International Orthopaedics (SICOT) (1994) 18: 96–101

International
Orthopaedics
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# Biomechanical comparison of methods of fixation of isolated osteotomies of the posterior acetabular column

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Accepted: 5 October 1993

**Summary.** *Ten fresh frozen specimens of a hemi-pelvis, including the hip joint, capsule and proximal femur, from elderly cadavers were used to evaluate three methods of internal fixation of isolated posterior column osteotomies. Intact and reconstructed specimens were tested at 30° and 60° of hip flexion in a specially designed joint simulator. The three methods of fixation used were a single 3.5 mm reconstruction plate, two such plates, and a 4.5 mm lag screw with a single plate. Motion at the fracture site in three orthogonal directions, and the overall stiffness of the construct, were recorded simultaneously. No significant differences were noted in stiffness for the three procedures and all retained 80% of the intact stiffness. At 60° of flexion, smaller interfragmentary compliances were allowed by fixation with a lag screw and a neutralisation plate ($p < 0.05$). At 30°, the position of the load plane relative to the fracture plane allowed less interfragmentary motion, so that no significant differences were found between the 3 methods.*

**Résumé.** *Dix hémi-bassins comportant la capsule articulaire de la hanche et le tiers supérieur du fémur ont été prélevés sur des cadavres frais congelés, afin d'évaluer trois méthodes actuellement utilisées pour l'ostéosynthèse des fractures isolées de la colonne postérieure du cotyle. Cette fracture a été simulée par une ostéotomie. Les spécimens intacts et reconstruits ont été montés dans un appareil à tester les matériaux, simulant un mouvement articulaire. Les tests ont été effectués à 30° et 60° de flexion de hanche. Trois types d'ostéosynthèse ont été étudiés séquentiellement sur chaque hémi-bassin: une plaque à reconstruction de 3,5 mm, deux de ces plaques placées sur la colonne postérieure, soit enfin une vis de traction de 4,5 mm associée à une plaque de neutralisation. Les déplacements interfragmentaires dans trois directions perpendiculaires ainsi que la rigidité globale du système ont été enregistrés simultanément pendant les tests. Concernant la rigidité, aucune différence statistiquement significative n'a été notée entre les types de fixation pour les deux amplitudes articulaires. Les hémi-bassins reconstruits ont tous atteint 80% de la rigidité des spécimens intacts. En terme de déplacement interfragmentaire, à 60° de flexion de hanche, les fractures fixées par la vis de traction et une plaque de neutralisation se sont révelées plus stables que les autres ($p < 0,05$). A 30° de flexion, les déplacements interfragmentaires sont restreints et les différences ne sont pas statistiquement significatives.*

## Introduction

Open reduction and internal fixation is widely recognised as the treatment of choice for acetabular fractures where there is incongruity greater than 3 mm and/or instability of the hip joint. Operation carries risks of the usual general and local complications of infection, deep vein thrombosis, sciatic nerve palsy and heterotopic ossification. There may also be specific problems associated with internal fixation such as intra-articular penetration of screws or loss of fixation, which may

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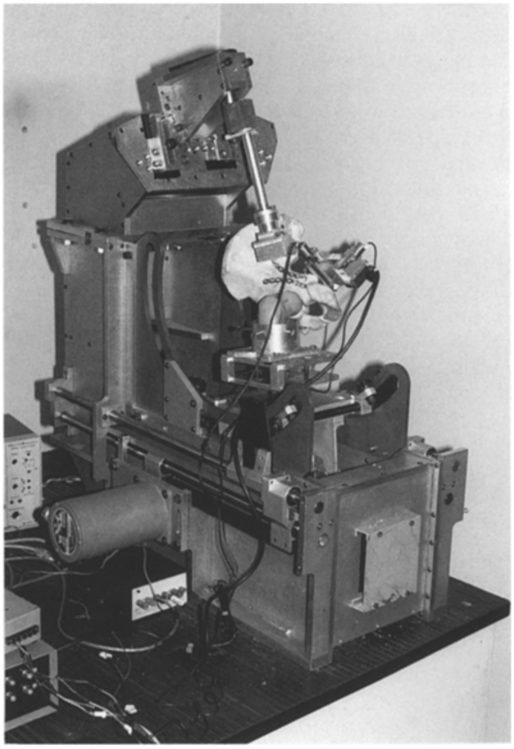

**Fig. 1.** Joint simulator in which the hemipelvis is attached proximally through the iliac wing. The proximal femur is fixed to the movable carriage allowing for different angles of hip flexion

lead to the rapid development of osteoarthritis or chondrolysis [1, 2, 5, 7, 14].

