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Stability of acetabular fractures after internal fixation

A cadaveric study

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The rigidity of a transverse acetabular fracture in a laboratory cadaveric model immobilized by internal fixation was studied. On the application of a longitudinal load imposed on the fifth lumbar vertebra, four modes of displacement of the acetabular fracture were monitored by the use of variable impedance transducers. The rigidity of various combinations of lag screws and plates was assessed.

The fracture deformations documented were generally quite small at any observation point with any of the fixation methods, and in most cases they were recoverable on load release. Anterior column lag screw fixation combined with plate fixation of the posterior column provided a degree of stability indistinguishable from that of other methods, and allowed the minimal exposure and devascularization of the pelvis. The 3.5 mm reconstruction plate, which is readily contoured to the intricate peri-acetabular bony structure, showed no significant difference in rigidity compared to the other apparently more rigid plates under study.

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Several methods of internal fixation of acetabular fractures have been reported (Levine 1943, Urist 1948, Elliott 1956, Okelberry 1956, Knight & Smith 1958, Judet et al. 1964, Letournel 1980, Pennal et al. 1980, Riska et al. 1980, Tile 1980), but the various methods have not been compared experimentally. A laboratory study was therefore undertaken to compare the mechanical rigidity that could be achieved by the use of lag screws to that achieved by buttress and neutralization plate and combined techniques.

Materials and methods

Nine fresh, unembalmed cadaveric pelves were obtained from males less than 70 years of age who had expired from diseases, such as myocardial infarction, which are unrelated to the skeletal system. The fifth lumbar vertebra and the proximal one-third of both femurs were included in the specimens. The specimens were grossly cleaned and frozen, then thawed at room temperature immediately prior to the biomechanical tests.

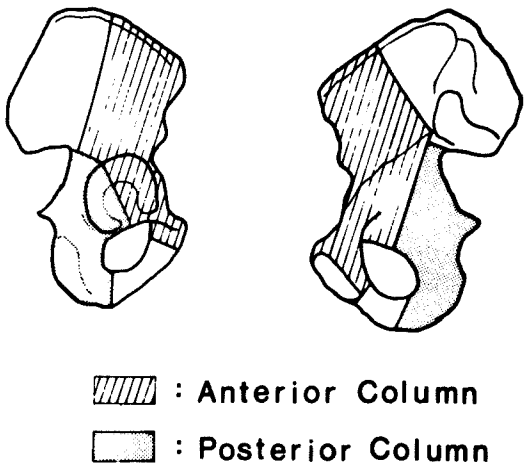

Figure 1. Lateral (left) and medial (right) views of the columns of the acetabulum.

The variety and unusual biomechanical complexity of acetabular fracture configurations favor an experimental rather than an analytical evaluation of the rigidity of internal fixation. A transverse central acetabular fracture was adopted as a representative acetabular fracture involving both columns (Figure

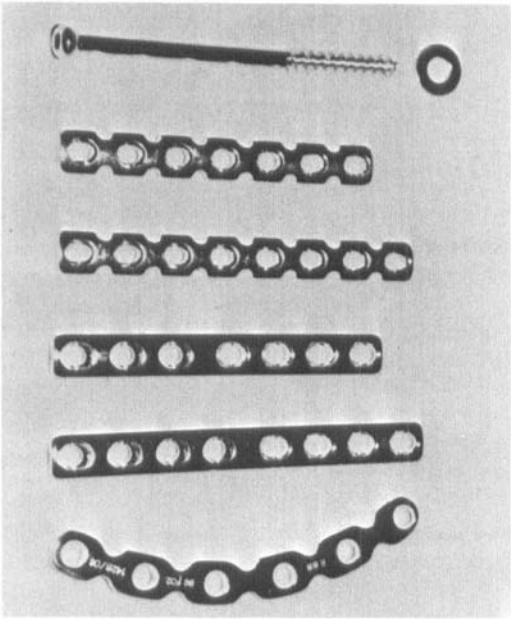

Figure 2. Internal fixation devices employed in this study. From the top, a 32 mm threaded 6.5 mm AO cancellous screw, 90 mm in length, with a washer; a seven-hole 3.5 mm Reconstruction Plate; an eight-hole 3.5 mm Reconstruction Plate; a seven-hole 3.5 mm Dynamic Compression Plate; an eight-hole 3.5 mm Dynamic Compression Plate; and a six-hole Letournel Plate.

