Pelvic ring fractures internal fixation: Iliosacral screws versus sacroiliac hinge fixation

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\textbf{KEYWORDS}
Sacroiliac fixation; Pelvic ring fractures; Iliosacral screw; Biomechanics

\textbf{Summary}
\textit{Introduction:} Pelvic ring fractures are severe injuries whose functional results depend on the quality of reduction. Numerous internal fixation alternatives have been described, but the biomechanical studies comparing them remain rare.

\textit{Hypothesis:} This study compared the biomechanical behavior of iliosacral screws (ISS) with sacroiliac hinge type fixation (SIF) following unstable pelvic ring fractures fixation.

\textit{Materials and methods:} A lesion simulating sacroiliac disruption and pubic disruption was created on 14 cadaver pelves. After randomization, the fractures were internally fixed using an anterior plate associated with either an ISS or an SIF. The specimens were then submitted to forces applied vertically at the coxofemoral joints. Relative movements in vertical translation and in rotation between the iliac wing and the sacrum, as well as the stiffness and the forces at failure of the assemblies were measured and compared.

\textit{Results:} The mean age of the bodies was 66 years (± 8). No significant difference was demonstrated between the groups in terms of residual motion and stiffness in both vertical and rotational displacement. The results showed a slight residual mobility in rotation of the hemipelvis. The SIFs presented greater, although non significant resistance to failure. No fixation, however, restituted stiffness comparable to a healthy pelvis.

\textit{Discussion:} The results of this study show that aTile C.1.2-type injury to the pelvic ring can be treated as effectively with ISS or SIF when combined anterior and posterior fixations are performed. SIF therefore seems reliable and its continued use is justified. The long-term clinical outcomes should nevertheless be evaluated, notably on the younger population, more often affected by this type of injury.

\textit{Level of evidence:} Level III: Comparative in vitro therapeutic study.

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Introduction

Sacroiliac disruptions (type C.1.2 in the Tile classification [1,2]) result from high-energy injuries and associated vertical instability with rotator instability of the hemipelvis. They are most often treated with surgery, and many techniques of posterior osteosynthesis have been described in the literature [3–6]. The objective of posterior fixation is to provide stable fixation for healing and early mobilization for patients, who often have multiple injuries. The use of iliosacral screws (ISS) is a technique that leaves little impairment, but other than possible mechanical failures, this method is technically difficult and can be contraindicated depending on the shape of the sacrum [7–9]. Consequently, a new unilateral sacroiliac osteosynthesis technique has been developed that controls both the ascension and rotation of the iliac wing, while preserving mobility in the axial plane so that anterior lesions can be reduced if necessary [10].

The objective of this study was to compare the biomechanical resistance of ISS with sacroiliac hinge fixation (SIF) after osteosynthesis of a traumatic injury to the pelvic ring.

Material and methods

Preparation and assembly of anatomical specimens

Fourteen pelves were harvested from fresh cadavers that had no history of pelvic ring fracture. This included the pelvis with the last lumbar vertebra (L5). All the soft tissues were then resected, except for the following ligaments: iliolumbar, sacroiliac, symphysis pubis, sacrospinous, and sacrotuberous ligaments. The specimens were preserved at −24 °C and thawed 24 h before the experiment. The pelves were mounted on a stable fixture, with a 30° sacral tilt (Fig. 1), using bolts at the L5 vertebra and the sacrum (S3).

Making the lesions and posterior osteosynthesis

A lesion simulating a sacroiliac disruption and a pubic disruption was created by sectioning the ligaments with the scalpel, thus releasing the hemipelvis with regard to the rest of the pelvic girdle. Two types of posterior osteosynthesis were used, randomly assigned to the different specimens. In the first group, an ISS technique was used with two 6.5-mm-diameter cannulated screws (Stryker™, Howmedica™, Allendale, NJ, USA), with lengths varying from 65 to 75 mm depending on the size of the pelvis. The trajectory of the two screws perpendicular to the sacroiliac joint terminated at the S1 body, with entry holes separated by at least 15 mm.

