

External fixation of the pelvic ring

An experimental study on the role of pin diameter, pin position, and parasymphyseal fixator pins

Kees-Jan Ponsen¹, Pieter Joosse¹, Gilbert A Hoek van Dijke² and Chris J Snijders²

¹Trauma Unit, Department of Surgery, Academic Medical Centre, University of Amsterdam, Amsterdam, ²Department of Biomedical Physics and Technology, Faculty of Medicine, Erasmus University Rotterdam, Rotterdam, the Netherlands

Correspondence K-JP: K.J.Ponsen@amc.uva.nl

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Background The mechanical properties of current external fixator systems for unstable (type C) pelvic ring fractures are inferior to internal fixation, and are not optimal for definitive treatment. We explored methods to increase stability of external fixator constructs.

Methods An experimental model was used for load tests. The same pelvic fixator was used while different pin diameters, pin positions, and modes of pubic symphysis fixation were tested.

Results Changing of the pin diameter of the unthreaded part from 6 to 8 mm resulted in an increase in stiffness of 20%. An increase in stiffness by a factor of 1.9 was found by placing a pin on the iliac crest and one supra-acetabular. An additional increase by a factor of 3.6 was obtained by adding pubic symphysis plate fixation. Parasymphyseal pin fixation instead reduced stiffness, but not so much as when parasymphyseal pins were connected to the external fixator of the pelvic ring. The final configuration was at least 6 times stiffer than the initial configuration.

Interpretation The new concept of parasymphyseal pin fixation connected to an external fixator of the pelvic ring produces a considerable increase in stability for the treatment of type C pelvic ring injuries, as does an increase in pin diameter and alternative pin positioning.

In the initial management of unstable pelvic ring injuries, external fixation can play an important role (Garbuglia et al. 1998, Vrahas et al. 1998).

However, the mechanical properties of the current external fixator systems are not optimal for definitive treatment; the long-term outcome is not satisfying (Pohlemann et al. 1996, Lindahl et al. 1999).

Experimental and clinical studies have shown that the mechanical stability of internal fixation of the disrupted pelvic ring is far superior to that of external fixation (Tile 1988, Culemann et al. 2000, Yinger et al. 2003, Sagi et al. 2004). Thus, several authors prefer definitive internal stabilization of the anterior and posterior pelvic ring. In most cases this is technically demanding, especially with regard to the posterior pelvic ring (Rouff, Jr. et al. 1995a, 1996, Templeman et al. 1996, Pohlemann et al. 1998, Burkhardt et al. 2005).

As can be concluded from the results in the literature (Gansslen et al. 1996, Garbuglia et al. 1998, Siegmeth et al. 2000), the majority of patients with unstable pelvic ring injuries do not receive internal fixation of the posterior pelvic ring, despite the unfavorable outcomes and insufficient mechanical stability of external fixation alone. On behalf of the German working group “Pelvis”, Pohlemann et al. (1996) published a large series on treatment and outcome of pelvic ring injuries. In this prospective multicenter study of 1,722 pelvic ring injuries, some form of internal or external fixation of the anterior pelvic ring has been reported in 54/186 of type C injuries (29%). The rate of internal or external fixation of the posterior pelvic ring was about 35% in type C injuries (65/186). Thus, it seems

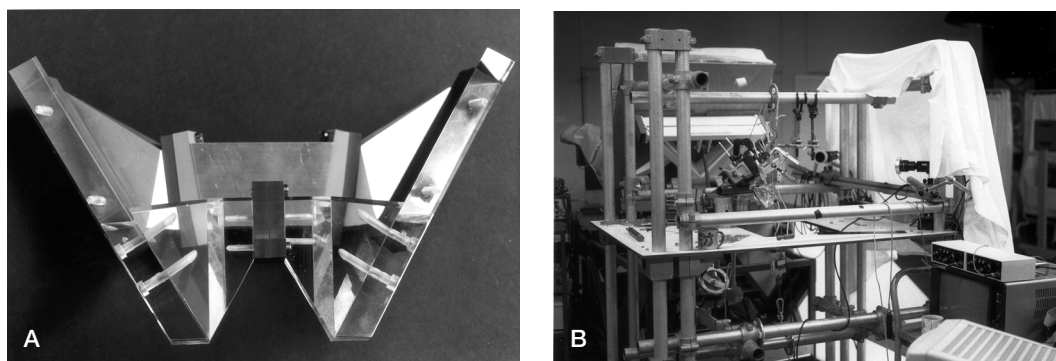


Figure 1. Photographs of the pelvic model made of perspex and aluminium (A), and the loading apparatus (B).

relevant to further optimize the performance of external fixation of the pelvis. In this experimental study, we tested the effect of pin modification, different pin positions, and a combination of external fixation of the iliac crest and pubic bone. Furthermore, we describe a new mode of anterior pelvic ring stabilization.

