A commentary by Brett D. Crist, MD, is linked to the online version of this article.

Emergency Department Stress Radiographs of Lateral Compression Type-1 Pelvic Ring Injuries Are Safe, Effective, and Reliable

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Background: Occult instability of lateral compression type-1 (LC1) pelvic ring injuries may be determined with a fluoroscopic stress examination under anesthesia (EUA) performed in the operating room. We hypothesized that LC1 injuries, similar to some fractures of the extremities, could be radiographically stressed for stability in the emergency department (ED). Our primary objective was to determine if stress examination of LC1 fractures could be safely and accurately performed in the ED and could be tolerated by patients.

Methods: A prospective, consecutive series of 70 patients with minimally displaced LC1 pelvic injuries (<10-mm displacement on presentation) underwent stress examinations performed by the on-call orthopaedic resident in the ED radiology suite. The stress examination series included static 40° inlet, internal rotation stress inlet, and external rotation stress inlet views. Pelvic fractures that had positive stress results (≥10 mm of overlap of the rami) were indicated for a surgical procedure. These fractures also underwent EUA in order for the 2 techniques to be compared.

Results: All patients tolerated the ED stress examination without general anesthetic or hemodynamic instability. Fifty-seven patients (81%) had negative stress results and were allowed to bear weight. All patients with negative stress results who had 3-month follow-up went on to radiographic union without substantial displacement. For the patients with a positive stress result in the ED, the mean displacement was 15.15 mm (95% confidence interval [CI], 10.8 to 19.4 mm) for the ED stress test and 15.60 mm (95% CI, 11.7 to 19.4 mm) for the EUA ($p = 0.86$). Two patients with a negative ED stress test did not mobilize during their hospitalization and underwent EUA and conversion to a surgical procedure. Thus, a total of 11 patients underwent both stress testing in the ED and EUA; no patient had a positive result on one test but a negative result on the other.

Conclusions: ED stress examination of LC1 injuries is a safe and reliable method to determine pelvic ring stability. The displacement measured in the ED stress examination is similar to the displacement measured under general anesthesia. Furthermore, a negative ED stress examination predicts successful nonoperative treatment. Given the results of this study, we encourage the use of stress examination in the ED for LC1-type injuries involving complete sacral fractures only. Widescale adoption of this streamlined protocol may substantially diminish cost, anesthetic risk, and potential operations for patients.

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Lateral compression type-1 (LC1) fractures are common injuries, accounting for approximately 50% of all pelvic ring injuries[1-3]. They occur secondary to a lateral compressive force on the pelvis causing medialization and internal rotation of the hemipelvis[1,3,4]. These injuries have historically been treated nonoperatively, but current surgical indications are controversial[5,6].

The LC1 group represents a wide spectrum of injury severity[4,7-9] and presumed instability. Static imaging with radiographs and computed tomography (CT) may only capture a

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portion of the associated displacement[10,11]. Additionally, a subset of minimally displaced LC1 fractures have been shown to go on to later displacement if treated nonoperatively[10]. Examination under anesthesia (EUA) has emerged as a diagnostic adjunct to identify occult instability of the pelvic ring and is used by many surgeons who operate on the pelvis[12,13]. Experience with EUA has shown that a substantial portion of minimally displaced LC1 fractures are unstable under stress examination and that a negative stress examination can predict reliable healing of LC1 fractures without displacement, highlighting the important role that stress examination can play in the treatment algorithm of these injuries[12,14,15].

Although EUA may be a useful diagnostic tool, it is associated with certain drawbacks. The examination requires a trip to the operating room (OR) and use of a sedative or general anesthetic. This inevitably results in increased cost, morbidity, and time. Also, the subjectivity of the EUA may predispose surgeons to a bias in favor of operative treatment. We hypothesized that these injuries, similar to fractures of the extremities, could be stressed radiographically in the emergency department (ED) to test for stability[16-18].

Our institution enacted a protocol in which all minimally displaced LC1 pelvic fractures underwent a radiographic stress examination in the ED to determine pelvic ring stability. Our primary objective was to determine if an ED stress examination of LC1 pelvic fractures could be performed safely and reliably and could be tolerated by patients, in order to avoid potentially unnecessary anesthetic exposure and OR charges.

