Can a Modified Anterior External Fixator Provide Posterior Compression of AP Compression Type III Pelvic Injuries?

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Abstract

Background Current anterior fixators can close a disrupted anterior pelvic ring. However, these anterior constructs cannot create posterior compressive forces across the sacroiliac joint. We explored whether a modified fixator could create such forces.

Questions/purposes We determined whether (1) an anterior external fixator with a second anterior articulation (X-frame) would provide posterior pelvic compression and (2) full pin insertion would deliver higher posterior compressive forces than half pin insertion.

Methods We simulated AP compression Type III instability with plastic pelvis models and tested the following conditions: (1) single-pin supraacetabular external fixator (SAEF) using half pin insertion (60 mm); (2) SAEF using full pin insertion (120 mm); (3) modified fixator with X-frame using half pin insertion; (4) modified fixator using full pin insertion; and (5) C-clamp. Standardized fracture

compression in the anterior and posterior compartment was performed as in previous studies by Gardner. A force-sensitive sensor was placed in the symphysis and posterior pelvic ring before fracture reduction and the fractures were reduced. The symphyseal and sacroiliac compression loads of each application were measured.

Results The SAEF exerted mean compressions of 13 N and 14 N to the posterior pelvic ring using half and full pin insertions, respectively. The modified fixator had mean posterior compressions of 174 N and 222 N with half and full pin insertions, respectively. C-clamp application exerted a mean posterior load of 407 N.

Conclusions Posterior compression on the pelvis was improved using an X-frame as an anterior fixation device in a synthetic pelvic fracture model.

Clinical Relevance This additive device may improve the initial anterior and posterior stability in the acute management of unstable and life-threatening pelvic ring injuries.

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Introduction

Unstable pelvic ring injuries occur in 14% to 20% of patients with multiple trauma [9, 27]. This injury reportedly is associated with an increase in mortality rates from 15% to 35%, when associated with multiple injuries [2, 8, 19, 20]. The major sources of bleeding are assumed to be the presacral and retroperitoneal veins [30], sacral arterial disruptions [24], or cancellous bone surfaces [24].

There is consensus regarding the importance of anterior and posterior reduction and stabilization [5, 7, 9, 18, 21, 28, 29]. In displaced fractures, anterior external fixation is commonly used [3, 5, 9, 18]. While this technique reduces the pelvic ring and is simple to apply, it fails to provide posterior compressive forces [14].

Theoretically, posterior stabilization is desirable because it facilitates tamponade and clotting around the fractured bone surfaces and disrupted veins [34]. In addition, enhanced mechanical stability would improve pain control and the care of patients in the intensive care unit. Several investigators [13, 15, 23, 31, 32] have modified anterior external fixation to improve posterior compressive forces. Several studies [15, 31] suggest these constructs increase load across the sacroiliac joint. Slätis and Krarhariju [31, 32] described a trapezoidal fixator that achieved this goal in experimental and clinical investigations. Egbers et al. [13] introduced a complex modified fixator, although the posterior compression achieved was insufficient to allow full weightbearing in unstable pelvic ring injuries [28]. While these reports suggest improved stability of the reduced pelvic ring, they are complex, cumbersome, and are not established in clinical use [23, 31, 32]. We therefore designed a modification to a standard single-pin anterior supraacetabular external fixator (SAEF) that allows preloading of the Schanz pins before fixation. We coined the name X-frame for the device.

We determined whether (1) an experimental anterior external fixation construct with a second anterior articulation (X-frame) would provide posterior pelvic compression and (2) the use of full pin insertion would deliver higher compressive forces on the posterior pelvis than half pin insertion.

Materials and Methods

The symphyseal and sacroiliac joints of 12 hard plastic pelvis models (Sawbones®; Serial Number 1301; Pacific Research Laboratories, Vashon, WA, USA) were disrupted to mimic AP compression Type III (Young-Burgess) pelvic ring injuries. This type of instability reportedly results in both rotational and vertical instability of the hemipelvis [6]. Each pelvis was used to test each of the following three devices: (1) an SAEF using a single supraacetabular Schanz pin (5 × 250 mm) in each side and two 11 × 300 mm steel bars connected with one coupling (DePuy Synthes, Warsaw, IN, USA) (SAEF group; n = 12); (2) a device with an added X-frame to apply a pretension load on the same supraacetabular Schanz pins used in the SAEF group configuration (X group, n = 12) (Fig. 1A); and (3) a C-clamp device (Pelvic C-Clamp II Set; DePuy Synthes) positioned according to the manufacturer's guidelines [10] (C group, n = 12). In both the SAEF and X groups, we used two pin configurations, half and full pin insertions, resulting in a total of five configurations. The testing sequences for the five configurations for each of the 12 pelvises was random except half pin insertions were always tested before full pin insertions.

