Received: 5 March 2024 | Revised: 25 May 2024 | Accepted: 8 June 2024

DOI: 10.1111/vsu.14132

CLINICAL RESEARCH

WILEY

External skeletal fixation for the treatment of pelvic fractures in cats

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Abstract

Objective: To report the technique and the outcome for the repair of pelvic fractures in cats using external skeletal fixation (ESF).

Study design: Retrospective case series.

Animals: Client-owned cats ($n = 125$).

Methods: Medical records of cats with pelvic fractures, treated with an ESF between June 2001 and June 2009, were reviewed. Preoperative, immediate postoperative, and more than 4 weeks' postoperative radiographs were compared. Clinical examination was performed 4 to 9 weeks following surgery. Longer term follow up (4 to 80 months) was conducted by client questionnaire.

Results: No intraoperative complications occurred. There was no change in the pelvic canal width observed on follow-up radiographs ($p = .16$). Implant loosening was noted on follow-up radiographs in 16/125 (13%) of cases, and 67/803 (8%) pins were palpably loose at the time of frame removal. The mean time to frame removal was 37 ± 9 days. No long-term complications were reported. Long-term mean mobility score was 95 ± 5 and median lameness was 0 (range: 0–2).

Conclusion: An ESF may be successfully applied for the stabilization of various pelvic fractures in cats.

Clinical significance: The application of an ESF for the management of pelvic fractures in cats provides good outcomes.

1 | INTRODUCTION

Feline pelvic fractures are common and account for 22 to 32% of all feline fractures.[1–3] The pelvis allows the transfer of force from the pelvic limb to the axial skeleton; this is often referred to as the "weight-bearing axis." Conservative management is an option for ambulatory, nonpainful animals; however surgical stabilization provides analgesia and may be advocated for most fractures to the weight-bearing axis of the pelvis.[4–9] In addition, pelvic canal collapse is often present, which may lead to recurrent constipation, obstipation, and megacolon. For

Abbreviations: ESF, external skeletal fixation; KE, Kirschner-Ehmer; PART, pin anchor realignment technique; PAST, pin anchor slide technique; SaI, sacral index; SI, sacroiliac; VAS, visual analogue scale.

this reason, it has been suggested that all pelvic fractures resulting in pelvic canal narrowing should be stabilized surgically.[5]

Various surgical techniques utilizing internal fixation have been reported for stabilization of sacroiliac (SI) fracture-luxations,[10–17] ilial,[7,18–23] and acetabular[24–26] fractures in cats and dogs.

Several reports published between 1940 and 1970 described the successful use of external skeletal fixation (ESF) for the stabilization of a variety of pelvic fractures in dogs and cats.[27–32] Despite these positive reports, concerns regarding impingement of musculotendinous and neurovascular structures, pin loosening, infection, and problems related to patient compliance precluded the widespread use of this technique. Recent improvements in pin design, frame configuration and pin insertion techniques have resulted in improved outcomes for ESF of long bone fractures[33–36] and successful outcomes have also been reported for the stabilization of pelvic fractures with external fixation.[37]

The purpose of this study is to describe a technique for stabilization of pelvic fractures in cats using external skeletal fixation and to report the results of this technique in 125 consecutive cases. Our null hypotheses were that there would be no difference in pelvic canal width, or fracture reduction, between immediate postsurgery and follow-up radiographs, and that the presence of pin loosening would not impact clinical outcomes.

2 | MATERIALS AND METHODS

Medical records of cats with pelvic fractures between June 2001 and June 2009 were reviewed. Inclusion criteria were (i) surgical stabilization solely by ESF and (ii) radiographs taken 4–9 weeks after repair. Fractures were classified into three main groups: (1) unilateral or bilateral sacroiliac fracture/luxation with or without concurrent fractures of the pubis or ischium, but with no evidence of ilial or acetabular fractures; (2) fractures of the ilium with or without fractures of the pubis or ischium or sacroiliac luxation but with no evidence of acetabular fracture; (3) fractures of the acetabulum with or without fractures of the pubis or ischium, sacroiliac luxation or ilial fracture. All surgical procedures were performed by the same surgeon (NF).

Sacral fractures were classified as previously reported,[38] however only type I and type II fractures were subsequently included in the study as these alar wing and sagittal fractures were considered clinically similar to sacroiliac luxation and thus it was deemed feasible to group them together with sacroiliac luxation for subsequent analysis.

