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AU1) Please check if the running head introduced is correct.
AU2) Please provide department name (if any) for the first affiliation.
AU3) Please consider rephrasing the sentence "In all 11 patients, the actual…" to retain clarity.
AU4) Please provide volume number for Refs. 4, 5, 15, 25, and 30.
AU5) Please provide edited book title and publisher location for Ref. 27.
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AU7) Please check if "F, M, MCA, and MVA" in footnote of Table 1 spelled out as "female, male, motor cycle accident and motor vehicle accident" are correct. Also check if "PED" in footnote of same table could be spelled out as "pedestrian" and clarify "Semi and Crushed" provided in the fourth column and "preinjury left sacroiliac joint fusion" in last column of the same table.

Skeletal Deformity After Anterior External Fixation of the Pelvis

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Objective: To study the deformity of acutely injured unstable pelves before and after emergent application of an anterior external fixator.

Design: Retrospective.

Setting: Large pelvic fracture referral practice.

Patients: Eleven of 151 patients referred to our institution after emergent application of an external fixator by the referring orthopaedist before transfer who were hemodynamically unstable and had a mechanically unstable pelvic injury with pre–external fixator radiographs and post–external fixator radiographs adequate to determine pelvic deformity.

Main Outcome Measurements: We reviewed all available radiographs both before and after placement of the external fixator (the anterior–posterior, inlet, outlet, and computed tomography), determining whether the external fixator improved or worsened the deformity.

Results: Although many deformities existed, we found that application of an anterior frame consistently worsened this deformity. Seven of the 11 patients (64%) had worsening of the posterior cephalad translation or posterior diastasis despite apparent improvement anteriorly on the anterior–posterior radiograph. "External fixator deformity," defined as increased flexion and/or internal rotation of the hemipelvis, also occurred in 8 of 11 patients (73%). After placement of the external fixator, all patients displayed greater than 1 cm of either posterior cephalad translation or posterior diastasis (average 3.4 cm, range 1.3–4.6 cm).

Conclusions: Due to the forces placed on the pelvis during application of an anterior external fixator by the surgeon, an external fixator deformity may occur (flexed and internally rotated hemipelvis). Furthermore, most patients had an increase in posterior cephalad translation or posterior diastasis with placement of an external fixator. The surgeon should be aware of the potential of increasing the pelvic deformity when applying an emergent anterior external fixator.

Key Words: pelvic fractures, external fixation, pelvic deformity, unstable pelvis, emergent pelvic fixation

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INTRODUCTION

Anterior external fixation as the definitive treatment of Bucholz type III,[1] Tile type C,[2] or AO/OTA type 61-C[3] unstable pelvic injuries has resulted in unacceptable rates of failure, and its use is no longer advocated for this purpose.[4,5] Its use in the acute setting for the management of the acute hemodynamically unstable patient with a mechanically unstable pelvis has been recommended by many authors.[6–16] However, none of these studies have proven to be definitive, there being substantial clinical,[17–21] biomechanical,[4] and anatomic,[1] evidence questioning the value of an emergent external fixation. An important consideration is that the associated injuries and coagulopathies may contribute more to hemodynamic instability than the bony pelvic injury itself.[1,9,19] Therefore, suggested initial stabilization treatments for acute pelvic injuries include medical stabilization with possible angiography without external fixation,[18] anterior external fixation,[13,21] pelvic binders,[22,23] and posterior external fixation.[24–26] Despite the ongoing debate, anterior external fixation continues to be recommended as a primary method to reduce and stabilize a hemodynamically unstable patient with a mechanically unstable pelvis in the acute setting.[27]

Several authors have previously described the acute deformity of the pelvis after injury; however, none of these have reported on the change in deformity after application of an anterior external fixator.[14–16,20,28–33] Our purpose is to review the deformity of the acutely injured pelvis before and after emergent application of an external fixator. Our hypothesis was that the anterior external fixator placed in the emergent life-saving conditions may actually worsen bony alignment of the pelvis.