The power analysis according to Biau et al. [4] was based on the biomechanical measures and results of

Fig. 1A–C (A) A single X-frame is shown with the reversed-threaded rod (top) providing compression (red arrow) and distraction (green arrow). (B) The first X-frame applied to the SAEF facilitates a symphyseal compression by the use of the reversed-threaded rod on the top of the frame, (C) while the second X-frame enables a compression force across the sacroiliac joint by distraction of the Schanz pin tips.

Gardner et al. [15]. The key variable of interest was defined as the posterior compression force in the plane of the pelvic ring. Full weightbearing by the sacroiliac joints requires multidirectional force transmission [12]. Gardner et al. [15] assumed a clinically relevant load on the dorsal pelvic ring would be at least $\frac{1}{2}$ of the load exerted by a C-clamp (ie, 100 N). The analysis of the sample size assumed a power of 95% due to the expected difference of 50 N in the measured load. The power analysis resulted in a minimum sample size of five specimens in each group.

A single orthopaedic surgeon (RMS) applied all constructs to each model. In the SAEF group, half-threaded pins were entered in the region of the anterior inferior iliac spine (AIIS) and directed to the posterior superior iliac spine (PSIS) as described by Solomon et al. [33].

Pin placement was assured using fluoroscopy. All pins were inserted without predrilling and not removed once inserted. The clamps connecting the pins with the bars were located 50 mm from the pin insertion site. Another surgeon (PK) manually reduced the pelvis anatomically and applied what he presumed was an appropriate amount of manual compression loading indirectly using the pins. The sacroiliac and symphyseal joints were compressed by maximum manual manipulation of the pins. Then the bars and couplings connecting the frame were tightened in the reduced position before releasing the manual compression. This was applied according to the mechanical study of Gardner et al. [15]. Load measurements at the symphyseal and unilateral sacroiliac joints were taken before releasing the manual compression and after tightening the frame, as described below. All measurements in the SAEF and X groups were taken with pins inserted bilaterally halfway (60 mm) between the AIIS and the PSIS and then again after full insertion of the pins (120 mm).

In the X group, the pins were initially inserted as described above. The pelvis was reduced manually and then the modular X-frame device was applied in the following manner. The first X-frame construct was connected with the pins by rotating couplings 10 mm from the insertion of AIIS. The second X-frame was connected to the pins 120 mm more distantly again with the rotating couplings (Fig. 1B–C). We then followed a two-step procedure. First, the inferior X-frame was tensioned by a reversed-threaded rod at the top of the frame, resulting in a symphyseal compression (Fig. 1B). Once the frame was tightened, the pins retained only one degree of freedom allowing pivoting around the rotating couplings in the coronal plane. This determined a center of rotation that allowed the pins to move in the plane of the pelvic ring aperture. Second, the couplings of the second X-frame were attached 120 mm distantly and then driven apart by turning the reversed-threaded rod at the top of the

X-frame in the direction opposite to that used for the rod of the first X-frame. This movement resulted in an indirect compression across the posterior pelvic ring applied by the pins (Fig. 1C). Finally, the bars of the SAEF were applied and tightened in the standardized fashion. The resulting symphyseal and sacroiliac load measurements were recorded without releasing the X-frames. The tests for the X group were again determined using both half and full pin insertions. Finally load measurement was repeated after the X-frames were released from the bars of the tightened fixator.

In the C group, a C-clamp was used to apply compression on the pelvic ring according to the manufacturer's guidelines.

Pilot investigations were undertaken to assess the quantification of posterior load measurements. During the study, loads were separately measured for the symphysis and the sacroiliac joint. If pins were inserted previously, they were left in the pelvis. We encountered no technical failures with the measurement tools during the pilot studies or any of the tests.