Material and methods

In previous studies, we developed a pelvic model made of perspex and aluminium (Figure 1) in order to guarantee identical geometry and a reproducible method of pin fixation in each test (Ponsen et al. 2002, 2003). The model was interrupted at the sacroiliac joint and the pubic symphysis, creating a situation analogous to an unstable pelvic ring disruption (Tile/AO type C1).

The pelvic model was mounted in a specially developed loading apparatus (Figure 1), which was initially used in a study of human pelvis specimens by Vleeming et al. (1989). The injured hemipelvis was connected to the rigid basis of the loading apparatus, while a vertical pulling force was applied at a point just ventral to L5 and 15 mm lateral from the midline at the uninjured side. This loading situation simulates weight bearing on the leg of the injured hemipelvis. Thus, the injured hemipelvis bears the total body weight minus the load of the weight-bearing leg. For a person of 70 kg, we defined a load of 560 Newtons (N) in this condition (70 kg minus 14 kg). In each test, the force was gradually increased while the dislocation of the surfaces of the SI-joint was monitored in relation to the applied force. The force was increased until the dislocation

exceeded 15 mm. Each time before a mechanical test was performed, the pelvic ring was restored and both the hemipelvises were rigidly connected by a special construction to guarantee an identical starting position in every test. This connection was removed after the external fixator—with or without anterior fixation—was applied.

The external fixator used in the experiment was a modification of the Orthofix external fixator. Adaptations were made to allow for various testing situations. The displacement between the joint surfaces was registered with the help of a video system and a mini-computer capable of digitizing and analyzing video images (Keemink et al. 1991). The Direct Linear Transformation (DLT) method (Abdel-Aziz and Karara 1971) enabled us to calculate the displacement between the fracture parts in three dimensions.

For every configuration, 2 load cycles were applied followed by dismounting and again mounting of the fixator system, after which 2 more load cycles were performed. In this experiment, the stiffness of a fixator was defined as the force (F_{max}) required to produce a dislocation of 15 mm. The performance of a particular fixator configuration was expressed as the average of these two results.

We used the loading apparatus as described above to evaluate and optimize the performance of external fixation by varying the following parameters.

Pin modification

Fixator pin modifications of the standard Orthofix (250/50) 6-mm half pin were produced, in which the diameter of the unthreaded part of the standard



Figure 2. 6-, 8- and 10-mm pins.

6-mm pin was increased to 8 and 10 mm (Figure 2). The experiment that followed was done with the 8-mm fixator pins.

Combination of iliac crest and pubic fixation

In this step, we combined different pin positions with a double plate fixation (4-hole 3.5-mm steel DC plate by Synthes/Davos) of the pubic symphysis. The different pin positions were 1,2 and 1,3 and 2,3 (Figure 3).

Design of experimental fixation

As an alternative to internal plate fixation, we inserted fixator pins on both sides of the symphysis at an angle of 90 degrees to each other, mimicking intramedullary position of the threaded part of the pin (Figure 4). These parasymphyseal pins were either interconnected with a fixator rod or connected to the external fixator. The distance from symphysis to clamp was 7 cm.

Results

With respect to the influence of the unthreaded parts of the fixator pins that are outside of the bone, we found an increase in stiffness of 20% when the diameter was increased from 6 to 8 mm. In comparing 6 mm with 10 mm, we found an increase in

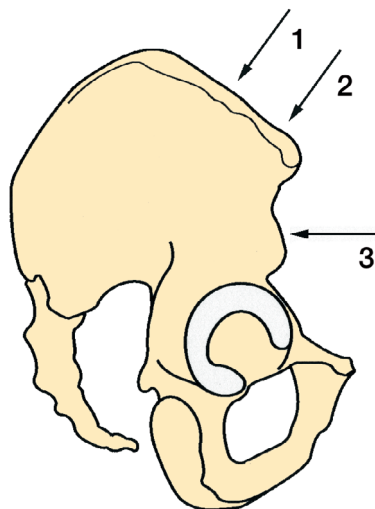


Figure 3. Pin positions (lateral view). The 2 most cranial pins are inserted on top of the pelvic rim, 3 cm and 1 cm posterior to the anterior superior iliac spine (referred to as position 1,2). The ventral pin is inserted 1 cm cranial to the anterior inferior iliac spine (position 3), in combination with pin 1 (referred to as pin position 1,3) and in combination with pin 2 (referred to as pin position 2,3). Insertion depths of 50 mm in predrilled holes in the perspex hip bone were standard. The distance from pelvis to clamp on the fixator pins was also standard. This distance was 3 cm in the cranial position, and 6 cm in the ventral pin position.