PATIENTS AND METHODS

Between 1986 and 1994, 151 pelvic fractures were referred to our institution for definitive operative treatment. Sixteen of these patients were hemodynamically unstable, having systolic blood pressure less than 90 mm Hg, and had an external fixator placed emergently by the referring orthopaedist before transfer. Four of the 16 patients lacked the required radiographs demonstrating the pelvic deformity before application of anterior external fixation, and 1 had an associated acetabular fracture that made defining the deformity of the pelvis difficult, leaving 11 for the study (Table 1). T1
According to the OTA classification,[3] there was 1 61-B1, 9 61-C1, and 1 61-C2 (Table 1). All anterior–posterior views (AP), inlet (caudad) and outlet (cephalad) radiographs, and computed tomography (CT) were reviewed before and after

external fixator placement. However, the linear deformities F1 – F3 were measured using only the AP radiographs (Figs. 1–3). The CT scan was used to measure internal/external rotation deformities (Fig. 3). The inlet and outlet radiographs were used to further substantiate the deformities defined on the AP radiograph and CT scan (Table 1, Figs. 1–3).

Linear measurements made on the AP radiograph comparing the pelvis before and after external fixator application were made in the following manner. The x-, y-, and z-axes were defined (Fig. 1). Direct measurements were made between the 2 pubic bones and the iliac bone and the sacrum along the x-axis for symphysis diastasis and sacroiliac joint diastasis, respectively. To measure vertical translation of the hemipelvis, a reference line was drawn horizontally, parallel to the x-axis (Fig. 2). Measurements along perpendicular lines (which parallel the y-axis) to the x-axis line provided estimates of leg length discrepancy and sitting imbalance (as described in Figs. 2A, B).[30,33] Next, pelvic malrotation was determined by quantitative and qualitative methods (Fig. 3). On the CT scan axial section, a line was drawn perpendicular to the sacrum and another parallel to the quadrilateral surface just cephalad to the joint (Figs. 3B, C). The resulting angle was

TABLE 1. Overall Data of Patient Population

Number	Age (yrs)	Sex	Mechanism of Injury	OTA Classification	Greatest Posterior Displacement	Loss of Reduction	Worsening of Flexion or IR	Final Reduction After ORIF	Flexion	IR	Deformity	Associated Injuries
1	25	M	MVA	61-C1.2	2.8-cm diastasis	No	Yes	G	No	No	Add, Flex, ER, Ceph, POST	None
2	32	F	Semi versus Bike	61-C1.3	5.4-cm cephalad translation	No	Yes	G	Yes	Yes	Flex, IR, POST, Ceph	None
3	18	M	MCA	61-C1.3	3.5-cm diastasis	No	Yes	E	No	No	Add, Ceph, POST	Right supracondylar femur fracture, right subtrochanteric femur fracture, right elbow fracture, right ankle fracture, right transverse acetabular fracture
4	33	M	MCA	61-C1.3	2-cm diastasis	No	No	P	Yes	Yes	IR, Ceph	Left T-type posterior wall acetabular fracture, left tibia fracture
5	18	M	MVA	61-C2.1	2.7-cm cephalad translation	Yes (post)	Yes	G	Yes	Yes	Abd, Flex, Ceph	None
6	63	M	MVA	61-C1.2	1.5-cm cephalad translation	Yes (post)	No	E	No	No	Abd, Flex, Ceph	Left transverse acetabular fracture with dislocation of femoral head, preinjury left sacroiliac joint fusion
7	26	M	MVA versus PED	61-C1.2	2.8-cm diastasis	No	Yes	E	Yes	Yes	Add, IR, Ext, Ceph, POST	None
8	30	M	MVA	61-B1.1	3.2-cm diastasis	Yes (ant)	Yes	E	No	No	Abd, IR	Posterior dislocation of left hip, right femur fracture
9	43	M	Tractor	61-C1.2	4.6-cm diastasis	No	Yes	3 Stage	Yes	Yes	Abd, Flex, IR, Ceph	Bladder injury, shoulder injury
10	39	F	MVA	61-C1.3	2.4-cm diastasis	No	Yes	E	No	No	Add, Flex, POST	Closed head injury, bladder injury, right ankle fracture, right tibial/fibular fracture
11	40	F	Crushed	61-C1.3	1.5-cm diastasis + H9	No	No	3 Stage	No	No	ER, Ceph	Right femur fracture, right patella fracture, left tibia fracture