Materials and Methods

This study was conducted at a single level-I academic trauma center with umbrella institutional review board approval. A consecutive series of 70 patients were prospectively collected over the course of 18 months and outcomes were analyzed. We included patients presenting with a minimally displaced LC1 pelvic fracture, defined as <10-mm displacement in any plane on the standard pelvic static presentation radiographs or CT, as described previously[19,20]. LC1 pelvic fractures were classified as any disruption of the anterior pelvic ring along with a compression fracture of the sacrum. Fracture patterns with vertical displacement, a posterior ilium fracture (crescent), or a contralateral open-book-type injury were excluded[4]. All injuries classified as LC1 injuries were reviewed and were confirmed by 1 of 4 fellowship-trained traumatologists prior to the stress examination. Additional exclusion criteria included patients <18 years of age, patients with a concomitant acetabular injury, patients with a proximal femoral fracture, patients who were hemodynamically unstable or intubated, and patients who were pregnant.

Retrospective analysis of all pelvic ring injuries using Current Procedural Terminology codes identified 164 patients during the study period (91 patients with an LC1 fracture, 13 with an LC2 fracture, 5 with an LC3 fracture, 25 with anterior and posterior compression injuries, 13 with combined acetabular and pelvic ring injuries, 7 with vertical shear injuries, 5 with insufficiency fractures, 2 with ischial avulsion injuries, 1 with an iliac wing fracture, 1 with a U-type sacral fracture, and 1 with a locked symphyseal injury). Of the 91 patients with an LC1 fracture, 11 were excluded secondary to ≥10-mm displacement on static presentation radiographs, 4 were excluded secondary to intubated and sedated status, 2 had a concomitant proximal femoral fracture, 2 were excluded secondary to age of <18 years, and 2 were taken to the OR prior to an ED stress examination being performed. The final cohort included 70 patients with minimally displaced LC1 fractures who underwent an ED stress examination of the pelvis.

Fig. 1

(*Left*) The patient was positioned supine in the radiology suite and the x-ray beam was positioned for a 40° inlet view. (*Right*) The resulting pelvic radiograph of the patient.

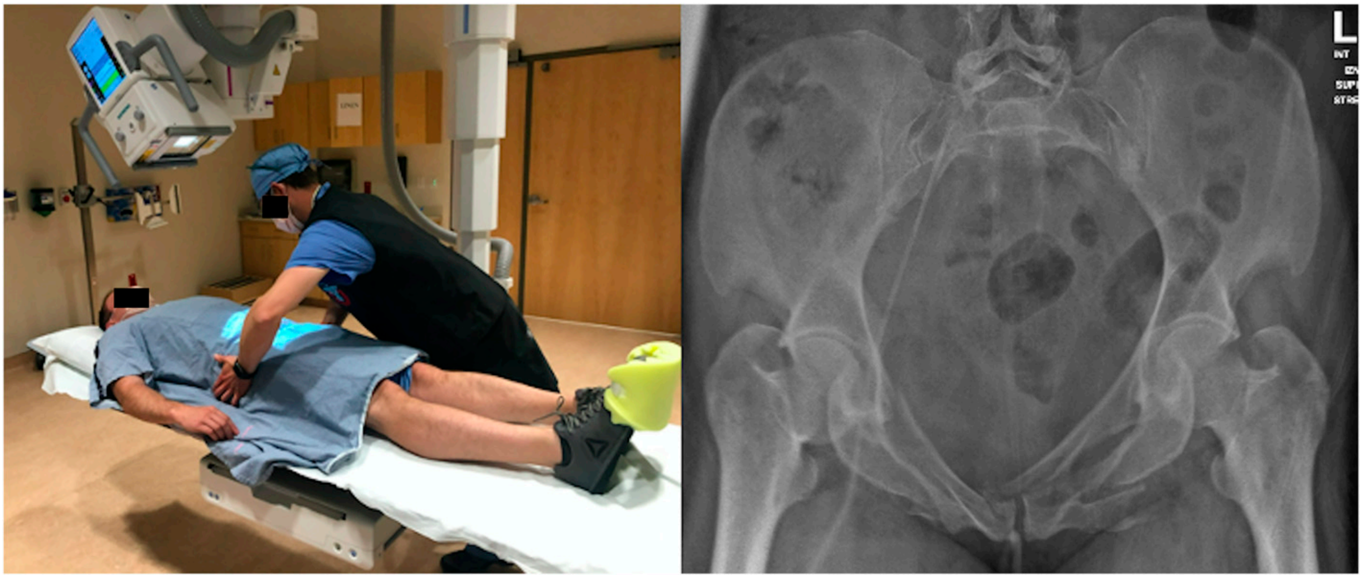

Fig. 2
(*Left*) With the patient in the supine position and the lower extremities internally rotated, the examiner positioned his hands over the greater trochanters bilaterally and an internal rotation force was applied. (*Right*) A 40° inlet radiograph was made in this position of internal rotation stress.