1). This fracture model was created reproducibly in the cadaveric pelvis by the use of a chisel. The fracture line was prepared 1 cm below the base of the anterior inferior iliac spine and passed through the highest point of the cotyloid fossa.

The anterior column was secured with one of the following: a 3.5 mm Dynamic Compression Plate* (D), a 3.5 mm Reconstruction Plate* (R), a Letournel plate† (L), or a long (32 mm) threaded 6.5 mm AO cancellous screw* (S) (Figure 2). In the appropriate cases, the anterior column plate was applied from the inner surface of the ilium to the superior surface of the superior pubic ramus. When screw fixation was employed, the screw was inserted with a washer from the outer surface of the ilium superior to the acetabular dome into the superior pubic ramus (Figure 3). In all of these cases the posterior column was immobilized with a plate which extended from the outer surface of the ilium to the ischial tuberosity. All of the plates were secured with 3.5 mm cortical screws (Synthes Ltd., Wayne, Pennsylvania, USA).

For the purpose of comparison, plates and screws of identical length were used. With the 3.5 mm Dynamic Compression and Reconstruction Plates, seven holes were used for the anterior column, and eight holes were used for the posterior column. For the Letournel plate, six holes were used for both columns. For the anterior column lag screw, a 6.5 mm cancellous screw, 90 mm in length, was used (Figure 2). Six different combinations of implants were used to fix the anterior and posterior column: D-D, R-R, L-L, S-D, S-R, and S-L. These combinations were studied with a particular testing sequence which minimized the potential for artifactual losses in screw purchase.

The specimens were subjected to quasi-static (1.27 cm per min) longitudinal compressive loading of the fifth lumbar vertebral body, up to a maximum of 1334 N. The pelves were mounted in a standing position and supported distally by articulation with intact femoral heads. The latter were potted in separate epoxy resin blocks. The loads were supplied by an Instron unit with a constant crosshead speed (Figure 4). Active muscular loading was not included in the model. The resulting deformation at the fracture site was measured by non-contacting variable impedance transducers (Proximity Measuring Sys-

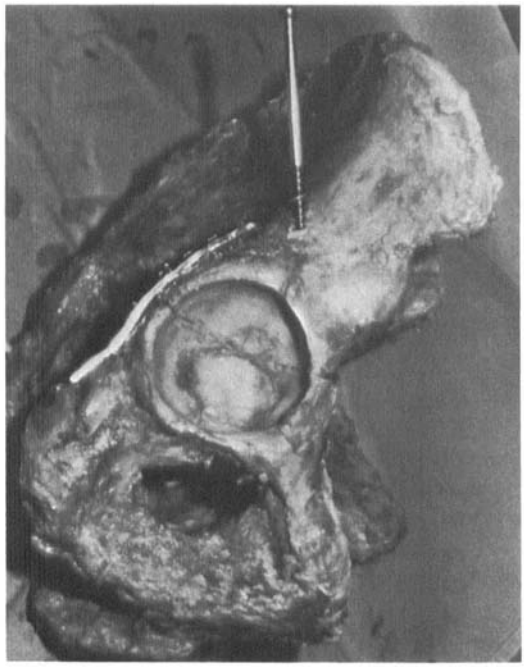

Figure 3. The anterior column fixation with the screw. The 6.5 mm AO cancellous screw with a washer is inserted from the outer surface of the ilium, above the acetabular dome into the superior pubic ramus. A posterior column plate can also be seen. An experimental transverse fracture line traverses from a point 1 cm below the base of the anterior inferior iliac spine and passes through the highest point of the cotyloid fossa.

* Synthes Ltd., Wayne, Pennsylvania, USA.

† Howmedica, Inc., Rutherford, New Jersey, USA.