Fractures of the ilium and acetabulum were subclassified into those with simple (two-piece), mildly comminuted (three fragments), or highly comminuted (four or more fragments) fractures.

2.1 | Preoperative care

Anesthesia protocols were based on individual patient requirements. All patients received multimodal perioperative analgesia. Intravenous cefuroxime 22 mg/kg (Zinacef; GlaxoSmithKline, Brentford, UK) or amoxicillin/clavulanic acid 22 mg/kg (Augmentin; GlaxoSmithKline) were administered 30 min prior to surgery and repeated every 90 min until the completion of all surgical procedures. Postoperative antibiotics were administered on an individual patient basis if indicated based on concomitant pathology.

2.2 | Patient preparation

The fur was clipped circumferentially from the level of the third lumbar vertebra to include the proximal third

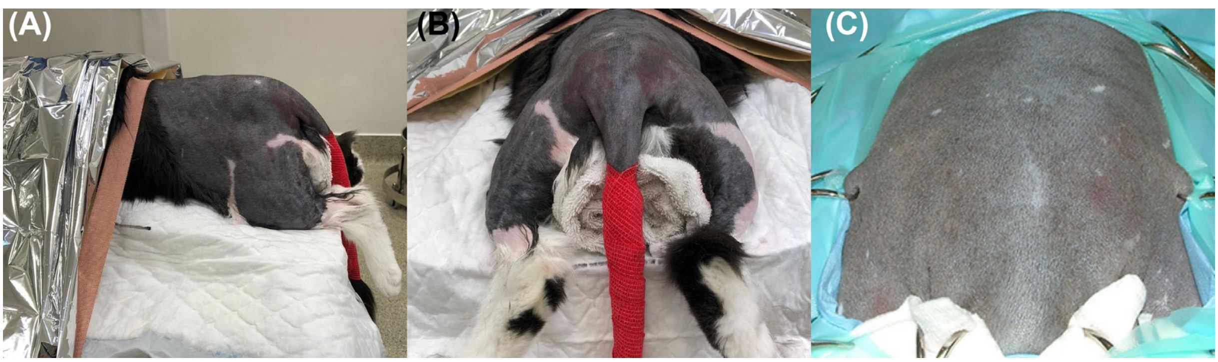

FIGURE 1 Cat prepared for surgery and positioned in ventral recumbency on a towel to position the flexion angles of the hips and stifle joints to approximately 90 degrees. Photograph taken from the side (head is to the left) (A) and view from behind (B). Photograph of patient draped for surgery; view from behind, where primary surgeon would stand (C).

of the tail. The clip extended distally to the level of the stifle joints. An anal purse string suture was placed. The cat was positioned in ventral recumbency with a rolled towel positioned ventral to the pubis so that the flexion angles of the hip and stifle joints approximated 90° in the sagittal plane (Figure 1A,B). The clipped area was aseptically prepared, and the pelvis was four-quarter draped with the tail draped outside the surgical field. Care was taken to ensure that the ischiatic tuberosities were completely exposed within the sterile field (Figure 1C).

3 | SURGICAL TECHNIQUE

3.1 | Group I: Sacroiliac fracture luxation

3.1.1 | Frame application for unilateral sacroiliac fracture luxation

In all cases ESF frames were constructed using small Kirschner–Ehmer (KE) components (Veterinary Instrumentation, Sheffield, UK) and three 1.6 mm diameter negative profile partially threaded pins (Veterinary Instrumentation). A three-pin frame was used for all cases. Via a dorsal midline skin incision, the luxated sacroiliac joint was exposed via a limited dorso-lateral approach to achieve direct visibility of the articular surfaces of the sacrum and ilium. The first ilio-sacral pin was then placed through a lateral stab incision and inserted dorsolateral-ventromedial (30° from the horizontal axis) to exit within the center of the articular surface on the medial aspect of the ilium. To prevent skin tension following wound closure the skin edges were approximated prior to making the stab incision. The pin was driven until the entire threaded portion was visible at the ilial articular surface (Figure 2A). The tip of the pin was then placed at the point on the sacral articular surface matching the pin exit point on the ilium (Figure 2B) and was driven into the sacral body to a minimum depth such that the threaded portion of the pin was not visible (Figure 2C). Ideally the pin would just exit the ventral surface of the sacrum. It is noteworthy that the pin could be used to manipulate the displaced ilial wing caudally and in such cases where sufficient caudal traction was difficult, the pin was partially driven into the sacral body at a cranio-caudal angle and then used as a lever to then pull the ilial wing caudally prior to seating it within the sacral body. With the smooth portion of the pin now acting as a reduction guide, reduction of the sacroiliac luxation was completed by sliding the ilial wing along the pin by axially applied compression over the ilial wings. The authors have termed this the "pin anchor slide technique" (PAST). Compression was either applied using digital pressure or pointed bone holding forceps (Figure 3). In the cases of sacral fracture where the articular surface of the sacrum was not present, the entrance point for the pin into the sacral body was estimated to correspond with the exit point of the pin through the center of the lateral ilio-sacral segment and the fracture reduced using PAST technique as previously described. Assessment of reduction of the articular facet was used to aid accurate reduction.[27]