Anatomical reduction and stable fixation are essential for the best longterm clinical results [4, 5, 14], particularly since malunion can result in accelerated degradation of articular cartilage. Letournel reported good clinical results in 75% of surgically treated acetabular fractures followed for 2 to 21 years. This figure increased to nearly 90% good or excellent results when the initial reduction was anatomical and was maintained, but was only about 55% when reduction was imperfect [4].

Procedures using plates or lag screws, or both in combination, have been advocated for fixation of posterior column fractures [3, 5, 7, 10, 14]. Few studies have assessed the biomechanical efficacy of the fixation methods of acetabular fractures [6, 13], while none have considered posterior column fractures which occur frequently in high energy fractures of the acetabulum. This simple fracture pattern is of clinical significance and is easily reproducible with an osteotomy.

This study was undertaken to evaluate and compare, by in vitro mechanical testing, the stability provided by plate and/or lag-screw fixation of the osteotomised posterior column of the acetabulum.

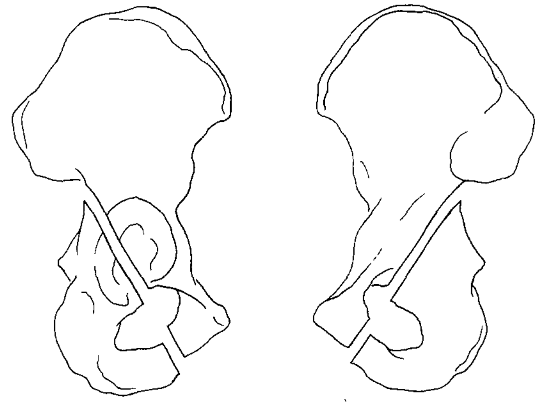

**Fig. 2.** Position of the osteotomy line simulating a typical isolated posterior column fracture of the acetabulum, viewed from inside and outside the pelvis

## Materials and methods

Ten fresh unembalmed pelves, providing two paired specimens for testing, were removed from cadavers of individuals whose ages had ranged from 57 to 89 years (mean 74 years). The femur was divided 8 cm distal to the tip of the greater trochanter. The specimens were frozen at –20° C. Thawing at room temperature for 16 to 20 hours was carried out before biomechanical testing, and the tissues kept moist with water before and during the experiments. Soft tissues were removed except for the capsule of the hip joint.

Each hemipelvis was then mounted in the load train of a specially designed joint simulator which was capable of providing control axial loading and rotational displacement. A proximal fixture, secured to the wing of the ilium, was used to establish neutral alignment of the innominate bone. The distal end of the femur was placed in a pot of bismuth alloy of low melting point and attached rigidly to a mobile carriage which was supported by the side plates of the simulator (Fig. 1). Rotational translation of this carriage was used to determine the angle of hip flexion, tests being carried out at 30° and 60° relative to the anatomically neutral orientation of the pelvis and femur. A coronal reference frame was established by aligning the anterior/posterior iliac spines with the pubic tubercle, and marked by three orthogonally placed Kirschner wires fixed to the posterior superior iliac spine. These wires were used to confirm the alignment of the construct relative to the rotational and load axes of the simulator which ensured that the load axis of the femur passed through the centre of the hip joint. An axial force of 550 N (0.75 times body weight), with a two second duration, was applied to the femur which provided load transfer to the acetabulum. This load was well below physiological levels so that multiple tests could be carried out without the specimen failing. The specimens were preconditioned by cyclical loading at 0.5 Hz for 60 seconds before data was collected.

After testing the intact bone, the hemipelvis was removed from the simulator and a typical isolated posterior column fracture was created using an oscillating saw (Fig. 2). Three types of surgical fixation were sequentially and randomly

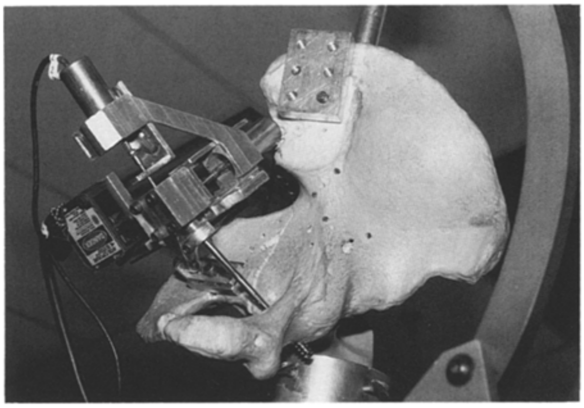

**Fig. 3.** Measurement devices attached to an aluminium fixture fixed to the posterior column fragment. The target is clamped to a cancellous bone screw fixed onto the superior pubic ramus, and sits so that the three devices measure the interfragmental displacements in three orthogonal axes

performed on each hemipelvis. The methods used were single plating along the posterior column, double plating, and a lag screw combined with a single neutralisation plate.