The second technique consisted of an SIF, made of CD Legacy Titanium (Medtronic™, Memphis, TN, USA). Two pedicle screws, 5.5 mm in diameter, were inserted in S1 and S2. The S1 screw had a forward, upward, and inward trajectory, terminating under the anterior part of the superior surface of S1. The S2 screw was oriented diagonally outward, parallel to the orientation of the sacroiliac. A 5.5 mm-diameter stem with two sacroiliac connectors were then connected to the screws. After reduction with an external sacroiliac joint maneuver, two screws, 7 mm in diameter and 60–80 mm long, were inserted into the iliac wing, through the two connectors. The upper screw had an upward trajectory, whereas the lower screw was directed toward the ischiatic notch.

In all cases, anterior fixation was associated, using a plate with four holes positioned on the cranial part of the pubic symphysis and maintained by a 4.5 mm-diameter screw.

Application of forces and measurements

First, force was applied vertically at the acetabulum using a hemispheric aluminium piece to simulate monopodal weightbearing (Instron™ 5500R). For each failure test, the force was applied progressively up to 400 N at a speed of 0.1 mm/s (corresponding to 50% weightbearing for a 60 kg patient).

Relative movements in vertical translation and in rotation between the ilium and the sacrum were measured using the Polaris™ optoelectronic reflection tracking system (NDI, Waterloo, ON, Canada). We could therefore study the kinematics of the specimens with an infrared and tripodal transmitter-receptor that had been placed on the sacrum and tuberosity of the ischium (Fig. 2).

The parameters studied were the following:

- displacement in translation along the vertical axis while a load between 100 and 400 N was being applied;
- stiffness between 200 and 400 N, expressed in N mm⁻¹, defined by the ratio between the force and the vertical displacement;
- displacement in rotation (i.e., flexion-extension in the sagittal plane) between the ilium and the sacrum, measured during the T2 test and expressed in degrees;
- the force required for failure, with failure defined as the first reduction in stiffness on the force—displacement curves.
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Figure 2 Posterior view of a pelvis subjected to vertical forces applied at the acetabulum and on which tripods (rigid bodies) of the Polaris™ system have been put in place.

Trial protocol

Given the anatomical damage following the test ending in rupture, it was not possible to study the successive effect of the ISS then SIF on each pelvic ring. Consequently, the specimens were randomized and seven of them were instrumented with hinge fixations (SIF), whereas seven others were synthesized using sacroiliac screws (ISS). Each specimen was then submitted to trials according to the following sequence:

- trial up to 400 N on intact pelvis (T0);
- creation of the posterior lesion (sacroiliac opening) and placement of sacroiliac implants;
- radiological verification of implant position;
- trial up to 400 N on pelvis with posterior fixation only and intact pubis symphysis (T1);
- creation of anterior lesion and placement of anterior pubic plate;
- trial until rupture with combined anterior and posterior osteosynthesis (T2);
- radiological assessment after rupture to analyze the rupture zones.

Statistical analysis

In each group, the stiffnesses and displacements in translation along the vertical axis were compared between the T0, T1, and T2 conditions using paired t-tests. The values obtained in the sacroiliac screw group were then compared to the values obtained in the hinge fixation group using independent t-tests. All the statistical analyses were performed with SPSS version 12.0 software (SPSS Inc., Chicago, IL, USA). Significance was set at $p < 0.05$.

Results

The mean age of the bodies was 66 years ($\pm$ 8 years; range, 47–81 years). There were 10 females and four males.

Vertical displacement

Stiffness

The mean stiffness of the intact pelves (T0) between 200 and 400 N was 219.3 N mm$^{-1}$ ($\pm$ 112 N mm$^{-1}$) for the ISS group and 216.5 N mm$^{-1}$ ($\pm$ 138 N mm$^{-1}$) for the SIF group. The difference between the groups was not significant ($p = 0.96$) (Table 1).

During T1, the mean stiffness decreased from 165.8 N mm$^{-1}$ ($\pm$ 127 N mm$^{-1}$) for the ISSs and 96.6 N mm$^{-1}$ ($\pm$ 33 N mm$^{-1}$) for the SIFs. This decrease was not significant in the two groups, even though they approached the threshold in the SIF group ($p = 0.19$ and $p = 0.06$, respectively). The difference between the groups was not significant ($p = 0.20$).