A small stab incision was then made over the contralateral dorsal aspect of L7-S1 facet joint and the tip

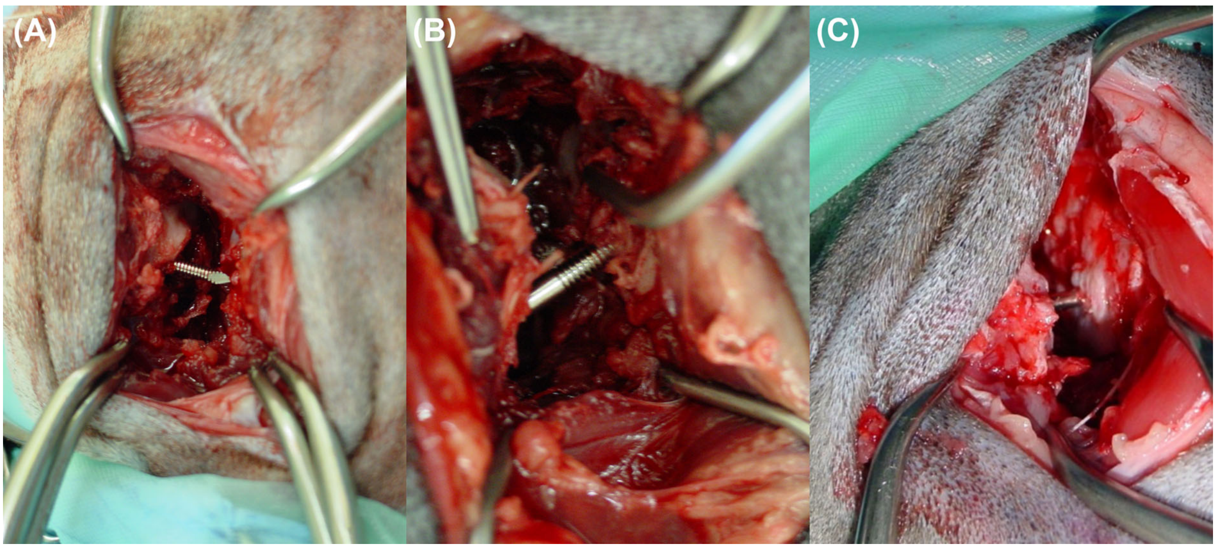

FIGURE 2 Pin anchor slide technique (PAST). The pin is driven through the ilial wing until all of the threaded portion is visible at the articular surface of the ilium (A). The pin is then driven into the corresponding point on the articular surface of the sacrum (B). The pin is driven into the sacrum until the threaded portion is no longer observed (C).