The load measurements on the pelvic joints were recorded by using force-sensitive sensors (FlexiForce® A201; Tekscan Inc, South Boston, MA, USA) based on the previously described technique [1]. These electroresistive sensors determine the force applied on a sensitive area of 9.0 mm in diameter and a thickness of 0.2 mm. To ensure load transmission across the joint, small pucks of hard rubber were applied on either side of the film (Fig. 2). One of these setups was located in each of the symphyseal and sacroiliac joints. The load measurements were recorded simultaneously using the corresponding software (MELF System, Version 3.40; Tekscan Inc). Before the measurement in this model, each force-sensitive sensor was preconditioned 10 times by repeating loads and unloads up to 550 N to avoid the effect of hysteresis. Calibration of each force-sensitive film was applied, using an MTS 858

Fig. 2 Force-sensitive sensors are positioned in the symphyseal and sacroiliac (SI) joints to detect load transmission.

MiniBionix® II unit with a 10-kN measuring probe (MTS Systems Corp, Eden Prairie, MN, USA).

The differences in the measured loads between the constructs were calculated by a Kruskal-Wallis test. Since the measures from each group were not normally distributed, a nonparametric test was used. The post hoc analyses were implemented with a Mann-Whitney U test with the Bonferroni correction as described previously [15]. We performed statistical analyses using SPSS® software (Version 20; IBM Corp, Armonk, NY, USA).

Results

The X group experienced increased anterior and posterior load compared with the SAEF group (Table 1). In the SAEF group, the average anterior load was 7 N (range, 2–23 N) with half pin insertion and 7 N (range, 2–14 N) with full pin insertion. The average posterior load was 13 N (range, 3–26 N) with half pin insertion and 14 N (range, 4–26 N) with full pin insertion. In the X group, the average load was 123 N (range, 89–156 N) with half pin insertion and 133 N (range, 95–167 N) with full pin insertion at the symphyseal joint. With pretension of the pins by the second X-frame, an average load of 174 N (range, 82–236 N) was delivered on the posterior pelvis with half pin insertion and 222 N (range, 180–279 N) with full pin insertion. The X group exhibited greater loads ($p < 0.001$ for both groups) in the symphysis and sacroiliac joint than the SAEF group independently of the mode of pin insertion (ie, both half and full pin insertions). The C group achieved the highest values in posterior compression, which were greater ($p < 0.001$) than that with the X-frame. The average symphyseal load also lower ($p = 0.001$) in the C group than in the X group (Table 1). Application of the C-clamp resulted in a posterior compression of 407 N (range, 390–429 N). The average anterior load was 54 N (range, 28–79 N).

The loads with half and full pin insertions were similar in the constructs of the SAEF and X groups (Table 2).

The average load across the symphyseal and sacroiliac joints decreased in all subgroups when the X-frame

was released (Table 3). The average anterior load was 35 N (range, 22–48 N) with half pin insertion and 36 N (range, 20–53 N) with full pin insertion. The mean posterior load was 43 N (range, 28–59 N) with half pin insertion and 58 N (range, 38–83 N) with full pin insertion.

Discussion

In patients with pelvic instability, external compression devices should be properly applied in a rapid and effective way to achieve reduction, compression, and adequate rigidity. Reduction of the pelvic ring results in decreased volume and improved stability [17, 22, 35]. The benefit of anterior external fixators in AP compression pelvic ring instability is well described [21, 28], but they lack the capacity to produce posterior compression across the sacroiliac joint [15]. We designed a modular device (X-frame) to improve the posterior compression achieved by a standard anterior external fixator and its efficiency. We determined whether (1) an anterior external fixator with the X-frame would provide posterior pelvic compression and (2) full pin insertion would deliver higher posterior compression than half pin insertion.

We note limitations associated with our experimental setup. First, we used synthetic bone models imitating human pelvic geometry but without soft tissues. The absence of a soft tissue envelope, including ligaments and muscles, can influence the biomechanical behavior of pelvic ring instability and reduction [22]. The pelvic ring is mainly stabilized by the osseous and ligamentous structures. In the case of a partial disruption of the sacroiliac joint, the sacrospinous and sacrotuberous ligaments and the muscles of the pelvic floor can modify the degree of instability. Clinically, this may result in a partial reduction and close to normal appearance of pelvic structures on the initial radiograph [12, 22]. It was our aim to explore the basic mechanical behavior of different pelvic frame constructs and applications in a simplified mechanical experiment and reduce other variables such as soft tissues or soft tissue injuries. Thus, our findings should be

Table 1. Load measured at the anterior (symphysis) and dorsal (sacroiliac joint) pelvis after reduction

Group	Anterior load (N)				Dorsal load (N)			
	Mean	SD	Range	p value	Mean	SD	Range	p value
X-frame*	133.1	31.6	95–167	< 0.001	222.3	36.6	180–279	< 0.001
SAEF*	6.8	4.5	1.75–14		13.8	8.1	3.5–26	
X-frame*	133.1	31.6	95–167	< 0.001	222.3	36.6	180–279	< 0.001
C-clamp	53.8	15.2	28–79		407.2	19.7	390–429	

* Full Schanz pin insertion; SAEF = supraacetabular external fixator.