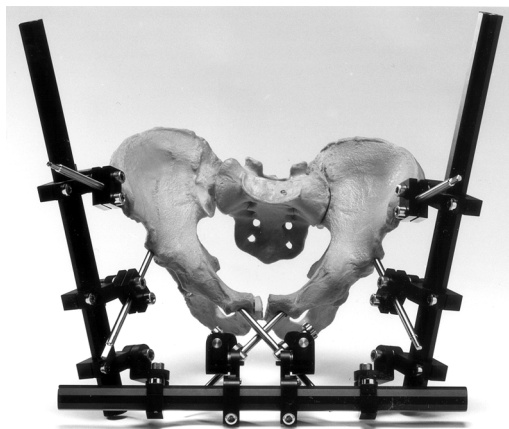


Figure 4. The Orthofix experimental external fixator with parasymphyseal pins connected to it. (The replica of a pelvis shown here is not the perspex model described in the text).

Results of 2-load test expressed as the maximum force required to create a 15-mm dislocation in 10 different external fixator configurations. The parasymphyseal pin position is indicated as pin position 4

Test	Pin diameter (mm)	Pin position	Anterior plating	Parasymphyseal pins	F _{max} 1 (N)	F _{max} 2 (N)	F _{max} average (N)
A	6	1,2			90	94	92
B	8	1,2			110	110	110
C	10	1,2			117	119	118
D	8	1,3			191	187	189
E	8	2,3			210	204	207
F			Yes		285	285	285
G	8	1,2	Yes		568	579	574
H	8	1,3	Yes		674	698	686
I	8	2,3	Yes		724	764	744
J	8	2,3,4		Not fixed to frame	529	540	535
K	8	2,3,4		Fixed to frame	700	698	699

stiffness of 28%. The experiments were continued with 8-mm pins.

Variation of the pin position on the iliac crest showed that in pin position 1,3 an almost 72% increase in stiffness could be achieved in comparison to position 1,2. When we compared pin position 1,2 with pin position 2,3 we found an 88% increase in stiffness in favor of the latter.

In the next experiment, we found that additional symphyseal plate fixation resulted in an increase in stiffness by a factor of 5.2 for the 1,2 pin position, 3.6 for the 1,3 position, and by a factor of 3.6 for the 2,3 position. Anterior plating alone was 1.4 times stiffer than the stiffest external fixator configuration without plating.

The experiment was extended for the stiffest configuration (2,3 position, 744 N) by exchanging symphyseal plate fixation for two interconnected parasymphyseal pins.

This resulted in a decrease in stiffness of 28% compared to symphyseal plating, when the 2 parasymphyseal pins were not connected to the Orthofix fixator. However, connecting the 2 parasymphyseal pins to the Orthofix fixator resulted in a decrease of 6% (Table).

Discussion

Fixator pin diameter is an important factor for stiffness in external fixation. As suggested by Beh-

rens (1989) and Palmer et al. (1992), we tried to improve external fixator performance by increasing the stiffness of the fixator pins. The major contribution to pin deformation comes from bending, consequently causing displacement of the fixator or fixator parts. Bending stiffness is related to material properties and geometry. The bending stiffness of a pin is proportional to the fourth power of the diameter (Dubbel 1986).

In comparison with a pin with a diameter of 5 mm, a pin with a diameter of 6 mm will bend $(5/6)^4 = 0.48$ times, given a certain load. Pin diameter is limited by the dimensions of the bone to which the pins are applied, because pinholes that are too large could cause damage to the bone. Edgerton et al. (1990) stated that a proportionate loss of structural strength occurs with each increase in circular cortical defect size greater than 20% of the bone diameter.

In order to increase pin stiffness without introducing a higher risk of pinhole fractures, we tested the concept of fixator pins with a larger diameter of the part of the pin outside the bone. By increasing the diameter and thus the stiffness of this part of the pin, its contribution to the pin deformation is reduced, in this way increasing overall pin stiffness. In addition, one could argue that the pelvic bone allows larger pinholes and thicker pins to be used. Especially in the supra-acetabular region, the bone stock is thick enough to contain larger pins. For practical purposes, we chose to continue this

study using the pins with the 8-mm solid part “outside the bone”.