AU7 Abd, abduction; Add, adduction; Ant, loss of reduction of the anterior pelvis, that is, symphysis; Ceph, cephalad translation; E, excellent (<4 cm); ER, external rotation; Ext, external extension; F, female; Flex, flexion; G, good (4–1 cm); IR, internal rotation; ORIF, open reduction and internal fixation; M, male; MCA, motorcycle accident; MVA, motor vehicle accident; P, poor (>1 cm); Post, loss of reduction of the posterior pelvis, that is, sacroiliac joint; POST, posterior translation, posterior cephalad translation, and posterior diastasis; 3 Stage, stage pelvis reconstruction.

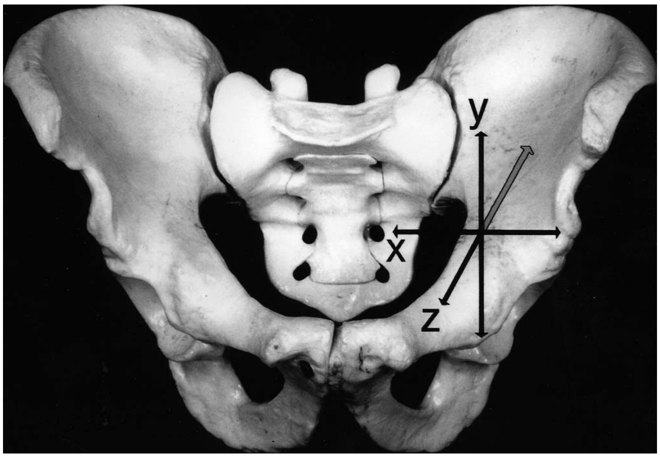

FIGURE 1. The system for defining the hemipelvis deformity. The x-axis defines the flexion/extension rotational deformity and the diastasis/impaction translational deformity. The y-axis defines the internal/external rotational deformity and the cephalad/caudad translational deformity. The z-axis defines the abduction/adduction rotational deformity and the anterior/posterior translational deformity.

compared with the normal side (Figs. 3D, E), and degree of malrotation around the y-axis measured (internal/external rotation). In addition, the presence of abduction/adduction deformity was determined (Fig. 3C). It was not possible however to assign a degree measurement of this deformity. On the AP radiograph, the Z measurement from Figure 2 increased as internal rotation increased (Fig. 3A). However, once again, the degree of internal rotation could not be measured using this method.

Worsening of the deformity was defined as >2 mm change on any linear measurement. In addition, we noted the presence of malrotation and whether this malrotation, using the described techniques, qualitatively worsened with the external fixator.

RESULTS

After placement of the external fixator, all 11 patients had greater than 1 cm of either posterior cephalad translation or posterior translational diastasis (Table 1) with an average displacement of 2.4 cm (range 1.3–4.6 cm). In all 11 patients, AU3 the actual deformity pre-external fixator was similar to the deformity post–external fixator only worsened in most cases.

The anterior measured change in diastasis of the symphysis after external fixation ranged from 3.8 cm improvement to 1 cm worsening, with the average being an improvement of 7 mm. Posterior diastasis ranged from 2.1 cm improvement to a worsening of 2.7 cm and averaged 2 mm of improvement. Posterior cephalad translation ranged from 2.4 cm improvement to 1.5 mm worsening for an average of 4 mm worsening. In the case example (Figs 2, 3), there was an improvement of the symphysis diastasis from 3.9 to 0.1 cm. However, sacroiliac joint diastasis worsened from 2.1 to 2.8 cm on the AP radiograph.

Seven of 11 patients (64%) had worsening of the deformity posteriorly (either cephalad translation or diastasis) with the placement of an anterior external fixator. Three patients lost reduction with the external fixator before definitive treatment with open reduction and internal fixation. Two of these had worsening of the posterior cephalad translation, and 1 had worsening of the posterior diastasis (Table 1).