Patients who met inclusion criteria were taken to the radiology suite adjacent to the ED for a radiographic stress examination by the orthopaedic on-call resident. First, the patient was positioned supine and the 40° static inlet view radiograph was made with the lower extremities internally rotated (Fig. 1). Without changing the patient position, an internal rotation stress radiograph was made. The examiner positioned his hands over the bilateral greater trochanters and applied a medially directed force consistent with the technique described by Sagi et al.[12] (Fig. 2). Finally, a third inlet radiograph was made in which the examiner positioned his hands bilaterally at the inner tables of the ilium and applied a downward and external rotational force (Fig. 3) to rule out an occult LC3 injury[12,21].

Before measurements were made, the static radiographs were calibrated by using the femoral shaft width just distal to the lesser trochanter as a reproducible landmark and calibrating each inlet radiograph to the pelvic CT scan[22-24]. Measurements were

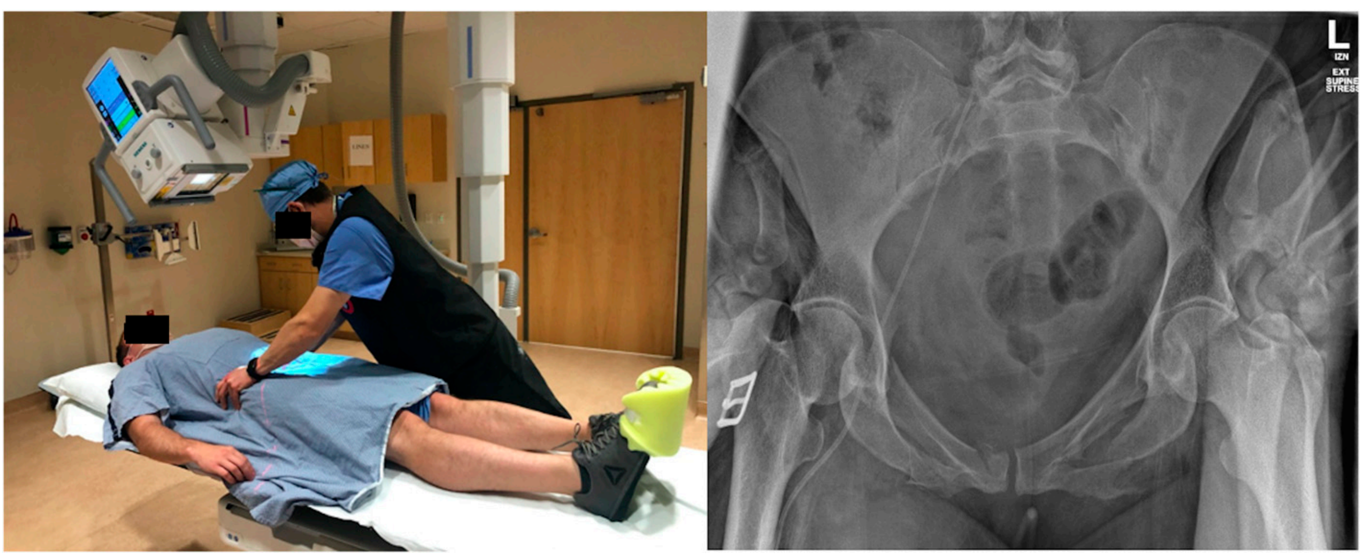

Fig. 3
(*Left*) The final stress view was achieved with the examiner's hands at the inner tables of the ilium bilaterally and a downward or external rotation force was applied. (*Right*) A 40° inlet radiograph was made in this position of external rotation stress to rule out an occult LC3 injury. Note that the examiner should always wear lead gloves when performing this examination to protect from radiation exposure.