An aluminium fixture, consisting of mutually orthogonal attachments for two linear variable differential transducers (LVDT), and for one laser displacement transducer, was attached to the posterior fragment. A one inch cubic target was fixed with a cancellous bone screw into the superior pubic ramus and aligned so that each measurement device was seated perpendicular to one face of the cube (Fig. 3). A hinged alignment jig, partially seated in the fracture, located the mounting holes of the fixture in the distal fragment and positioned the fixture relative to the plane of the fracture so that the two LVDTs could be aligned within this plane to record vertical and mediolateral shear displacement at the fracture site. The laser transducer was aligned perpendicular to both LVDTs and measured anteroposterior separation of the fragments. By so aligning the transducers all compliance measurements were relative to the fracture plane and not the load plane. Comparisons of complicance measurements could therefore be made between different specimens without having to ensure that all fracture planes maintained the same relative position and orientation in each hemipelvis tested. The set-up allowed the recording of motion at the fracture site in three orthogonal directions simultaneously, as well as the overall stiffness of the construct.

Each construct, with the measurement hardware attached, was remounted in the simulator in the same location which had been used for the tests on the intact pelvis. This technique maintained the same relative compliance associated with the simulator and the bone, and thus permitted comparison of the intrinsic stiffness of the intact and surgically reconstructed hemipelvis. The orientation of the fracture plane was noted relative to the line of force of the simulator and the hip orientation, and was expressed in terms of the previously defined reference frame.

A 386 sx microcomputer, with data acquisition interface, was used to record digitally the output signals from the measuring devices, as well as the axial displacement of the femur and force output from the load cell of the joint simulator. Data collection was carried out at a sampling rate of 100 Hz for 10 seconds and stored digitally for subsequent analysis.

*In vitro surgical techniques.* The three types of surgical fixation were assessed biomechanically. Nine-hole 3.5 mm AO reconstruction plates were used and carefully contoured to the posterior column with a template. The single lag-screw was a 4.5 mm AO cortical screw, 70 to 80 mm long, which was inserted from the distal fragment, parallel to the quadrilateral plate, aiming upwards towards the iliopectineal line, as perpendicular as possible to the plane of the fracture.

Single plate fixation or neutralisation plating involved placing the plate along the lateral aspect of the posterior column, positioned so that three screws could be placed on either side of the fracture line. The intermediate holes proximal to the sciatic spine were left empty as is usually recommended in order to avoid penetrating the articular surface [1, 14].

Double plating involved anchoring a second contoured plate medial to the first, along the inner edge of the posterior column. The plates were fixed with 3.5 mm AO cortical screws angled away from the hip joint.

The final reduction for all methods of fixation was checked visually and by digital palpation along the fracture lines. Figure 4 shows an example of each method.

Six tests were carried out on each reconstructed specimen for the three methods of fixation and the two hip alignments. The sequence of the type of fixation could be random since none of the screw holes interfered with previous ones, and the sequence of testing had no apparent effect on the mechanical behaviour of the tested specimens.

*Statistical analysis.* The stiffness data, and the compliance data from the three orthogonal axes of interfragmentary displacement, were independently compared by three-way analysis of variance followed by contrasts. A level of $p < 0.05$ was considered to show a significant difference between means for the intact and reconstructed specimens, between the positions of hip flexion, or between methods of fixation.

## Results

The mean overall stiffness of the 10 intact and reconstructed specimens for each surgical procedure at both orientations of hip flexion on 10 specimens is shown in Fig. 5. Each value was obtained by first averaging 4 successive loading cycles, as the load increased in the range of 200 to 400 N. These values were subsequently averaged across the test specimens for corresponding methods of fixation.