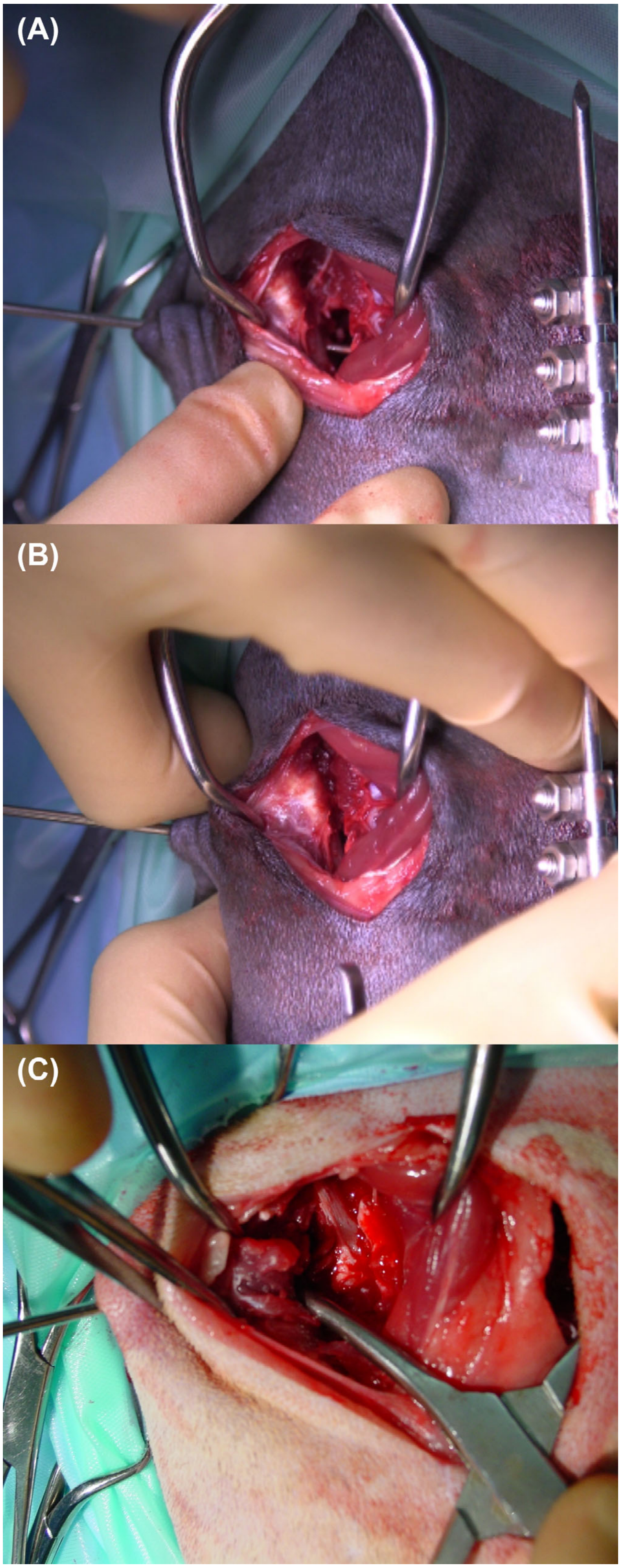

FIGURE 3 Pin anchor slide technique (PAST). The ilial wing is then slid down the smooth portion of the pin (A) to reduce the sacroiliac joint via axial compression with digital pressure (B) or pointed bone holding forceps (C).

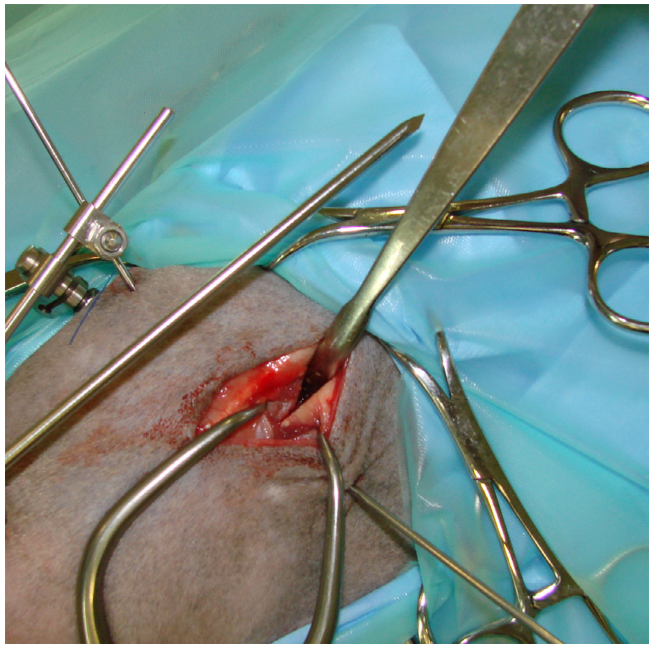

FIGURE 4 Placement of a pin across nonluxated sacroiliac joint. The Hohmann retractor is walked off the cranial aspect of the sacral facet to act as a landmark for pin placement. A pin has already been placed in the contralateral SI joint, along with partial construction of the connecting bars.