Fig. 4

Examples of measurements used to judge displacement with stress radiographs made in the ED. (*Left*) The distance between femoral heads was measured on a static inlet and an internal rotation stress inlet radiograph, and the difference between the 2 calibrated radiographs was calculated. In this example, the pelvis displaced medially 16.13 mm through the left side, and this patient was indicated for EUA. (*Right*) The medial distance between the femoral heads was measured on the static inlet view, with the femoral shaft width used to calibrate the image to a pelvic CT.

made between the medial borders of the bilateral femoral heads to determine the medial displacement of each LC1 pelvic fracture (Fig. 4). Pelvic fractures that had a positive stress examination, defined as ≥10 mm of overlap of the rami on internal rotation stress[12,14], were indicated for a surgical procedure. These patients had a repeat stress examination performed in the operating room

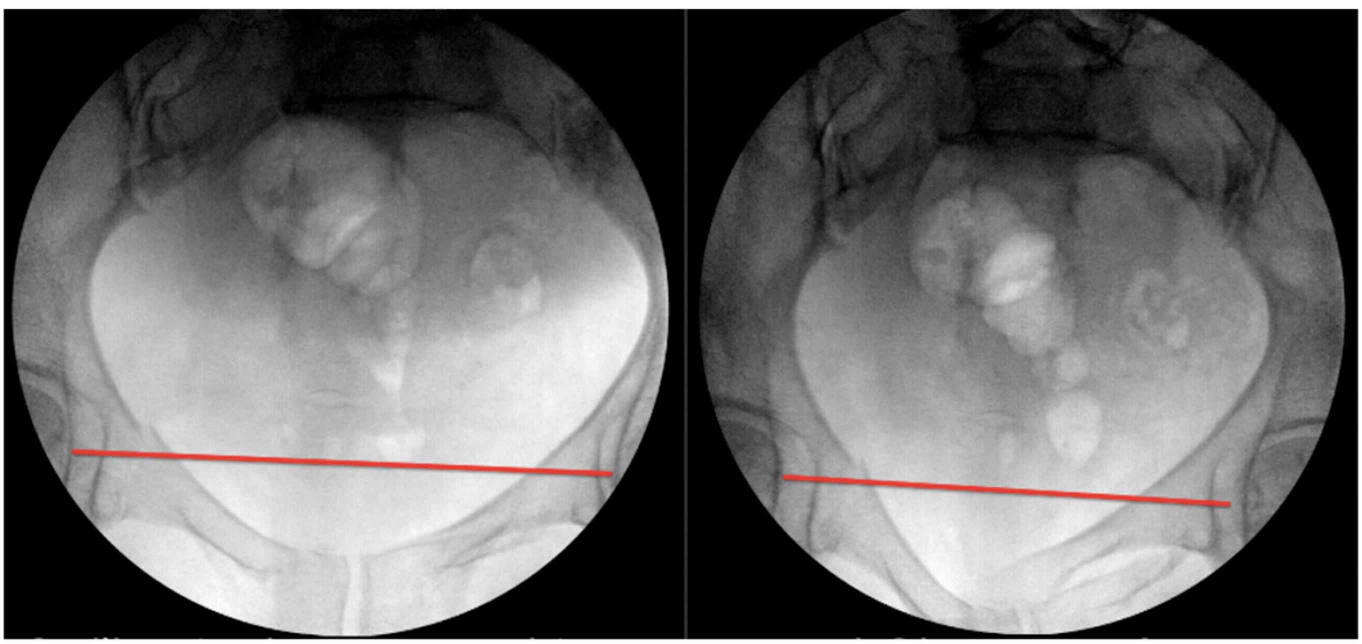

Fig. 5

An example of saved fluoroscopy from the EUA performed on the patient from Figure 4. (*Left*) Internal rotation stress demonstrated a positive EUA, with approximately 19.55-mm internal displacement compared with static fluoroscopy. This patient was treated with operative fixation for occult instability demonstrated on the stress radiograph in the ED examination and confirmed on EUA. (*Right*) The static inlet view achieved in the OR, with the distance between the medial sides of the femoral heads measured.

