

Are Anterior Plates More Effective than Iliosacral Screws to Fix the Sacroiliac Joint? Biomechanical Study*

Placas anteriores são mais eficazes do que parafusos iliossacrais na articulação sacroilíaca? Estudo Biomecânico

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Abstract

Introduction Sacroiliac joint dislocations are caused by high energy trauma and commonly treated with the iliosacral screw fixation or the anterior plating of the sacroiliac joint (SIJ). However, there is a lack of consensus regarding which procedure is the most successful in treating sacroiliac joint dislocations. This aims to compare stiffness and maximum load of pelvises with sacroiliac joint dislocations treated with both procedures in a synthetic bone model.

Methods Synthetic pelvises were mounted and divided into 2 treatment groups ($n = 5$): a model with two orthogonal plates placed anteriorly to the SIJ (PPS group) and another with two iliosacral screws fixating the SIJ (SPS group), both with pubic symphysis fixation. The maximum load supported by each sample was observed and the stiffness was calculated from the curve load vs displacement. The mean values of load to failure and stiffness for each group were compared with the Mann-Whitney U test ($p < 0.05$ was considered significant for all analysis).

Results The mean load to failure supported by the PPS group was 940 ± 75 N and the SPS was 902 ± 56 N, with no statistical difference. The SPS group showed higher values of stiffness (68.6 ± 11.1 N/mm) with statistical significant difference in comparison to the PPS sample (50 ± 4.0 N/mm). The mode of failure was different in each group tested.

Conclusion Despite lower stiffness, the anterior plating fixation of the sacroiliac joint can be very useful when the iliosacral screw fixation cannot be performed. Further studies are necessary to observe any differences between these two procedures on the clinical and surgical setting.

Keywords

- ▶ bone plates
- ▶ joint instability
- ▶ sacroiliac joint
- ▶ biomechanical phenomena

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Resumo

Introdução Usualmente, as luxações sacroilíacas são tratadas com parafusos iliossacrais ou com placas anteriores à articulação sacroilíaca (ASI). Este estudo compara a rigidez e carga máxima suportada pelos dois tipos de fixações acima citados, utilizando pelvis sintéticas.

Método Dez pelvis sintéticas foram divididas em dois grupos ($n=5$). No grupo denominado PlaCF, a ASI foi fixada com duas placas anteriores. No grupo ParCF, a ASI foi fixada com dois parafusos iliossacrais no corpo da primeira vertebra sacral (S1). A rigidez e carga máxima suportada por cada montagem realizada, foi mensurada. A análise estatística foi realizada através do teste U de Mann-Whitney ($p < 0.05$ foi considerado estatisticamente significativo para todas as análises).

Resultados A carga máxima suportada até a falha da fixação pelos grupos PlaCF e ParCF foram respectivamente 940 ± 75 N e 902 ± 56 N, não havendo diferença estatística entre eles. A rigidez obtida pelo grupo ParCF foi maior e com diferença estatística em relação ao grupo PlaCF (68.6 ± 11.1 N/mm e 50 ± 4.0 N/mm respectivamente).

Conclusão Apesar da menor rigidez obtida no grupo PlaCF, as placas anteriores à ASI podem ser uma ótima opção no tratamento da luxação sacroilíaca quando os parafusos iliossacrais não puderem ser utilizados. Outros estudos são necessários para detectar possíveis diferenças entre os dois procedimentos do ponto vista cirúrgico e clínico.

Palavras chave

- ▶ placas ósseas
- ▶ instabilidade articular
- ▶ articulação sacroilíaca
- ▶ fenômenos biomecânicos

Introduction

Sacroiliac joint dislocations (SJDs) usually result from high energy trauma. Pelvic fractures can damage intrapelvic structures and neurovascular bundle, producing severe hemorrhages with high mortality rates.¹⁻⁴

Since the sacroiliac joint (SIJ) contributes significantly to stabilize the pelvic ring, its fractures or dislocations are surgically challenging. When not adequately managed, such lesions can lead to pain, shortening of the limb, nerve damages, as well as sexual and urinary dysfunctions after the procedure.²⁻⁴

Poor outcomes are directly related to inadequate fixation of the pelvic lesion, which can cause long-term dysfunction due to osteosynthesis failure and loss of SIJ reduction. As it provides stability to the joint and is minimally invasive, SIJ fixation with iliosacral screws in S1 has been widely used.^{5,6} However, this procedure requires a surgical technique that involves percutaneous screw fixation under adequate intraoperative imaging. In addition, morphological dysmorphism on the sacral ala can preclude the insertion of iliosacral screws on S1 body. In the absence of these requirements, risks of complications are high, especially in patients with sacral abnormalities or nonanatomic articular reduction.⁷ In such situations, open reduction through the first window of the ilioinguinal approach is an option, making internal fixation of the SIJ with two orthogonal anterior plates a good alternative to the iliosacral screws.^{8,9}

The present study analyzes the mechanical behavior of iliosacral screws compared to that of two anterior plates. In the current investigation, an in vitro biomechanical evaluation of these two constructions was performed to compare

the load to failure, stiffness, and mode of failure of each group.