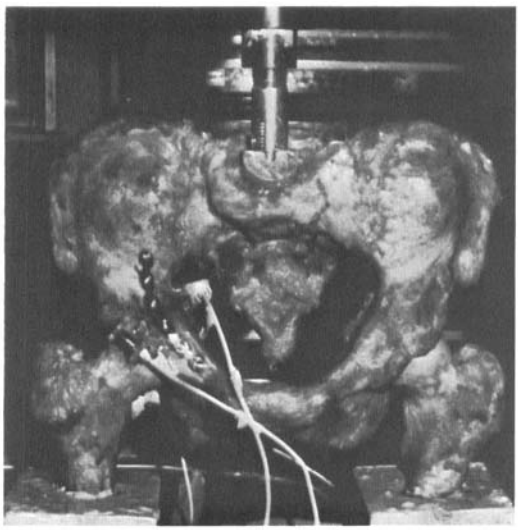

Figure 4. Specimen mounting arrangement for the measurement of acetabular fixation rigidity. Non-contacting electromagnetic displacement transducers mounted across the fracture line record shearing displacement along the quadrilateral area [T_1] and anterior column fracture gap normal movement [T_4].

tem, Model KD-2400, Kaman Sciences Corp., Colorado Springs, Colorado, USA). The transducer coil and a circular brass target were mounted on opposite sides of each experimental fracture. The measurement of planar axial displacement of the metallic target face relative to the coil permitted an assessment of the linear fracture displacement. Bench tests showed that the transducer output varied linearly with axial target displacements of up to 1.75 mm. The magnitude of the output signal was imperceptibly changed for transverse target displacements of less than 1.5 mm or for rotational target displacements of less than 15 degrees.

The resultant deformations were measured at four sites: shear [T_1] along the quadrilateral area, posterior column fracture gap normal (opening or closing) movement [T_2], posterior column fracture shear [T_3], and anterior column fracture gap normal movement [T_4] (Figure 4). The four displacement transducer outputs were displayed simultaneously against the Instron load cell output on a storage oscilloscope, i.e. in the form of load-deformation curves. The data traces were photographed for subsequent analyses.

To perform the tests with a limited number of pelves, two different combinations of fixation were tested on each acetabulum. Care was taken to avoid coming within two diameters of existing screw holes when inserting screws to secure a second plate. As to the anterior column, if a lag screw was inserted for the first combination of fixation, a plate was always used as the second combination of fixation. Also, the order of testing of different fixation methods was changed on every acetabulum. As bilateral acetabula were used, after completion of testing of the first acetabulum, its fracture was fixed very rigidly, using many plates and screws, to avoid any possibility of mechanical compromise of the contralateral acetabulum. Thus, four tests were performed on each pelvis. Using nine pelves, six independent tests could therefore be performed, for each of six different fixation modes.

Results

A considerable degree of variability was documented in the configuration of the load-deformation curves. Near linearity in the upload phase was observed in roughly half of the individual measurements, although a substantial hysteresis effect was recorded when the load was released. When the upload curve was distinctly nonlinear, the hysteresis was almost always appreciable. These upload nonlinearities most often involved an asymptotic approach toward a limiting deformation (i.e. increasing rigidity) as peak load was approached. Despite the degree of nonlinearity or hysteresis, however, almost always 90 per cent or more of the observed peak deformation was recovered upon load release. Moreover, the displacement magnitudes involved were generally quite small (series average = 0.096 mm, range = 0.006 to 0.455 mm), confirming the visual observation of gross integrity of fixation in all of the cases under study.

No consistent direction of displacement was observed for any of the transducers, irrespective of the methods of fixation. Since the degree of motion at the fracture site is the main obstacle to bony union, irrespective of its direction, the largest absolute value of the fracture deformations documented during a loading cycle was the principal point of interest.