Table 2. Comparison of load measurements between half and full pin insertions at the anterior and dorsal pelvis

Group	Anterior load (N)				Dorsal load (N)			
	Mean	SD	Range	p value	Mean	SD	Range	p value
SAEF								
Half pin	7.3	6.1	1.7–23	0.977	12.8	6.7	7–26	0.755
Full pin	6.8	4.5	1.75–14		13.8	8.1	3.5–26	
X-frame								
Half pin	123.3	23.7	89.3–156	0.855	174.1	38.4	82.1–236	0.06
Full pin	133.1	31.6	95–167		222.3	36.6	180–279	

SAEF = supraacetabular external fixator.

Table 3. Load behavior on the anterior and posterior pelvis before (X-tight) and after (X-release) X-frame release

Group	Anterior load (N)				Dorsal load (N)			
	Mean	SD	Range	p value	Mean	SD	Range	p value
Half pin								
X-tight	123.3	23.7	89–156	< 0.001	174.1	38.4	82–236	< 0.001
X-release	35.1	8.4	22–48		43.1	9.4	28–59	
Full pin								
X-tight	133.1	31.6	95–167	< 0.001	222.3	36.6	180–279	< 0.001
X-release	36.4	11.2	20–53		58.3	12.7	38–83	

confirmed in cadaver studies that explore soft tissue variables. Since the primary mechanism of external fixation is to aim at lateral compression force on the pelvic ring, the compression across the symphysis and sacroiliac joint were the main mechanical parameters [15]. Second, bone quality (eg, osteoporosis) and the heterogeneous properties of the pelvic bone cannot be addressed in a simplified approach using an experimental model. Third, we determined direct symphyseal and sacroiliac compression loads and neglected the vertical strength of the constructs in a model of both rotational and vertical instability. The vertical instability is important to measure as a resultant parameter addressed in further cadaver model. Fourth, our power analysis was based on a difference of 50 N between the various constructs. We have, however, no direct evidence that a 50-N difference will or will not affect the clinical course in patients in terms of maintenance of reduction under physiologic loading or likelihood of healing. If the loading that makes a difference in the clinical course is substantially higher than 50 N, our findings might not reflect clinically important differences.

We found a higher posterior compressive load in the X group than in the SAEF group. As shown previously [9, 18, 28, 35], the standard SAEF will maintain the reduction of the pelvic ring. However, the compression across the symphysis and sacroiliac joint, which was obtained manually, is not retained by the fixator [15, 16, 25]. The C-clamp delivered high compression loads on the posterior pelvic ring [18]. These values were reproducible

in our study with a small range. In contrast, the symphyseal load was lower, which can be explained by the influence of the insertion point of the C-clamp. The more anterior it is applied, the higher the anterior load to the symphysis is. The achieved symphyseal and posterior load by the X-frame provoked a desired pretension of the Schanz pins. Tightening the steel bars of the SAEF cannot maintain the high load level after release of the X-frames. The load values substantially decreased. Further modification of the SAEF, eg, double-bar construct, is required to maintain these load levels. Previous advancements of these external fixator frames have been directed at an improved posterior compressive force. Theoretically, this would allow patient transfer and mobilization with nursing care in the early period of treatment. Slätis and Krarhariju [31, 32] improved the use of Schanz pins for posterior compression through a far center of rotation within a trapezoid frame. They reported clinical benefits and a decreased rate of loss of reduction. Guntenberg et al. [23] showed this in a biomechanical setup. They tested the Hoffman-Slätis frame and achieved posterior compression loads able to stand weightbearing in AP compression Type III pelvic injuries. However, Lindahl et al. [26] showed important limitations of this construct. The complexity and height of the frame complicated clinical use. In addition, the weak iliac crest bearing the Schanz pins in this construct may fail under cyclical loading. The X-frame is a modular and additive device that allows pretension of the Schanz pins in case of urgent pelvic ring stabilization. The