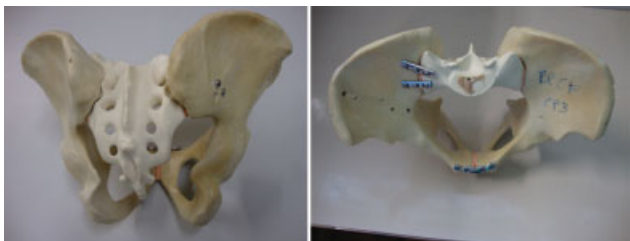
Material and Methods

The present study used synthetic pelvises number 4060 (Synbone AG, Zizers, Switzerland) with open pubic symphysis. We reproduced the fixation of a type C of Tile lesion. Two different models were tested: two iliosacral screws fixing the SIJ (SPS) and two orthogonal plates placed on anterior aspect of the SIJ (PPS), both with pubic symphysis fixation (► **Figs. 1** and **2**). All experiments were performed on the right SIJ. This study was approved by the internal committee of the institution.

Model Construction

In the case of the PPS model (orthogonal plates), 2 3-hole, 3.5-mm dynamic compression plates (Depuy-Synthes Companies, Raynham, MA, USA) were anteriorly placed on the right SIJ with two screws on the iliac bone and one on the sacral ala, avoiding the sacral foramina of S1.¹⁰

For the SPS model (iliosacral screws): two 7.0-mm cannulated screws (Depuy-Synthes Companies) measuring 75 mm were introduced from the outer table of the ilium across the SIJ to the body of S1, following the perpendicular track of the SIJ. Screws were anchored in the body of S1 without violating the anterior, posterior, and superior surfaces of S1, and avoiding the sacral foramina of this vertebra.¹¹ To be sure that the screws were in a satisfactory position in the body of S1, without radiological control, we purposely drilled the above mentioned limits of the vertebral body of S1 with the guide wire. After confirmation of the



Figs. 1 and 2 Tested synthetic models. Two iliosacral screws fixation model with pubic symphysis fixation (SPS), and two anterior plating model with pubic symphysis fixation (PPS), respectively.

proper position of the guide wire, it was retracted and we drilled and completed the fixation with cannulated screws.

The pubic symphysis was fixed in all samples by a 4-hole, 3.5-mm plate (Depuy-Synthes Companies) with 2 3.5-mm cortical screws on each side.

The synthetic pelvic samples (Synbone AG) came with a small screw on each side of the SIJ to maintain the ilium and sacrum connected. For the experiment, we removed the screw from the right side of all the tested models.

In all samples, the points of screw insertion were previously marked with ink to avoid differences between the tested models. Constructions were made in the same manner, respecting the same screw length and position in both experimental groups. Screws were tightened to a maximum torque of 1 Nm with a torque wrench.

Biomechanical Tests and Statistical Analysis

All biomechanical tests were performed with the standard test machine EMIC DL3000 (Instron Brasil Equipamentos Científicos Ltda., São José dos Pinhais, PR, Brazil) with a load cell of 5,000 N. The synthetic pelvises were mounted with the right hemipelvis resting on a bipolar prosthesis (external head of 42-mm) attached to the fixed (lower) head of the machine to simulate the gait position in which the load on the femoral head is maximal¹² (→ Fig. 3).

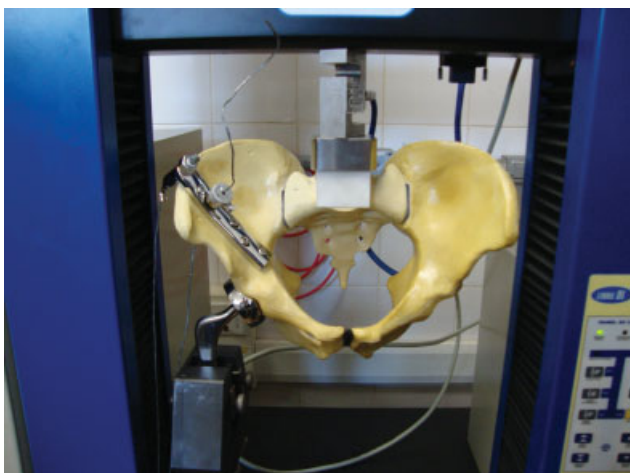


Fig. 3 Synthetic pelvis without any kind of fixation. This picture shows how the pelvis was positioned in the test machine.