TABLE I Demographic Data

	Positive Stress Test in ED (N = 13)	Negative Stress Test in ED (N = 57)	Total Population (N = 70)	P Value
Age* *(yr)*	51.0	61.0	59.2	0.15
Female sex†	9 (69%)	29 (51%)	38 (54%)	0.23
Mechanism†				0.002‡
High-energy	12 (92%)	26 (46%)	38 (54%)	
Low-energy	1 (8%)	31 (54%)	32 (46%)	
Polytrauma†	8	25	33	0.15

*The values are given as the mean. †The values are given as the number of patients, with or without the percentage in parentheses. ‡Significant.

(EUA) to compare the 2 techniques (Fig. 5). EUA consisted of the same views obtained in the ED. Again, a calibrated measurement of the medial displacement was performed[23]. Patients were treated surgically based on the algorithm presented by Avilucea et al.[14]. Patients with pelvic injuries that had negative results on the ED stress examination were allowed to bear weight as tolerated or as dictated by other injuries and had follow-up with clinical evaluation and subsequent radiographs of the pelvis. The pragmatic protocol developed by Whiting et al. was used in follow-up; radiographic union was defined as bridging callus across fractures without progressive displacement, and clinical union was defined as ambulation without pain[25].

Sacral fractures were characterized by the Denis zone and were defined as incomplete or complete based on whether the fracture extended through the posterior cortex on a CT scan[26]. Superior ramus fractures were classified according to the Nakatani system (root, mid-ramus, or parasymphyseal) and by fracture characteristics (transverse, oblique, comminuted, or segmental)[27]. If multiple superior ramus fractures were present, the injury was classified according to the more unstable fracture segment. Inferior ramus fractures were described as displaced or nondisplaced.

Descriptive statistics for continuous demographic variables were reported as the mean and the standard deviation. Chi-square tests were performed to compare categorical and binary outcomes. Independent sample t tests were performed to compare continuous variables, with significance set at $p < 0.05$. Analyses were performed with JMP (version 12; SAS Institute).

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The authors received no specific funding for this work.

Results

Seventy patients met inclusion criteria, and all 70 tolerated the ED stress examination without complication or hemodynamic instability. The mean age (and standard deviation) of the population was 59.2 ± 22.8 years (range, 18 to 92 years), and there were 39 female patients (56%). Of the entire cohort, 57 patients demonstrated a negative ED stress examination, and 13 patients (19%) demonstrated a positive ED stress examination. There were no significant differences in age, sex, or polytrauma status between the groups with positive and negative stress results. There was a difference in mechanism of injury between the 2 groups, with injuries via a high-energy mechanism in 92% of patients in the group with positive stress results and 46% in those with negative results ($p = 0.002$) (Table I). Overall, the rate of positive ED stress results in patients with a high-energy injury mechanism was 32%. High energy was defined as an injury mechanism other than a fall from a standing height.

Of the 57 patients with a negative ED stress examination, 55 patients underwent successful nonoperative treatment. The remaining 2 patients in this cohort were unable to walk due to intolerable pain. Both patients had sustained a high-energy injury after a fall from a height, and both patients presented with complete zone-2 sacral injuries and bilateral fractures of the rami (involving pubic root fractures for 1 patient and a mid-ramus location for the other patient). Both patients were taken for EUA and percutaneous fixation of the posterior pelvis[28,29]. Both patients again had a negative stress EUA, with a mean displacement of 6.65 mm that was similar to that of 5.95 mm on their previous ED stress examination ($p = 0.87$). After posterior stabilization, both patients were able to mobilize with physical therapy.

Of the 55 patients who were treated nonoperatively after negative ED stress examinations, 43 (78%) had follow-up of at least 3 months (mean, 5.3 ± 5.88 months). Twelve patients did not have follow-up to fracture union for various reasons (5 died, 6 were out of state, and 1 had unknown reasons). All 43 of the nonoperatively treated patients with 3-month follow-up went on to successful radiographic and clinical union without further radiographic displacement[25].

Thirteen patients demonstrated a positive ED stress examination and were indicated for a surgical procedure. In 9 of these patients, fluoroscopy of the EUA performed prior to fixation had been saved (Fig. 6). All 9 of these patients had a positive EUA similar to their ED stress examination ($p = 0.86$), with a mean displacement of 15.15 mm (95% confidence interval [CI], 10.8 to 19.4 mm) for the ED stress examination and 15.60 mm (95% CI, 11.7 to 19.4 mm) for the EUA.