of an 8 mm Hohmann retractor was "walked" off the cranial aspect of the sacral facet to aid correct placement of a second ilio-sacral pin across the nonluxated sacroiliac joint (Figure 4). This pin was placed in a similar fashion as the first, using the orientation of the first pin and the tip of the Hohmann as a guide. These two pins converged as they exited the ventral aspect of the sacral body. To place the third pin in the ischium, a small stab incision was made over the ischial tuberosity on the same side as the luxation and the tip of a Hohmann retractor placed within the lateral aspect of the obturator foramen near the lesser ischiatic notch. The tip of the Hohmann was used as a guide to aid pin placement. Two possible pin positions were used. In the first, the pin was placed from lateral to medial at an angle of 30° from the horizontal (either directly through the stab incision or through a separate stab incision). The entrance point into the bone was at the caudal aspect of the ischial body in the region of the lesser ischiatic notch, the pin exiting into the caudolateral aspect of the obturator foramen (Figure 5). In the other pin position, the pin was inserted from the ischiatic tuberosity into the ischiatic ramus, finishing caudo-medial to the acetabulum (Figure 6). This second option became the authors' preferred position. A

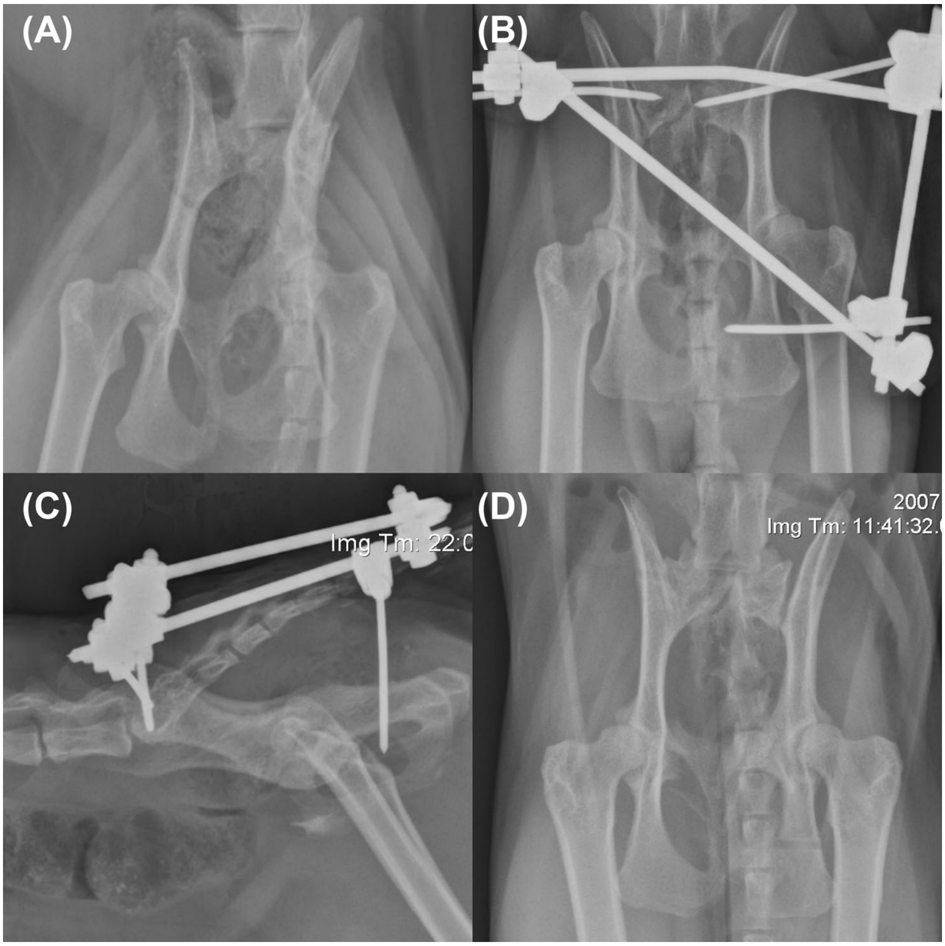

FIGURE 5 Sacroiliac luxation (Group 1): Case example 1. Ventrodorsal radiograph of left unilateral sacroiliac luxation (A). Ventrodorsal radiograph demonstrating triangular external skeletal fixation (ESF) immediately postsurgery (B). Lateral radiograph demonstrating triangular ESF immediately postsurgery (C). Ventrodorsal radiograph after ESF removal 3 weeks postsurgery (D).

single KE clamp was attached to each of the three pins. Lengths of appropriately contoured 3.2 mm Steinmann pins were used as connecting bars (connected via double KE clamps) between pins 1 and 2, 1 and 3 and 2 and 3 to create a rigid triangular frame (Figures 5 and 6).