Pelvises were attached to the load cell with the aid of a device especially constructed to hold the sacrum in orthostatic position. This device was produced in a 3D printer with polyamide 12, with good chemical resistance and ability to accept high loading of fillers. Its inferior portion reproduced the geometry of the proximal sacrum and was inserted there. Its superior portion was fitted into a steel coupling connected to the load cell, which, in turn, was attached to the moving (upper) head of the testing machine.

The right iliac bone was also connected to the lower head of the machine by means of two steel cables (1.6 mm) that simulated the gluteus medium muscle for pelvic stabilization. The cables were attached to the ilium with the aid of a plate. One of the cables was attached at the level of the iliac crest, and the other to the anterior gluteal line, near the tubercle of the iliac crest (→ Fig. 4).

A vertical compression load was applied to each model at a speed of 5.0 mm/min. Both the force measured by the load cell and the vertical displacement of the upper head measured by the internal machine sensor were recorded by the Tesc 3.04 software (Instron Brasil Equipamentos Científicos Ltda.), which in turn generated a force versus displacement curve in real time and saved the data for



Fig. 4 The right iliac bone was connected to the lower head of the machine by means of two steel cables (diameter 1.6 mm) that simulated the gluteus medium muscle for pelvic stabilization. The cables were attached to the ilium with the aid of a plate. One of the cables was attached at the level of the iliac crest and the other to the anterior gluteal line, near the tubercle of the iliac crest.

further analyses. Tests were stopped automatically when an abrupt rupture of any part of the model occurred or manually when the vertical displacement was reached approximately 25 mm.

The maximum force was recorded, and the mode of failure was observed. The stiffness of each model was obtained from the curves generated by the machine's software, by isolating the linear region and calculating its slope.

OpenStat software was used for the statistical analysis. The averages of maximum force and stiffness obtained for each group were compared with the use of the Mann-

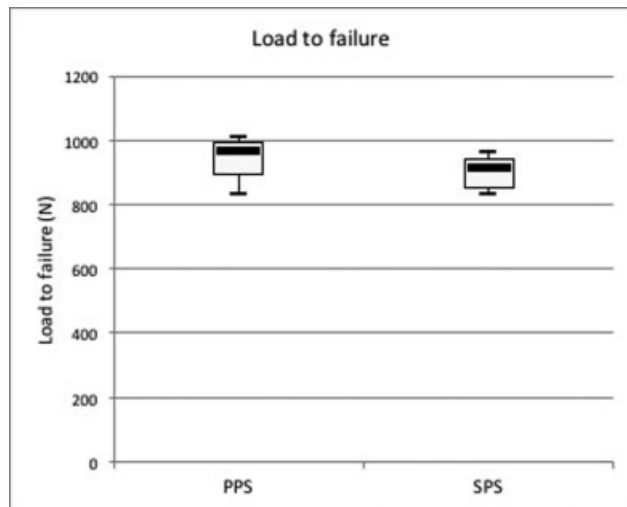


Fig. 5 Box-plot showing the results for load to failure (N). There was no statistically significant difference between the SPS (two S1 iliosacral screws fixing the sacroiliac joint with pubic symphysis fixation) and the PPS (two orthogonal plates placed anteriorly to the sacroiliac joint with pubic symphysis fixation) models.

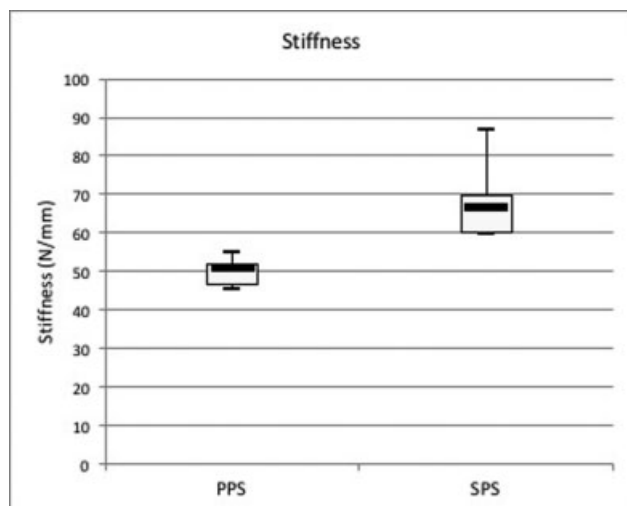


Fig. 6 Box-plot showing the results for stiffness (N/mm). Mann-Whitney U test pointed a statistically significant difference between SPS (two S1 iliosacral screws fixing the SIJ with pubic symphysis fixation) and PPS (two orthogonal anterior plates placed on the sacroiliac joint with pubic symphysis fixation) models.