The group with a positive ED stress result demonstrated strikingly different fracture characteristics than the group with a negative result. Nearly all patients in the group with a positive

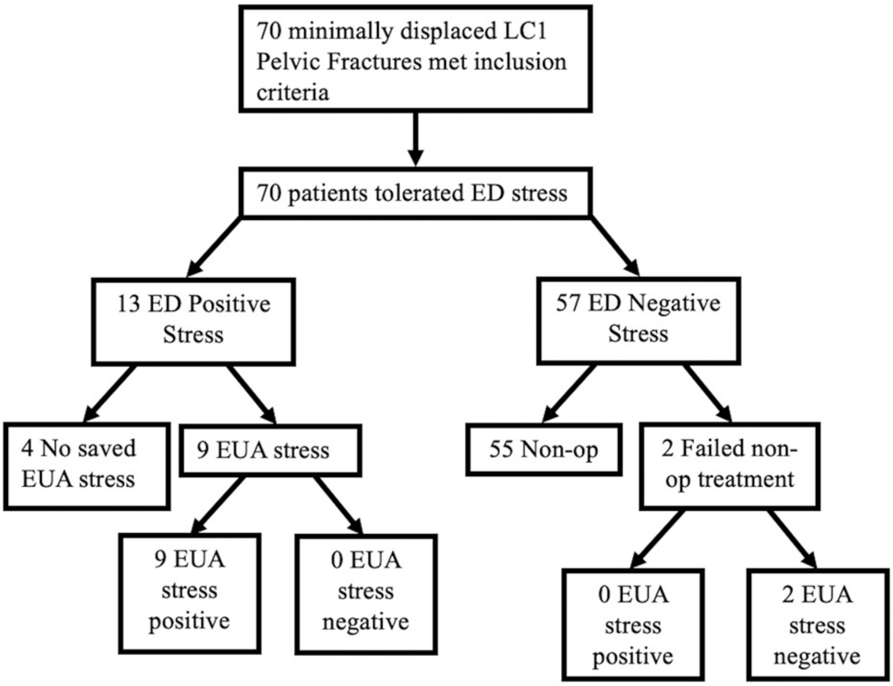

Fig. 6

Diagram detailing the cohort of patients who underwent a stress examination of a minimally displaced LC1 pelvic fractures in the ED. All patients tolerated the stress radiographs made in the ED, and no patients showed a discrepancy in results between the ED examination and the EUA. Non-op = nonoperative.

TABLE II Fracture Characteristics

	Positive Stress Radiographs in ED (N = 13)*	Negative Stress Radiographs in ED (N = 57)*	Total Population (N = 70)*	P Value
Complete sacral fracture	12 (92%)	16 (28%)	28 (40%)	<0.001†
Sacral fracture classification				0.08
Zone 1	5 (38%)	39 (68%)	44 (63%)	
Zone 2	7 (54%)	18 (32%)	25 (36%)	
Zone 3	1 (8%)	0 (0%)	1 (1%)	
Ramus fractures				<0.001†
Unilateral	3 (23%)	47 (82%)	50 (71%)	
Bilateral	10 (77%)	10 (18%)	20 (29%)	
Inferior ramus fracture	13 (100%)	49 (86%)	62 (89%)	
Displaced	6 (46%)	17 (30%)	23 (33%)	0.26
Superior ramus fracture location				0.007†
Root	1 (8%)	23 (40%)	24 (34%)	
Mid-ramus	3 (23%)	20 (35%)	23 (33%)	
Parasymphyseal	9 (69%)	14 (25%)	23 (33%)	
Superior ramus fracture description				<0.001†
Transverse	0 (0%)	30 (53%)	30 (43%)	
Oblique	1 (8%)	10 (18%)	11 (16%)	
Comminuted	7 (54%)	15 (26%)	22 (31%)	
Segmental	5 (38%)	2 (4%)	7 (10%)	

*The values are given as the number of patients, with the percentage in parentheses. †Significant.

TABLE III The Rates of Positive Stress Radiographs in the ED Examination by Fracture Characteristics

Fracture Combination	Total*	Positive Stress Test in ED		Displacement with Stress in ED† *(mm)*
		No.*	Rate	
Incomplete sacral fracture				
With unilateral ramus fracture	38	0	0%	3.69 (2.8 to 4.5)
With bilateral ramus fractures	4	1	25%	6.15 (2.8 to 9.5)
Complete sacral fracture				
With unilateral ramus fracture	12	3	25%	4.70 (0.2 to 9.1)
With bilateral ramus fractures	16	9	56%	10.38 (6.5 to 14.3)

*The values are given as the number of patients. †The values are given as the mean, with the 95% CI in parentheses.

result in the ED had a complete sacral fracture (92%) compared with only 16 patients (28%) in the group with a negative result ($p < 0.001$). There were also differences in the location of the superior ramus fracture ($p = 0.007$) and in the superior ramus fracture description between the 2 groups ($p < 0.001$) (Table II).