Regarding rotational deformity, there were 2 patients with an internal rotation deformity, 2 patients with a flexion deformity, and 4 patients with both a flexion deformity and an

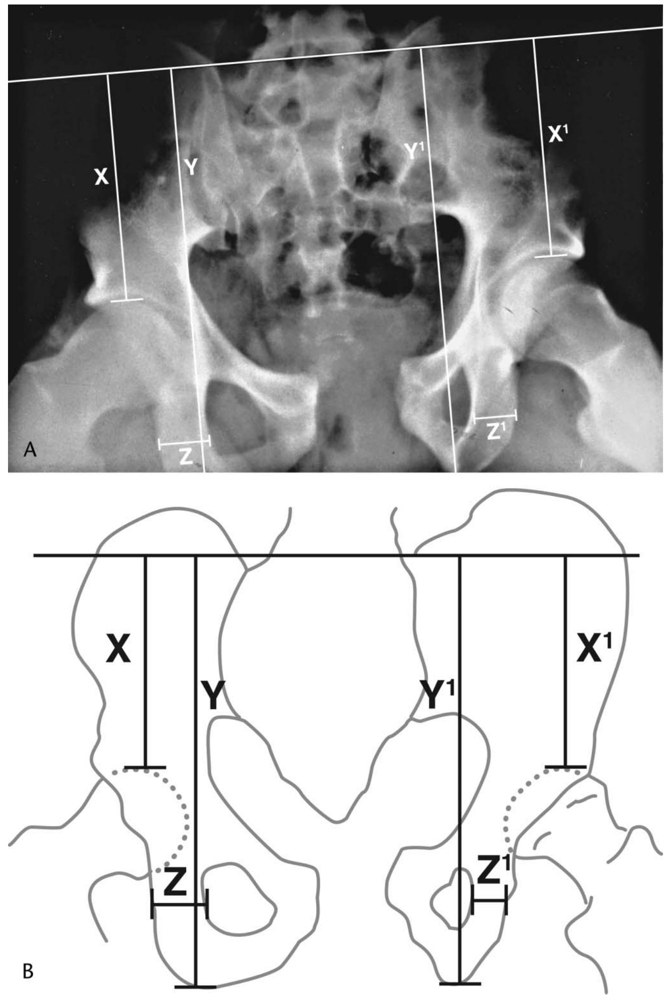

FIGURE 2. A, B, Demonstration of the method of linear measurement of deformity using the (A) AP radiograph of the pelvis obtained before the application of an external fixator in a 26-year-old pedestrian struck by a motor vehicle (case 7; Table 1) and (B) a corresponding line drawing. First, a line (unlabeled horizontal line in these figures) is drawn parallel to the x-axis (as defined in Fig. 1). Often, the remaining bilaterally intact sacral foramina can be used as guides to draw this line. Next, lines are drawn perpendicular to this first line, ending at the acetabular roof of the uninjured (X) and injured (X^1) hemipelves and the distal aspect of the ischium (Y and Y^1, uninjured and injured sides, respectively). Comparing X with X^1 provides a measure of leg length, and comparing Y with Y^1 provides a measure of sitting (ischial) imbalance. The width of the ischium (Z and Z^1, uninjured and injured sides, respectively) increases as internal rotation of the hemipelvis increases.