Table 1 Load to failure supported by each model and respective stiffness (mean \pm SD), and results of the statistical analysis between the tested models

Parameter	Model	Mean value	SD	<i>p</i> -value
Load to failure (N)	PPS	940	75	> 0.05
	SPS	902	56	
Stiffness (N/mm)	PPS	50	4	< 0.05
	SPS	69	11	

Abbreviation: SD, standard deviation.

Whitney U test. A $p < 0.05$ was considered significant for all analyses.

Results

►Figs. 5 and 6 show the results for load to failure and stiffness of the model tested, respectively. ►Table 1 presents the values of means and standard deviations for load to failure and stiffness of both models. The Mann-Whitney U test did not point out any statistically significant difference between PPS and SPS as for load to failure ($U = 17$, $z = 0.1481$, $p > 0.05$, two-tailed), while a statistically significant difference was found for stiffness ($U = 0$, $z = 0.0033$, $p < 0.05$, two-tailed).

Regarding the mode of failure, on the PPS model, screws of the plate (on the ilium) of the tested SIJ pulled out after maximum load. On the SPS model, failure occurred on the contralateral SIJ (disruption). The mode of failure of all models is shown in ►Fig. 7.

Discussion

Sacroiliac dislocations are severe injuries. Their prognosis is directly related to obtaining articular anatomical reduction and to the stability provided by the surgical procedure.^{13,14} Iliosacral screws have proven to be an excellent treatment method since it is a minimally invasive technique involving less blood loss and risks of infection. However, it requires a long learning curve.¹⁵ Furthermore, it may be difficult to obtain suitable X-ray images that can be used intraoperatively due to the presence of intra-abdominal contrast agents, bowel gases or morbid obesity.¹⁶ Besides, anatomical variations, such as dysmorphic sacrum,⁷ can make it extremely difficult, thus increasing the risks of complications. In such situations, an alternative to fix the sacroiliac joint would be to use two anterior plates. Although some reports in the literature mention iatrogenic injuries during the anterior approach,¹⁷ Salama et al.¹⁸ obtained excellent results with acceptable complication rates using this technique.

In the present study, although maximum load was similar in both experimental groups, stiffness was significantly different between them. When he compared these two techniques, Zhang et al.⁹ showed that the quality of the reduction obtained and the functional outcome in patients

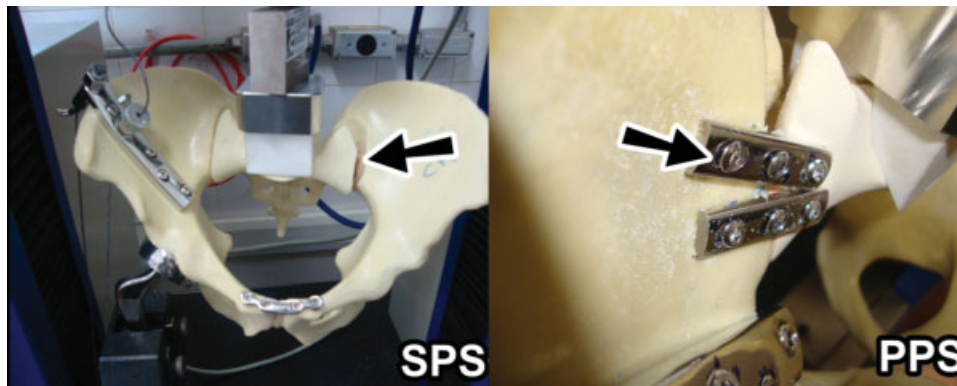


Fig. 7 The failure mechanisms of each model (arrow). On the SPS model, failure occurred on the contralateral sacroiliac joint (disrupted). On the PPS model, the screws of the plate (on the iliac) of the tested sacroiliac joint pulled out after maximum load.

were similar. Although iliosacral screws have less intraoperative bleeding and shorter surgery time, they are more dependent on intraoperative X-ray images and lead to more neurologic complications. Elzohairy and Salama¹⁹ divided the treatment of unstable pelvic ring injuries into two groups: open reduction with internal SIJ fixation and closed reduction with percutaneous SIJ fixation with screws. Since his results showed no difference in terms of the functional outcomes obtained, this author concluded that the technical decision should be multifactorial and consider the elapsed time since injury, general condition of the patient, skin condition, surgeon's experience, and the presence of sacral dysmorphism. Differently from these works, this study is an *in vitro* biomechanical test that measured the load supported by mounted pelvises and their stiffness. Reduction was always perfectly anatomical due to direct vision and to the preservation of the sample's anatomy, which suggests that the stiffness difference between both models could be even higher in practice. A comparison of our results with those of Zhang et al.⁹ and Elzohairy and Salama¹⁹ suggests that stiffness, at least within the value range found in this work, may be of little relevance to functional outcomes.