Finally, during T2, the mean stiffness was 172 N mm$^{-1}$ ($\pm$ 121 N mm$^{-1}$) for the ISSs and 103.5 N mm$^{-1}$ ($\pm$ 30 N mm$^{-1}$) for the SIFs, with no significant T1 condition ($p = 0.59$ and $p = 0.09$, respectively). The difference between the groups was not significant ($p = 0.18$).

Displacement

During T0, the mean of the displacement between 100 N and 400 N was 2.3 mm ($\pm$ 2.5 mm) for the ISSs and 2.1 mm ($\pm$ 1.3 mm) for the SIFs. This difference was not significant ($p = 0.86$).

| Table 1 Stiffnesses (between 200 and 400 N) and displacements (between 100 and 400 N) measured for each condition in vertical translation, after iliosacral screw osteosynthesis (ISS) or sacroiliac fixation (SIF). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Stiffness T0    | Displacement T0 | Stiffness T1    | Displacement T1 | Stiffness T2    | Displacement T2 |
| (N/mm)          | (mm)            | (N/mm)          | (mm)            | (N/mm)          | (mm)            |
| ISS mean (± S.D.) [range] | 219 (± 112) [39–333.5] | 2,3 (± 2.5) [0.95–8] | 165.8 (± 127) [26–385.5] | 4 (± 4.3) [0.9–12.3] | 172 (± 121) [28–394.5] | 3,4 (± 3.3) [1.1–10.3] |
| SIF mean (± S.D.) [range] | 216,6 (± 138) [53–440] | 2,1 (± 1.3) [0.8–4.6] | 96,6 (± 33) [54–154] | 3,5 (± 1.1) [2.8–5.4] | 103,4 (± 30) [59–144] | 3,7 (± 1.6) [2.2–7] |

T0 trial on intact pelvis, T1 trial after sacroiliac lesion and posterior fixation alone with intact symphysis pubis, T2 trial to failure with anterior and posterior osteosynthesis after anterior lesion.

ISS: iliosacral screw; SIF: sacroiliac fixation; S.D.: standard deviation.
During T1, it was 4 mm (± 4.3 mm) for the ISSs and 3.5 mm (± 1.1 mm) for the SIFs. The difference between T0 and T1 was not significant in any group (p = 0.11 and p = 0.06, respectively). The difference between the groups was not significant (p = 0.76).

Finally, during T2, the mean displacement between 100 N and 400 N was 3.4 mm (± 3.3 mm) for the ISS group and 3.7 (± 1.6 mm) for the SIF group. The difference between T1 and T2 was not significant in any group (p = 0.24 and p = 0.49, respectively). The difference between the groups was not significant (p = 0.86).

Rotation displacement

The mean rotation of the iliac wing on the sacrum at 500 N was 0.63° (± 0.1) in the ISS group and 0.70° (± 0.2) in the SIF group, with no significant difference between the groups.

Resistance to failure

The force required for failure was a mean 890 N for the ISS group and 1006 N for the SIF group (p = 0.24). Several types of failure were observed. In the ISS group, there were four cases of screw displacement in the sacrum and three cases of sacral wing fracture. In the SIF group, we observed three cases of sacrum fracture and four cases of sacral screw pullout.

Discussion

Pelvic ring fractures are serious lesions whose functional result depends on the associated neurological and visceral lesions on the one hand, but also on the initial reduction of the displacement [11]. It seems that the results are better if the residual displacement is less than 1 cm, which can only be obtained with internal fixation [3,11–14]. The results of our study show that ISS and hinge fixation are two equivalent techniques for osteosynthesis of pelvic ring injuries, without, however, restoring the biomechanical properties of a healthy pelvis.