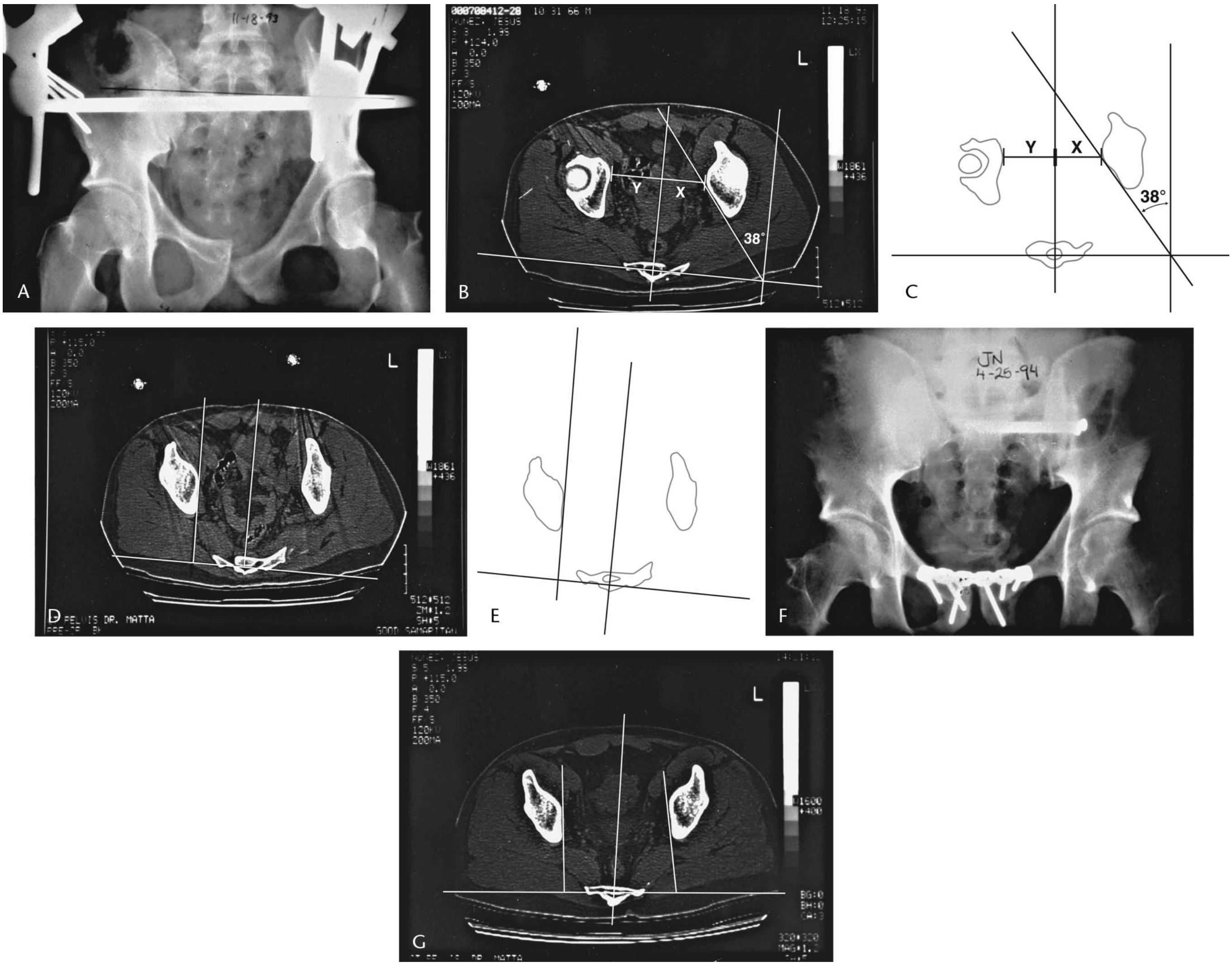

FIGURE 3. A–G, Pedestrian who sustained a left sacroiliac dislocation and symphysis diastasis (case 7; Table 1) from Figure 1. A, AP radiograph of the pelvis after application of external fixator. Notice the internal rotation of the left hemipelvis (widening of the ischium) and the widening of the sacroiliac joint posteriorly while closing the symphysis anteriorly. B, CT scan axial section showing 38 degrees of internal rotation of the left hemipelvis. C, Artist's rendition of (B) with an internal rotation deformity at 38 degrees. Available as additional information on this study is the decreased distance from the quadrilateral plate to the midline on the injured (X) as compared with the uninjured (Y) side, which suggests the presence of an adduction deformity or a medial impaction of the injured hemipelvis. D, CT scan axial section showing the uninjured right hemipelvis having internal rotation of 1 degree. In this patient, the pelvis was not perfectly perpendicular to the CT scanner gantry. Therefore, a different CT scan axial section was required for measuring the uninjured side. E, Artist's rendition of (D) showing internal rotation of 1 degree on the uninjured side. F, AP radiograph of the pelvis after open reduction and internal fixation. G, CT scan axial section showing an almost complete correction of the internal rotation deformity of the left hemipelvis.