Fracture characteristics were combined to determine the rates of positive stress results in the ED. All 38 patients with an incomplete sacral fracture and a unilateral ramus fracture had negative stress results, with a mean displacement of 3.69 mm (95% CI, 2.8 to 4.5 mm). One of 4 patients with an incomplete sacral fracture and bilateral fractures of the rami had a positive result on stress testing in the ED. Twelve patients with a complete sacral fracture and a unilateral ramus fracture had a mean displacement of 4.7 mm (95% CI, 0.2 to 9.1 mm) on the stress examination in the ED; 25% had a positive stress test in the ED. Sixteen patients with a complete sacral fracture and bilateral fractures of the rami had a mean displacement of 10.38 mm (95% CI, 6.5 to 14.3 mm) on the stress radiographs in the ED; 56% had positive stress radiographs (Table III).

The ED stress radiographs showed displacement similar to that of the EUA fluoroscopy. Eleven patients underwent both ED examinations with stress radiographs and EUA with saved fluoroscopy; of these, 9 had positive stress radiographs in the ED, and the other 2 had negative stress radiographs in the ED but were subsequently not able to mobilize. The mean displacement was 13.48 mm (95% CI, 9.2 to 17.8 mm) on the examinations in the ED and 13.97 mm (95% CI, 10.0 to 17.9 mm) on the EUA ($p = 0.85$) (Table IV). All patients who underwent ED stress radiographs and EUA had agreement between their 2 examinations. Finally, no patients had a positive external rotation stress radiograph, and, therefore, no occult LC3 injuries were identified.

Discussion

This study demonstrates that stress testing of LC1 fractures in the ED is safe and reliably predicts EUA rotational displacement. All patients tolerated this examination without excessive discomfort or complications. Furthermore, negative results on the ED stress testing predicted successful nonoperative treatment with weight-bearing as tolerated in >90% of cases. Finally, similar to previous findings, incomplete sacral injuries represented a stable fracture pattern and did not require a stress examination in the ED prior to nonoperative treatment.

Stress EUA has become an important part of the treatment algorithm of LC1 fracture patterns[5,10,11,13,15,25]. However, EUA requires general anesthetic or a sedative and OR time and may predispose to an operative bias. A recent report on early experience with lateral stress radiography of awake patients with minimally displaced LC1 injuries demonstrated displacement measurements similar to those obtained with EUA[30]. Compared with the lateral stress radiograph, the supine stress radiograph is more similar to the stress view obtained in the OR and, therefore, is less susceptible to changes in pelvic obliquity and compares better with the EUA. The current investigation shows the supine

TABLE IV Pelvic Fracture Displacement: Stress Radiographs in ED Examination and EUA

	Displacement* *(mm)*		
	Stress Radiographs in ED	EUA	P Value
Negative stress examination (n = 2)	5.95	6.65	0.87
Positive stress examination (n = 9)	15.15 (10.8 to 19.4)	15.60 (11.7 to 19.4)	0.86
Total (n = 11)	13.48 (9.2 to 17.8)	13.97 (10.0 to 17.9)	0.85

*The values are given as the mean, with or without the 95% CI in parentheses.

stress test in the ED to be safe, well tolerated, and accurate when compared with the intraoperative examination.

Given these findings, there are several reasons to consider this algorithm. Stress radiographs may add objectivity to this process, as one can measure displacement precisely. The evaluation of EUA is generally performed in real time, on a fluoroscopy screen, without formal measurements of displacement. The EUA method seems to rely more on the surgeon's gross estimation of the displacement and instability. This is also a setting with potentially conflicting incentives for the surgeon. The ED stress test is an examination that can be easily performed through simple instructions without the presence of an attending surgeon or the need for general anesthetic. Also, the abridged stress protocol with 2 to 3 inlet radiographs requires very little time or cost and minimal radiation exposure. Furthermore, patients with isolated LC1 injuries who have negative stress results in the ED can often be discharged from the ED without a hospital admission or mobilization with physical therapy. The adoption of this practice for the treatment of minimally displaced LC1 fractures with complete sacral injuries could greatly decrease cost and exposure to anesthetic and potentially could reduce surgeon bias toward operative intervention.

