meier survival curve of the endurance of the fixation until failure measured as 10 mm displacement at the symphysis.

DISCUSSION

In the literature several authors have used sacroiliac screws[11-13,19,21-24]. However, no study has examined the sacroiliac screw fixation under cyclic loading conditions. Most authors found similar results for sacroiliac plate and screw fixation [19,23] but the fixation remained inferior compared to the intact pelvis[1,11,12,15,21,22]. 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 12 embalmed pelves we determined the stiffness, the load to failure and the endurance using a 3D video system measuring displacement of the fracture parts.

The smooth fracture surface, created by the use of a saw, and the lack of muscle support represent a worst case scenario[11,25,26]. Despite this fact, the use of combined anterior and posterior pelvic ring fixation allowed us to apply a physiological force (representing the upper body mass).

Routt recommends the use of anterior fixation in Tile C fractures to be limited to fractures in which there is over 1 cm displacement in any direction[27,28]. In a comparison between the load to failure in this study and in a previous experiment in which isolated sacroiliac screw fixation was performed, we found a significantly

5 mm displacement at sacral fracture		
	one sacroiliac screw	two sacroiliac screws
Median	255	710
Range	147 - 840	249 - 1005
10 mm displacement at symphysis		
Median	398	757
Range	201 - 857	401 - 1005

Table 2. Load to failure, measured as 5 mm displacement at the sacral fracture or 10 mm displacement at the symphysis.

higher load to failure (median 168 N versus 400 N) in combined anterior and posterior pelvic ring fixation ($p<0.0001$)[29]. In contrast with our previous study physiological forces could be used to determine stiffness under cyclic loading conditions. Stiffness could not be compared due to the different protocol.

Similar to other studies 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 to one screw. In the pelves which completed the protocol a decrease of 23% between the initial and final stiffness was seen, although this was not significant.

This study shows again 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. This suggests that further clinical research into direct postoperative weight bearing for the average (young) trauma patient with both anteriorly and posteriorly fixated Tile C fractures can be undertaken safely.

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