The complete conspectus of the data accrued for the transducer site displacements documented with the various fixation alternatives is shown in Figure 5. No measurement site consistently demonstrated a larger displacement than any other, irrespective of the type of fixation. This findings was confirmed by inde-

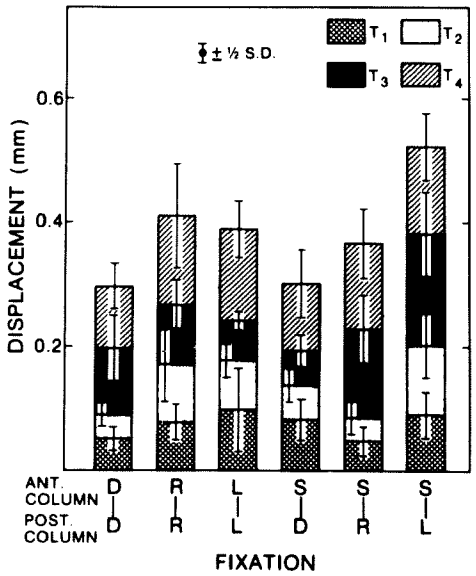

Figure 5. The transducer site displacement occurring with respect to the various fixation alternatives.
D: 3.5 mm Dynamic Compression Plate
R: 3.5 mm Reconstruction Plate
L: Letournel Plate
S: 32 mm threaded AO 6.5 mm cancellous screw
T_1: Shear along the quadrilateral area
T_2: Posterior column fracture gap normal movement
T_3: Posterior solumn fracture shear
T_4: Anterior column fracture gap normal movement
Assuming that the measured displacements behave statistically as normally-distributed variables, the 95% and 99% confidence levels were 1.96 and 2.58 standard deviations, respectively.

pendent groups t-testing. More importantly, the data fail to show clearly statistically significant ($p < 0.001$) or even marginally statistically significant ($p < 0.01$) differences between any of the fixation alternatives at any of the transducer sites.

Discussion

Intramedullary fixation of the anterior column with a lag screw was first introduced by Elliott (1956), using Hagie pins. He, however, did not use internal fixation to secure the posterior column. Senegas et al. (1980) described the insertion of a screw obliquely across the anterior column along with a plate to immobilize the posterior column, and achieved accurate realignment of the fracture fragments. In the present biochemical evaluation, the scatter of the measurements is appreciable, and the number of specimens under study is greatly limited by logistical problems. Nevertheless, the data clearly show that the method of anterior column lag screw fixation plus posterior column plate fixation provides a degree of stability indistinguishable from other methods under study.

Anterior column lag screw fixation can be readily undertaken by the use of our triradiate incision (Mears & Rubash 1983) with minimal stripping of soft tissues and devascularization of the inner aspect of the ilium and the superior pubic ramus. When the anterior column is secured with a plate, the inner surface of the ilium, distal to the superior ramus of the pubis requires extensive exposure and a potentially hazardous elevation of the femoral neurovascular structures. To insert an anterior column lag screw, the exposure is limited to the fracture site generally adjacent to the anterior inferior iliac spine.

While the data showed no significant difference in the rigidity afforded by the three plates under study, the crucial problem of contouring the plates to precisely replicate the complicated three-dimensional peri-acetabular bony structure is greatly reduced by the use of a 3.5 mm Reconstruction Plate. This plate is rapidly and accurately shaped by the use of its special contouring device and bending irons.

While the load imposed on the lumbar spine during unsupported sitting is about 1.4 times body weight, it is reduced by supported sitting (Nachemson 1975). The displacement magnitudes at fracture sites were quite small, and permanent deformations seldom occurred when the load of 1334 N (roughly two times the body weight of a 70 kg person) was exerted. This result provides evidence that a patient can sit up on the first postoperative day, provided that secure fixation of a simple fracture pattern is obtained during surgery.

Despite the apparent equivalent stability of screw and plate fixation of the anterior column achieved in benchtop work documented in this study with denuded cadaver pelves, the absence of active muscular deforming forces provides an obvious potential source of an experimental error. Nevertheless, the results appear

to provide a legitimate comparison of the relative mechanical effectiveness of an anterior column lag screw fixation and a plate fixation of the posterior column, which is relevant for the clinical situation.

Our laboratory study was performed with a "simple" transverse fracture model. Of course, in the presence of a comminuted fracture, some modification in the fixation technique is needed to provide sufficient stability.

Acknowledgements

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