Next, we evaluated the influence of the fixator pin position, either more dorsally or ventrally on the iliac crest, in combination with an anterior pin in the supra-acetabular bone. The combination of these pin positions has been described previously and tested by Rubash and Mears (1983), while Kim et al. (1999) found increased mechanical performance with fixators mounted in the supra-acetabular position. The configuration with the cranial fixator pin in the ventral position on the iliac crest gave a slightly better result in our study. This can be explained by less deformation of the connecting bar because of a shorter distance between the pins (Behrens 1989). Furthermore, by this pin placement angulation of the pins with respect to the parallel plane is introduced, which has also been described to be a factor that will improve stiffness of the fixator, as was emphasized by Stöckle et al. (2000) in their experimental study.

Tile (1984) showed that additional plate fixation of the pubic symphysis markedly increases the stability of the unstable pelvic ring. The major contribution to stability of anterior plating was confirmed in our study. In all three configurations involving anterior plating, the Fmax exceeded 560 N and would—on a theoretical basis—allow weight bearing on the injured side. This would also apply to the configuration in which the parasymphyseal pins are connected to the external fixator frame.

Internal fixation in these often severely injured, often multitrauma patients does, however, have certain disadvantages. In the acute phase, an open procedure carries the risk of loss of pelvic tamponade—and as a consequence persistent blood loss. For this reason, minimally invasive procedures in these patients are preferable. A technique that combines the advantages of external fixation and anterior ring stabilization would reduce these risks.

We therefore introduced the concept of parasymphyseal pins. Instead of plating, we inserted pubic pins in both superior pubic rami. These 2 pins were connected to each other, and in the next step the pins were attached to the external fixator bar. The latter configuration resulted in stiffness comparable with the construct where internal plate fixation of the anterior pelvic ring was used in addition to external fixation. However, until now this mini-

mally invasive approach of the pubic bones has only been described for retrograde pubic screws (Roult et al. 1995b) and not for external fixator pins. Furthermore, with respect to the clinical setting we expect this concept of using parasymphyseal pins to be an alternative only in the case of disruption of the pubic symphysis. It should also be noted that correct parasymphyseal pin placement is technically more demanding than anterior plating, and that fluoroscopy is obligatory.

The concept of parasymphyseal pin fixation should be tested on cadaveric bone before it can be evaluated in the clinical situation.

Contributions of authors

KJP: wrote the study protocol and did the loading tests in cooperation with GHvD and CJS. KJP and PJ: wrote the article and did the interpretation and statistical analysis of the data. All authors commented on the definitive version of the manuscript.

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No competing interests declared.

Abdel-Aziz YI, Karara HM. Direct linear transformation from comparator coordinates into object space coordinates. Proc. ASP/UI Symp. on Close range Photogrammetry, American Society of Photogrammetry, Falls Church, 1-18. 1971. Ref Type: Conference Proceeding.

Behrens F. General theory and principles of external fixation. Review. Clin Orthop 1989; (241): 15-23.

Burkhardt M, Culemann U, Seekamp A, Pohlemann T. Strategies for surgical treatment of multiple trauma including pelvic fracture. Review of the literature. Unfallchirurg 2005; 108: 812, 814-812, 820.

Culemann U, Pohlemann T, Hufner T, Gansslen A. 3-dimensional movement analysis after internal fixation of pelvic ring fractures. A computer simulation. (German). Unfallchirurg 2000; 103: 965-71.

Dubbel H. Taschenbuch für den Maschinenbau (Eds. Beitz W, Kuttner K H). Springer-Verlag, Berlin 1986.

Edgerton B C, An K N, Morrey B F. Torsional strength reduction due to cortical defects in bone. J Orthop Res 1990; 8: 851-5.

Gansslen A, Pohlemann T, Paul C, Lobenhoffer P, Tscherner. Epidemiology of pelvic ring injuries. Injury (Suppl 1): 1996; 27: S-20.