No statistically significant differences were noted in the stiffness measurements between the various surgical procedures tested at either hip orientation. Reconstructed specimens maintained a mean 82% of the stiffness of the intact specimens. For all intact and reconstructed specimens, the stiffness at 30° of flexion was greater than at 60° as was to be expected, since hip flexion increases the bending moment of the femoral force transferred to the posterior column. All tests of the reconstructed specimens were carried out with the fracture plane tilted 5° to 10° to the load plane when positioned in 30° of hip flexion. Thus at 60°

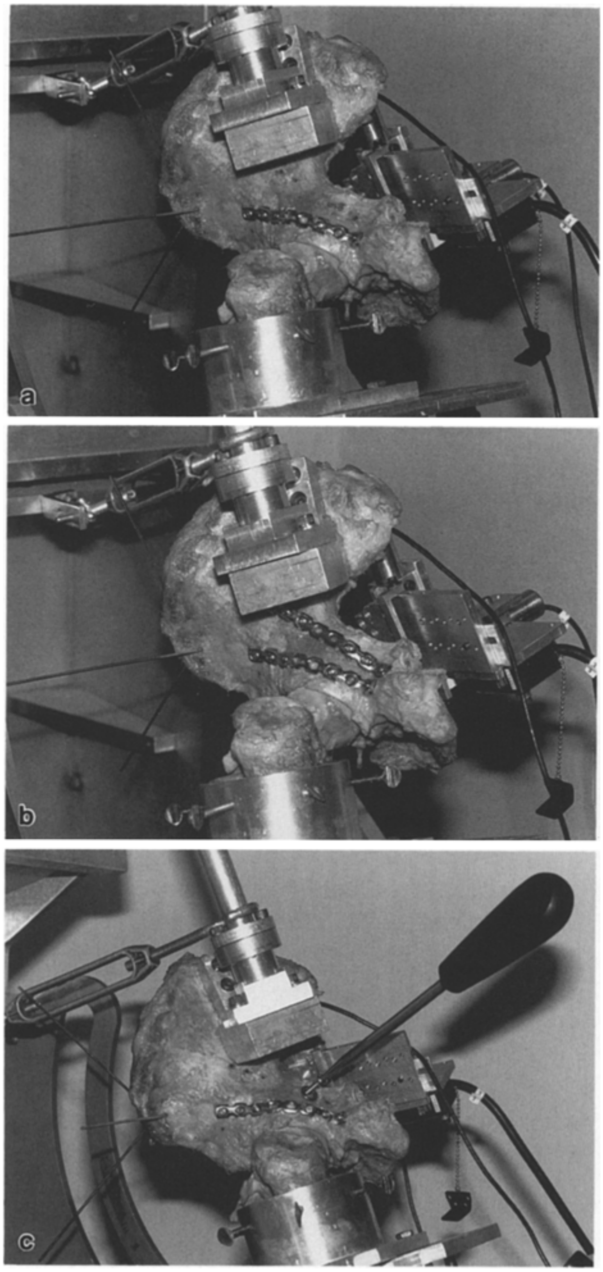


**Fig. 4a–c.** The three different constructs tested on each specimen. Three orthogonally placed K-wires in the anterior-superior iliac spine allow for neutral positioning of the hemipelvis in the simulator. **a** One 3.5 reconstruction plate; **b** two 3.5 reconstruction plates, **c** one 4.5 mm cortical lag screw and a neutralization plate. The screwdriver placed in the screwhead shows the direction of the lag screw aiming towards the pelvic brim

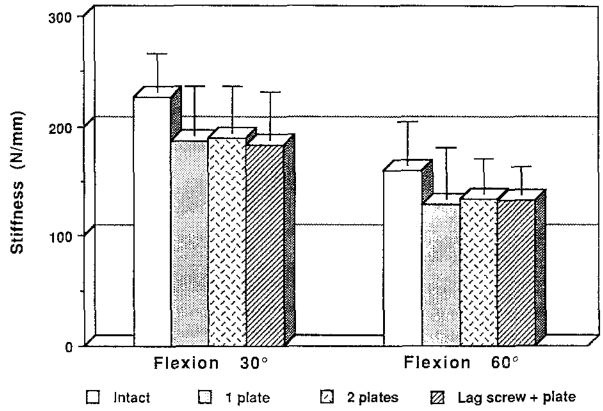


**Fig. 5.** Mean overall stiffness (in Newtons per millimeter of axial displacement) of the intact and reconstructed specimen. There are no significant differences between the fixations at either position of hip flexion