internal rotation deformity. Of the 6 patients with an internal rotation deformity pre-external fixation, 100% (6 of 6) had worsening of the internal rotation deformity. Of the 6 patients with a flexion deformity pre-external rotation, 83% (5 of 6) had worsening of the deformity. Overall, the accident caused the deformity, but in most cases, the external fixator caused worsening of the internal rotation or flexion deformity (Table 1). In summary, placement of the external fixator increased flexion (5 of 11), internal rotation (6 of 11), or both (4 of 11) in 8 of 11 patients (73%). Therefore, we termed this phenomenon "external fixation deformity."

DISCUSSION

The placement of an anterior external fixation frame for an acute pelvic injury to provide initial stabilization has been supported by many authors.[6,8–16,30] Other authors however question this treatment.[9,13,18,19] Our study does not preclude the use of anterior external fixation as an acute resuscitation frame. Instead, it highlights a potential problem an orthopaedist may encounter when using this treatment method as a poorly reduced posterior ring may contribute to more mechanical and hemodynamic instability in a patient.[28] Therefore, the orthopaedist should focus on the posterior and the anterior reduction.

Understanding both the pelvic deformity and the necessary reduction force gives the surgeon a better chance of preventing what we call an "external fixator deformity," defined as worsening of flexion, internal rotation, or both.[14,15,30] In our series, the posterior cephalad translation or posterior diastasis worsened in 7 of 11 patients (64%) after application of an anterior external fixator frame and 73% of patients had worsening of the internal rotation and/or flexion of the hemipelvis, causing an increased displacement posteriorly. Often, the pins of the external fixator are translated toward the midline anteriorly during application of the fixator, causing this excessive malrotation and displacement in the posterior ring of the pelvis. The surgeon applying an anterior external fixator must be aware of this potential for malreduction and should adjust the reduction vector to, hopefully, minimize the deformity. Often, a combination of leg traction (directly or skeletal traction) and manipulation of the posterior pelvis with compression of the posterior part of the pelvis, using a circular sheet or binder around the greater trochanters, can help reduce the pelvis while limiting the occurrence of pelvic deformity.

A potential error and limitation of this study was the comparison of linear measurements before and after external fixation. The AP films could have different magnifications and angles of exposures. This difference could affect the reliability of posterior cephalad translation and posterior diastasis measurements. The authors however believe that these differences in techniques were minimal and that the measurements were accurate (femoral head diameters had similar measurements before and after anterior external fixation).

The actual deformities of the hemipelvis were similar before and after external fixations. Therefore, the accident, not the external fixator, caused the deformity. However, as previously stated, in most cases, the deformity worsened with the placement of the external fixator. The most common deformities included posterior cephalad translation, posterior diastasis, internal rotation, and flexion. These deformities are similar to the deformities found in our study of the surgical treatment of pelvic malunions and nonunions.[30] In this malunion study, the most common deformities were internal rotation (67%) and posterior cephalad translation (100%) and posterior diastasis (67%). The failure of external fixation and traction in the definitive management of unstable pelvic fractures explains the similarity in deformities between the acute deformities measured in this article and the deformities seen in our study of pelvic malunions and nonunions.[30]

CONCLUSIONS

In this group of hemodynamically unstable patients with a mechanically unstable pelvis, we found a 73% worsening of rotational deformities (internal rotation and/or flexion) and the 64% worsening of translational deformities (posterior cephalad translation and/or posterior diastasis) with the use of anterior pelvic external fixators. When complete posterior disruption occurs, the application of an anterior external frame may worsen the pelvic deformity. Due to the forces placed on the pelvis during application of an anterior external fixator by the surgeon, an external fixator deformity may occur (flexed and internally rotated hemipelvis). Furthermore, most patients had an increase in posterior cephalad translation or posterior diastasis with placement of an external fixator. The surgeon must be aware of the potential for worsening an existing pelvic deformity when applying an emergent anterior external fixator.

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