Predicting stability in LC1 fractures based on imaging can be challenging[5,6]. Previous research has suggested that fracture characteristics such as a complete sacral fracture, a fracture in the greater sacral zone, bilateral fractures of the rami, and parasymphyseal fractures of the rami can be used to predict stability and future displacement in LC1 injuries[10,31]. Our results regarding stress examination in the ED are consistent with this previous literature. Fractures with complete sacral injuries, bilateral fractures of the rami, and comminuted or segmental fractures of the rami in a parasymphyseal location were more likely to be unstable on stress testing in the ED and EUA (Table II). Only 1 of 42 patients with an incomplete sacral fracture had a positive stress examination. It is possible that this patient had a complete sacral injury that was not identified on a CT scan, as the evaluation of the extent of the sacral fracture was quite difficult secondary to severe osteoporosis[32]. Similarly, Bruce et al. found that only 2.6% of patients in their series, which included 76 incomplete sacral fractures, went on to future displacement at the final follow-up after nonoperative treatment[10]. In a prospective study, Tosounidis et al. reported that all patients with LC1 injuries who had positive stress examinations had complete sacral fractures, while all those who had negative stress results had incomplete sacral fractures[15]. In the current study, a low-energy fracture mechanism also predicted a negative stress examination in the ED in 97% of cases (31 of 32). Secondary to this very low rate of positive stress tests for incomplete sacral fractures and fractures due to a low-energy mechanism, we advocate for allowing patients with incomplete sacral fractures or injury secondary to a ground-level fall to bear weight as tolerated without undergoing a stress examination[20].

Similar to the reports by Sagi et al. on the pelvic stress testing of 19 LC1 fractures, we found that the stress views did not identify any occult LC3 injuries[12]. We conclude that it may be safe to exclude the external rotation stress view from the ED stress examination of minimally displaced LC1 injuries unless there is clinical concern for contralateral sacroiliac joint widening (e.g., L5 transverse process avulsion, an anterior sacroiliac fleck sign, or imaging only obtained in a pelvic binder)[21].

Of the 57 patients who had a negative ED stress examination, only 2 (4%) were not able to mobilize during their hospitalization and were indicated for percutaneous posterior stabilization for intractable pain despite a negative EUA[28,29]. In both of these cases, the sacral injury was a complete fracture. Both patients were able to mobilize after their operative intervention. Previous work has shown that negative EUA reliably predicts the union of pelvic ring injuries without displacement[10,15,25]. The current study evaluated the pragmatic radiographic and clinical follow-up of 43 patients with negative stress examinations in the ED and at least 3 months of follow-up. All of these patients had successful radiographic and clinical nonoperative treatment, which suggests that negative stress radiographs in the ED reliably predict the successful nonoperative treatment of most patients with minimally displaced LC1 injuries.

We acknowledge several limitations of this study. First, the sample size of patients who underwent stress radiographs in the ED and EUA with saved fluoroscopy was small. However, the similarity in measured displacement and the 100% agreement in the 11 patients with saved fluoroscopic stress examination are encouraging. Second, some inherent issues with stress examination were not addressed through our protocol. There was no standard, quantified force applied for the ED stress examination or EUA. This method is pragmatic, as there is currently no evidence in the literature to guide how much force should be applied in a pelvic stress examination. Third, this study did not attempt to answer the question of how much displacement on a stress examination is important. We chose to use a previously utilized value of 10 mm of displacement as our operative cutoff, and, although this has been used in previous publications, we acknowledge that it may not have adequate literature support[14]. Additionally, indication bias with regard to other patient or injury factors may have influenced the radiographic measurements. Finally, previous literature has demonstrated low rates of pelvic instability in LC1 injuries with incomplete sacral fractures[10,15]. We chose to include all minimally displaced LC1 injuries to determine the safety and sensitivity to pelvic instability of this protocol, as this is a relatively novel technique. However, the results of this current study support the utilization of a stress examination of LC1-type injuries in the ED for complete sacral injuries only. ■

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