- Garbuglia A, Bossi E, Ronzani C, Sallusti M, Bazzoni D, Donzelli T, Marini A, Tiberio G. Severe pelvic injuries: indications and techniques of skeletal fixation. (Italian). *Chirurgia Italiana* 1998; 50: 61-71.
- Keemink C J, Hoek v D G, Snijders C J. Upgrading of efficiency in the tracking of body markers with video techniques. *Med Biol Eng Comput* 1991; 29: 70-4.
- Kim W Y, Hearn T C, Seleem O, Mahalingam E, Stephen D, Tile M. Effect of pin location on stability of pelvic external fixation. *Clin Orthop* 1999; (361): 237-44.
- Lindahl J, Hirvensalo E, Bostman O, Santavirta S. Failure of reduction with an external fixator in the management of injuries of the pelvic ring. Long-term evaluation of 110 patients. *J Bone Joint Surg (Br)* 1999; 81: 955-62.
- Palmer R H, Hulse D A, Hyman W A, Palmer D R. Principles of bone healing and biomechanics of external skeletal fixation. Review. *Vet Clin North Am Small Anim Pract* 1992; 22: 45-68.
- Pohlemann T, Tschernhe H, Baumgartel F, Egbers H J, Euler, Maurer F, Fell M, Mayr E, Quirini W W, Schlickewei W, Weinberg A. Pelvic fractures: epidemiology, therapy and long-term outcome. Overview of the multicenter study of the Pelvis Study Group. (German). *Unfallchirurg* 1996; 99: 160-7.
- Pohlemann T, Gansslen A, Stief C H. Complex injuries of the pelvis and acetabulum. Review (80 refs) (German). *Orthopade* 1998; 27: 32-44.
- Ponsen K J, Hoek van Dijke G A, Joesse P, Snijders C J, Agnew S G. Improvement of external fixator performance in type C pelvic ring injuries by plating of the pubic symphysis: an experimental study on 12 external fixators. *J Trauma* 2002; 53: 907-12.
- Ponsen K J, Hoek van Dijke G A, Joesse P, Snijders C J. External fixators for pelvic fractures: comparison of the stiffness of current systems. *Acta Orthop Scand* 2003; 74: 165-71.
- Roult M L, Jr., Kregor P J, Simonian P T, Mayo K A. Early results of percutaneous iliosacral screws placed with the patient in the supine position. *J Orthop Trauma* 1995a; 9: 207-14.
- Roult M L, Jr., Simonian P T, Grujic L. The retrograde medullary superior pubic ramus screw for the treatment of anterior pelvic ring disruptions: a new technique. *J Orthop Trauma* 1995b; 9: 35-44.
- Roult M L, Jr., Simonian P T, Agnew S G, Mann F A. Radiographic recognition of the sacral alar slope for optimal placement of iliosacral screws: a cadaveric and clinical study. *J Orthop Trauma* 1996; 10: 171-7.
- Rubash H E, Mears D C. External fixation of the pelvis. *Instr Course Lect* 1983; 32: 329-48.
- Sagi H C, Ordway N R, DiPasquale T. Biomechanical analysis of fixation for vertically unstable sacroiliac dislocations with iliosacral screws and symphyseal plating. *J Orthop Trauma* 2004; 18: 138-43.
- Siegmet A, Mullner T, Kukla C, Vecsei V. Associated injuries in severe pelvic trauma. (German). *Unfallchirurg* 2000; 103: 572-81.
- Stockle U, Going T, Konig B, Haase N, Duda G, Haas N P. Dorsal oblique pelvic fixator: development and biomechanical testing. *Unfallchirurg* 2000; 103: 618-25.
- Templeman D, Schmidt A, Freese J, Weisman I. Proximity of iliosacral screws to neurovascular structures after internal fixation. *Clin Orthop* 1996; (329): 194-8.
- Tile M. External fixation. In: *Fractures of the Pelvis and Acetabulum* (Ed. Tansill B). Baltimore: Williams and Wilkins, 1984: 121-31.
- Tile M. Pelvic ring fractures: should they be fixed? Review. *J Bone Joint Surg (Br)* 1988; 70: 1-12.
- Vleeming A, Van Wingerden J P, Snijders C J, Stoeckart R, Stijnen T. Load application to the sacrotuberous ligament; influences on sacroiliac joint mechanics. *Clin Biomech* 1989; 4: 204-9.
- Vrahas M S, Wilson S C, Cummings P D, Paul E M. Comparison of fixation methods for preventing pelvic ring expansion. *Orthopedics* 1998; 21: 285-9.
- Yinger K, Scalise J, Olson S A, Bay B K, Finkemeier C G. Biomechanical comparison of posterior pelvic ring fixation. *J Orthop Trauma* 2003; 17: 481-7.