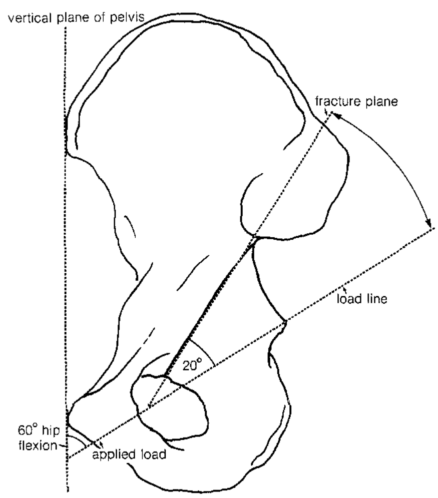


**Fig. 6.** Diagram showing the posterior inclination of the load line with respect to the fracture plane when the load is applied at 60° of hip flexion

of flexion, the load plane lay 20° to 25° posterior to the fracture plane, and resulted in loading of the posterior column predominantly (Fig. 6).

Mean compliances of the posterior columns are illustrated in Fig. 7. Shearing motion within the fracture plane is defined by the vertical and medio-lateral axes. Larger interfragmentary displacements occurred at 60° hip flexion and were greatest in an anteroposterior direction, which represented separation of the fracture surfaces. Typical load/displacement curves for each fixation method are shown in Fig. 8. The best stability with the least interfragmentary motion was achieved with a lag screw and a neutralisation plate which had the lowest mean compliance ($p < 0.05$). Single plate fixation permitted the greatest displacements in all three reference direction with the highest mean compliance ($p < 0.05$).

No significant differences were found between the three methods at 30° of hip flexion.

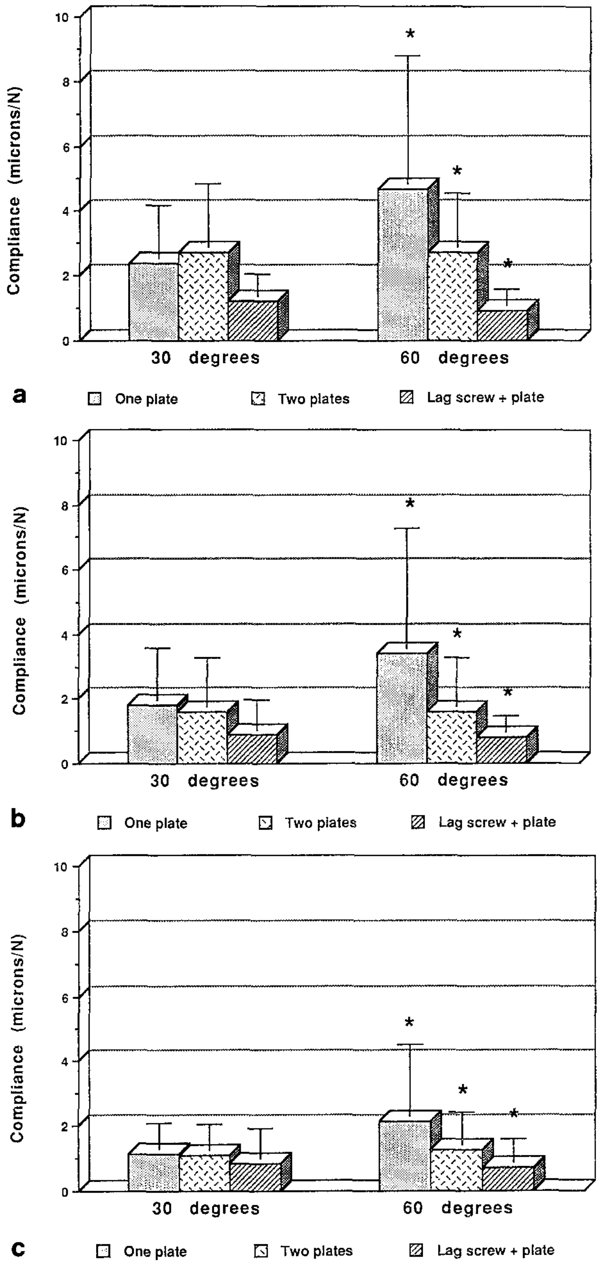


Fig. 7 a–c. Mean compliances of the reconstructed acetabulum at either 30° or 60° of hip flexion (in microns of interfragmental displacement per Newton of applied load); **a** anterior-posterior interfragmental displacement, **b** medial-lateral interfragmental displacement, **c** vertical interfragmental displacement; * $p < 0.05$