tightened frame has to preserve this pretension by itself. Egbers et al. [13] approximated the center of rotation and described an improved but complex mechanism of posterior compression. First, an anterior compression imparted a symphyseal reduction. Second, the distraction of the Schanz pins above provided a sacroiliac joint compressive force. Recently, Dickson and Matta [11] highlighted the risk of worsening an existing pelvic deformity with an anterior external fixator frame. A force-controlled and guided reduction is necessary to avoid this user-associated complication. The use of the X-frame may address this by the previously described two-step application. Gardner et al. [17] demonstrated the potential effect of internal rotation of uninjured lower extremities on the anterior pelvic ring in open-book injuries and illustrated a controlled symphyseal closure. The clinical challenge is in posterior pelvic ring closure and mechanical stabilization. However, in the case of vertical disruption and dislocation, a controlled reduction by any frame construct is limited. Often, the surgeon relies on closed reduction by manipulation of the lower limb. Some authors suggest improved results of table-grounded reduction frames. This may be an option for improving closed reduction but seems to be time-consuming and sophisticated in cases of unstable patients.

We found no differences in loads using half and full pin insertions with the SAEF or the X-frame. These results concur with the literature [15, 16]. However, with the X-frame, full pin insertion produced higher posterior loads in the second step of frame application.

In conclusion, the modular compressive X-frame device allowed application of improved loads of posterior compression across the sacroiliac joint in unstable pelvic ring injuries. We believe the two-step reduction might be beneficial in cases of AP compression Type III injuries. First, the anterior symphyseal closure must be assured and locked. Second, the posterior reduction, at the plane level of the pelvic ring, should follow by means of controlled compression. The modular reduction device introduced in this study implements this approach. The construct itself is bulky if the two X-frames are retained to maintain the applied forces. Whether further construct modifications may allow sustained pretension and bending of the Schanz pins has to be considered and tested. The controlled reduction of the anterior and posterior pelvic ring using the apical reverse-threaded rod of the frame may be beneficial. This could be advantageous as an adjunct device in the application of a standard anterior SAEF, supporting increased posterior compression loads across the sacroiliac joints, and may help in hemorrhage control within the first hours of urgent treatment protocols.

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References

1. Bachus KN, DeMarco AL, Judd KT. Measuring contact area, force, and pressure for bioengineering applications: using Fuji Film and TekScan systems. *Med Eng Phys.* 2006;28:483–488.
2. Balogh Z, King KL, Mackay P, McDougall D, Mackenzie S, Evans JA, Lyons T, Deane SA. The epidemiology of pelvic ring fractures: a population-based study. *J Trauma.* 2007;63:1066–1073.
3. Bassam D, Cephas GA, Ferguson KA, Beard LN, Young JS. A protocol for the initial management of unstable pelvic fractures. *Am Surg.* 1998;64:862–867.
4. Biau DJ, Kerneis S, Porcher R. Statistics in brief: the importance of sample size in the planning and interpretation of medical research. *Clin Orthop Relat Res.* 2008;466:2282–2288.
5. Biffl WL, Smith WR, Moore EE, Gonzalez RJ, Morgan SJ, Hennessey T, Offner PJ, Ray CE Jr, Franciose RJ, Burch JM. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. *Ann Surg.* 2001;233:843–850.
6. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS Jr, Poka A, Bathon GH, Brumback RJ. Pelvic ring disruptions: effective classification system and treatment protocols. *J Trauma.* 1990;30:848–856.
7. Cook RE, Keating JF, Gillespie I. The role of angiography in the management of hemorrhage from major fractures of the pelvis. *J Bone Joint Surg Br.* 2002;84:178–182.
8. Dalal SA, Burgess AR, Siegel JH, Young JW, Brumback RJ, Poka A, Dunham CM, Gens D, Bathon H. Pelvic fracture in multiple trauma: classification by mechanism is key to pattern of organ injury, resuscitative requirements, and outcome. *J Trauma.* 1989;29:981–1000.
9. Day AC. Emergency management of pelvic fractures. *Hosp Med.* 2003;64:79–86.
10. DePuy Synthes Companies. Available at: <http://www.depuyssynthes.com>. Accessed May 2008.
11. Dickson KF, Matta JM. Skeletal deformity after anterior external fixation of the pelvis. *J Orthop Trauma.* 2009;23:327–332.
12. DonTigny RL. Function and pathomechanics of the sacroiliac joint: a review. *Phys Ther.* 1985;65:35–44.
13. Egbers HJ, Draijer F, Havemann D, Zenker W. [Stabilizing the pelvic ring with the external fixator: biomechanical studies and clinical experiences] [in German]. *Orthopade.* 1992;21:363–372.
14. Gänsslen A, Giannoudis P, Pape HC. Hemorrhage in pelvic fracture: who needs angiography? *Curr Opin Crit Care.* 2003;9:515–523.
15. Gardner MJ, Kendoff D, Ostermeier S, Citak M, Hüfner T, Krettek C, Nork SE. Sacroiliac joint compression using an anterior pelvic compressor: a mechanical study in synthetic bone. *J Orthop Trauma.* 2007;21:435–440.
16. Gardner MJ, Nork SE. Stabilization of unstable pelvic fractures with supraacetabular compression external fixation. *J Orthop Trauma.* 2007;21:269–273.
17. Gardner MJ, Parada S, Routt ML. Internal rotation and taping of the lower extremities for closed pelvic reduction. *J Orthop Trauma.* 2009;23:361–364.
18. Ghanayem AJ, Stover MD, Goldstein JA, Bellon E, Wilber JH. Emergent treatment of pelvic fractures: comparison of methods for stabilization. *Clin Orthop Relat Res.* 1995;318:75–80.
19. Giannoudis PV, Grotz MR, Tzioupis C, Dinopolous H, Wells GE, Bouamra O, Lecky F. Prevalence of pelvic fractures, associated injuries, and mortality: the United Kingdom perspective. *J Trauma.* 2007;63:875–883.
20. Giannoudis PV, Pape HC. Damage control orthopaedics in unstable pelvic ring injuries. *Injury.* 2004;35:671–677.