Limits of the study

One of the main limits of this study was the mean age of the bodies of the donors whose pelves were tested, since pelvic ring injuries affect for the most part young subjects. The scattering of the results can be explained by the differences in anatomy and bone density between the pelves, which are difficult to obtain. For this reason, some authors prefer to use pelves made of composite materials, which are easier to obtain and have more homogenous biomechanical properties [15,16]. Cadaver bone was preferred in our study so that biomechanical characteristics closer to reality could be obtained.

The results of this in vitro study are encouraging, but their extrapolation to clinical situations runs into a number of unknowns: the difference in bone quality in young subjects, the role of the muscles attached to the pelvic girdle [17], and the loading conditions (seated or upright position, patient’s weight). In addition, only the displacement in vertical translation and in sagittal rotation were analyzed here, whereas Tile et al. [2] showed that monopodal weightbearing in the ipsilateral sacroiliac joint produced flexion, adduction, and internal rotation.

Stiffness and displacement

In the literature, the authors who studied human pelves never found differences between the various types of osteosynthesis [18]. However, Korovessis et al. [15] and Yinger et al. [19] demonstrated the superiority of osteosynthesis using two ISSs on pelves made of a composite material. For this reason, we chose to use two-screw assembly as the reference method for the ISS fixation [15,16]. Nonetheless, no significant difference was demonstrated between the two types of osteosynthesis in terms of stiffness and force at failure. ISSs can therefore be considered a reliable technique for treating lesions of the pelvic ring, at least equivalent to the reference method. The results of this study show satisfactory control of rotation after combined anterior and posterior fixation (< 1° at 500 N), confirming the study by Sagi et al. [20]. The data collected on rotations remain difficult to interpret, given the low level of displacement in rotation recorded on the specimens. This can be explained in part by the fact that the test was performed after combined posterior and anterior fixation, optimal for controlling rotations. Comstock et al. [21] showed that posterior fixation alone could reestablish in rotation 83–91% of the native pelvis’s stiffness. Moreover, the point where the force was applied was not responsible for a high momentum at the sacroiliac level in our protocol. Some authors have preferred to apply the force on the ischium by placing the pelvis in a retroversion position, simulating the seated position. In this configuration, the momentum exerted favored rotation in the sagittal plane.

Resistance to failure

The results of our study showed that the force necessary for failure, for both types of osteosynthesis, were close to the force exerted during weightbearing on one foot in an average-sized patient (approximately 950 N). These values are in agreement with those obtained by Gorczyca et al. [22], who, on eight pelves, compared ISS fixation osteosynthesis with transsacral bar fixation, without demonstrating superiority of one or the other. They also confirm that the hold in the sacrum is the weak point of pelvic ring osteosynthesis in the elderly subject. However, it is probable that the force required for failure in younger patients (corresponding to the population with this type of lesion) be higher because these patients have better bone quality [22]. Moreover, no case of disassembly because of hypermobility was revealed in this study, even though this is a frequent complication in clinical practice.

Clinical relevance

ISS presents the advantage of being a percutaneous technique, thereby limiting the risk of infection. However, this is an osteosynthesis method crossing the joint, guided
by the image intensifier or computed tomodensitometry (CT) and exposing the surgeon to irradiation [23]. Moreover, reduction that must be obtained preoperatively can be difficult, and use of an orthopaedic table is advised [7]. Finally, placing two screws, recommended by the biomechanical studies, increases the risk of nerve lesions [13,19].

SIF, on the other hand, allows open reduction while preserving residual mobility in the horizontal plane, so that anterior lesions can be reduced at a later time. If complementary anterior fixation is not indicated, this mobility can be neutralized by blocking the sacroiliac connectors on the stem. This technique therefore seems indicated in Tile C.1.2-type ruptures of the pelvic ring, associating complete rupture of the posterior arch through the sacroiliac joint and an anterior lesion. It can also be used in cases of bilateral posterior lesions passing through the sacroiliac joints. On the other hand, it is not recommended in lesions going through the sacrum and injuring the S1 pedicle. In a recently published clinical series, no early infectious or mechanical complication was reported [10].

Conclusion

This mechanical study showed no inferiority of the SIF assembly compared to consensual ISS screw assembly. Its continued use is warranted, but its long-term clinical results remain to be evaluated.

Conflicts of interest

None.

References