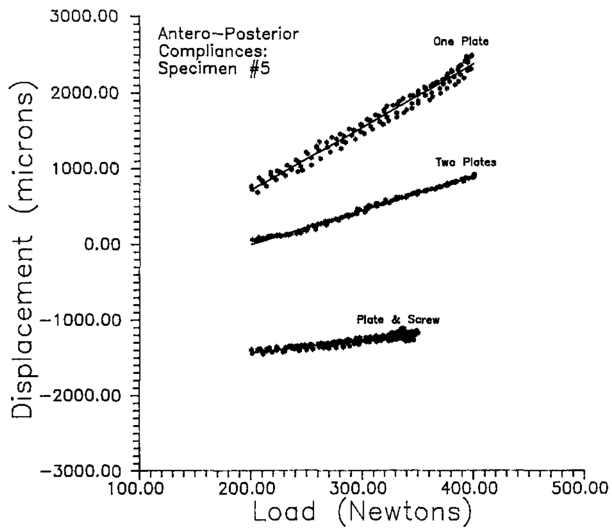


**Fig. 8.** Typical load/displacement curves for the three different constructs; this example shows the anterior-posterior displacements. The data from four successive loading cycles are plotted for each fixation, showing their reproducibility

## Discussion

Our results have demonstrated that the stiffness of the reconstructed acetabulum is not an adequate measure of the differences of stability provided by the different methods of fixation. Stiffness values were not only affected by the mechanical properties of the acetabulum and implants, but also by those of the whole innominate bone, the joint simulator and the mounting fixtures. These measures, however, effectively resolved the effects of load direction associated with the orientation of the hip.

Interfragmentary compression lag-screws have been advocated as the best initial stabilisation of acetabular fractures [3, 7, 9, 14]. Other surgical techniques have used reconstruction plates alone. Further, double plating of the posterior column has been recommended in order to improve fracture stability and decrease possible complications by avoiding the technically more demanding placement of lag screws (R. Winquist, personal communication). The dangers of penetrating the joint or the pelvis by screws, and the extreme precautions taken to avoid this complication, have been stressed by most authors [1, 2, 9, 10, 12].

In a cadaveric study of transverse acetabular fractures fixed by one reconstruction plate of three different types on the posterior column, and either another plate or a cancellous bone lag-screw for the anterior column, no significant differences were found between the different methods of fixation. Very small amounts of interfragmentary motion were recorded under loads of twice the body weight and it was concluded that these methods of fixation were secure enough to allow the patient to sit up on the first day after operation [13].

Another recent study evaluated the effects of different methods of fixation in comminuted fractures of the posterior acetabular wall and showed an improvement in stability, as measured by local displacement at the fracture site, when a buttress reconstruction plate was added to screws placed through individual fragments [6]. No other biomechanical data assessing stability provided by different types of internal fixation around the acetabulum was available in the literature.

Our results have shown that lag-screw fixation plus neutralisation plating provided greater stability in our posterior column model. Although compliance values for double plate fixation were on average 45% lower than for single plate fixation, and thus gave improved stability of fixation, they were still 30% greater than single plating combined with a lag screw. Our experiments demonstrated the effect of hip flexion during loading of the osteotomy site through the acetabulum; differences were found at 60° of flexion, while at 30° the less posteriorly tilted position of the load line relative to the fracture plane resulted in smaller interfragmentary compliances so that no significant differences were found.

Elderly denuded cadaveric specimens represent the worst conditions with regard to bone stock and soft tissue attachments, but the best for safe placement of the screws. The specificity of the fracture pattern tested, the strictly axial direction and amount of loading, which was below the physiological level, limit the application of such an in vitro biomechanical study. The ideal level of stability to warrant early rehabilitation without risk of failure of the fixation and secondary displacement has not yet been determined clinically. Extrapolation to in vivo conditions is impossible because of these limitations, and conclusions have to be drawn with caution.

Nevertheless, our data are in accordance with the previously demonstrated, and widely accepted, value of lag screws in the fixation of long bone fractures [11]. They provide a legitimate comparison of the mechanical effectiveness of internal fixation of posterior column fractures which may be relevant clinically. When technically possible, and safe for the patient, we recommend the use of lag screws around the acetabulum as a supplement to single plate fixation. If this is precluded by the pattern of the fracture, double plating can be considered.

*Acknowledgements.* This study was supported by a grant from the AO/ASIF Foundation, Switzerland. The authors thank Mrs C. Griffiths and Mrs C. Woodside (Synthes, Canada) for generously providing the implants used in this study, Dr J. P. Szalai and Dr M. Katic for their expert statistical guidance, and Dr I. A. Harrington of the Toronto East General Hospital for the use of the joint simulator.

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