In addition to these two works, the literature contains other direct comparisons between these two types of fixation. Therefore, the lack of studies comparing the resistance and stiffness of the sacroiliac dislocation fixation with anterior plates and iliosacral screws on the same model supports the presentation of this work. This study opted for two iliosacral screws into the S1 because previous studies^{20,21} have demonstrated it is better than using only one screw, independently of the fixation site (S1 or S2). In the other group, three-hole plates were used because, according to Chen et al.⁸ they offer more resistant fixation than two-hole ones. Special care was taken when mounting the models, since Bai et al.²² have demonstrated the importance of correctly placing the plates to maximize fixation stability. The fixation techniques of both the abovementioned studies were similar to those

used here. Still according to Bai et al. when fixing the SIJ with two anterior plates, one should be placed on the superior one-third and the other on the medium one-third part of the joint. Safety margin to avoid injuries, mainly to L5 root, should not exceed 2.5 cm and 1.5 cm medially on the superior and medial thirds of the joint, respectively. No plate should be placed on the lower one-third. Considering this small safety margin to fix plates, this study preferred double DC 3.5-mm plates to larger ones (4.5-mm).

In a biomechanical study on vertically unstable injuries with open symphysis, Sagi et al.²³ used 3 types of SIJ fixation: 1 screw into S1, 2 screws into S1, and 1 screw into S1 and another into S2. All constructions were tested with and without pubic symphysis fixation. Results showed that pubic symphysis fixation considerably increased the stability of the mounted pelvises and significantly diminished deviations on the axial, anteroposterior, and lateral planes. In this study, in accordance with the literature,^{23,24} pubic symphysis was fixed on the tested models. In addition, previously performed pilot tests demonstrated that mounted pelvises always fail at pubic symphysis, whenever it is not fixed, making it thus impossible to assess the SIJ fixation.

Spinopelvic fixation is an option in the treatment of SIJ dislocation. Sobhan et al.²⁵ showed good results with this method and the possibility of rapid restoration of full weight bearing. In our opinion, this kind of fixation is an option in delayed treatment of SIJ but not in acute cases because of wound complications and the difficult to put polytrauma patients in prone position.

Our results showed no statistical difference regarding the maximum load supported by the two groups tested to treat SJD. As for stiffness, the group using two iliosacral screws was proven superior. It is worth highlighting that different failure mechanisms appeared in each group.

Such results should stimulate further studies to assess if the greater stiffness obtained with iliosacral screws can

clinically affect earlier load bearing and pain reduction in the immediate postoperative period. The lack of significant difference between the maximum loads supported by both fixations suggests that using two anterior plates to fix the SIJ is an acceptable option to treat SJDs, whenever iliosacral screws cannot be used.

A limiting factor of this study is the fact that it used conventional 3.5-mm plates. Studies with large diameter plates, either non-locked or locked, should be performed. Another limitation is that it used synthetic models, whose features differ from cadaveric models due to the lack of musculoligamentous structures. To keep this confounding factor to a minimum, the test model used was able to reproduce the support of the limb during walking and a system of steel cables partly mimicked the action of the musculoligamentous structures, thus hindering any rotation of the contralateral hemipelvis during the tests. On the other hand, although the synthetic pelvises used did not reproduce the mechanical properties of human bones, this work was aimed at comparing the relative values obtained by different fixations of the SJDs. The intention was to find out whether one fixation was stiffer or more resistant than the other, independently of the absolute stiffness and resistance values. Thus, using synthetic pelvises may have had the advantage, when compared with cadaveric pelvises, of decreasing the dispersion of the values obtained during the tests. That all synthetic models came from the same batch gave us greater capacity to control the tests. In fact, cadaveric models do not always present the same features since, in addition to their anatomical variations, one rarely knows the subjects' age and sex, the presence of previous diseases, and the demineralization level.²⁶

Conclusions

There is no difference in terms of maximum load between two anterior plates and two iliosacral screws for the fixation of a disrupted SIJ. However, two iliosacral screws provide a stiffer construction compared with two anterior plates. It is also worth noting that the failure mechanisms were different for each construction model.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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