21. Gilliland MD, Ward RE, Barton RM, Miller PW, Duke JH. Factors affecting mortality in pelvic fractures. *J Trauma*. 1982;22:691–693.
22. Grimm MR, Vrahas MS, Thomas KA. Pressure-volume characteristics of the intact and disrupted pelvic retroperitoneum. *J Trauma*. 1998;44:454–459.
23. Guntenberg B, Goldie I, Slätis P. Fixation of pelvic fractures and dislocations: an experimental study on the loading of pelvic fractures and sacro-iliac dislocations after external compression fixation. *Acta Orthop Scand*. 1978;49:278–286.
24. Huittinen VM, Slätis P. Postmortem angiography and dissection of hypogastric artery in pelvis fractures. *Surgery*. 1973;73:454–456.
25. Kim WY, Hearn TC, Seleem O, Mahalingam E, Stephen D, Tile M. Effect of pin location on stability of pelvic external fixation. *Clin Orthop Relat Res*. 1999;361:237–244.
26. 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;81:955–962.
27. Matewski D, Szymkowiak E, Bilinski P. Analysis of management of patients with multiple injuries of the locomotor system. *Int Orthop*. 2008;32:753–758.
28. Rieger H, Winckler S, Wetterkamp D, Overbeck J. Clinical and biomechanical aspects of external fixation of the pelvis. *Clin Biomech (Bristol, Avon)*. 1996;11:322–327.
29. Riemer BL, Butterfield SL, Diamond DL, Young JC, Raves JJ, Cottingham E, Kislán K. Acute mortality associated with injuries to the pelvic ring: the role of early patient mobilization and external fixation. *J Trauma*. 1993;35:671–675.
30. Sadri H, Nguyen-Tang T, Stern R, Hoffmeyer P, Peter R. Control of severe hemorrhage using C-clamp and arterial embolization in hemodynamically unstable patients with pelvic ring disruption. *Arch Orthop Trauma Surg*. 2005;125:443–447.
31. Slätis P, Krarhariju EO. External fixation of the pelvic girdle with a trapezoid compression frame. *Injury*. 1975;7:53–56.
32. Slätis P, Krarhariju EO. External fixation of unstable pelvic fractures: experience in 22 patients treated with trapezoid compression frame. *Clin Orthop Relat Res*. 1980;151:73–80.
33. Solomon LB, Pohl AP, Chehade MJ, Malcolm AM, Howie DW, Henneberg M. Surgical anatomy for pelvic external fixation. *Clin Anat*. 2008;21:674–682.
34. Spanjersberg WR, Knops SP, Schep NW, van Lieshout EM, Patka P, Schipper IB. Effectiveness and complications of pelvic circumferential compression devices in patients with unstable pelvic fractures: a systematic review of literature. *Injury*. 2009;40:1031–1035.
35. Wild JJ Jr, Hanson GW, Tullos HS. Unstable fractures of the pelvis treated by external fixation. *J Bone Joint Surg Am*. 1982;64:1010–1020.