3.2 | Frame application for bilateral sacroiliac fracture luxation

Frame assembly in cases of bilateral sacroiliac luxation was as described for cases of unilateral luxation, the only difference being that the two ilio-sacral pins were placed in exactly the same manner by means of a limited open approach to achieve direct visibility of the articular surface of the ilium and auricular surface of the sacrum (Figure 7). Reduction was achieved using PAST bilaterally. Axial compression was applied during frame assembly by placing a large pair of pointed reduction forceps across the SI joints. Placement of the third pin and construction of the triangular-shaped frame was as previously described for cases of unilateral luxation.

3.3 | Group 2: Ilial fractures

3.3.1 | External skeletal fixation application principles for ilial fractures

All external skeletal fixators were constructed using small KE components (Veterinary Instrumentation) and 1.6 mm diameter negative profile partially threaded pins (Veterinary Instrumentation). Over the 8 year study period, there was a gradual evolution in ESF design. Evolution was influenced by increasing ease of application of the clamps and rods for all pins, in all fracture configurations. However, all configurations were subtle variations of one of two frame assemblies, namely, the triangular frame (Figure 8) and the quadrilateral frame (Figure 9). The triangular and quadrilateral frame names are derived from the approximate shape formed by the connecting bars; which depends on whether or not pins enter all four quadrants of the pelvis (quadrilateral frame), or just three quadrants (triangular frame). The broad principle of ESF assembly involved placement of independent pin and connecting bar assemblies into each major fracture bone segment, with two or three pins per

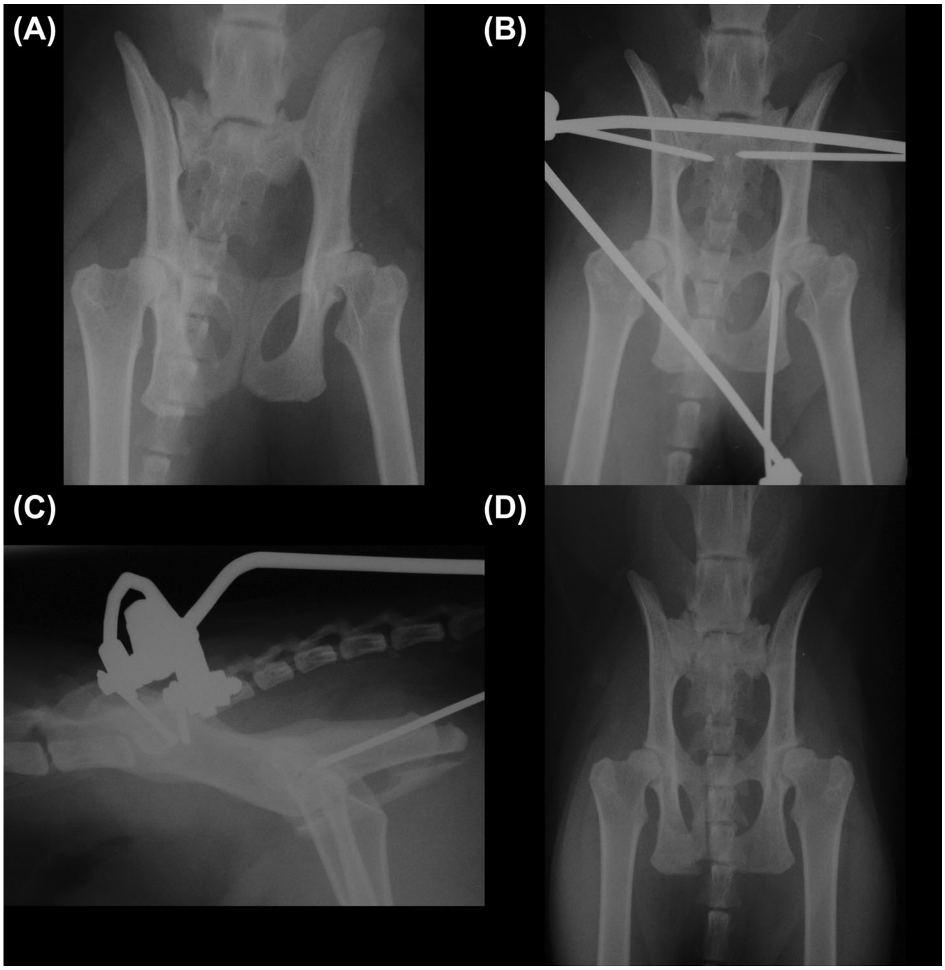

FIGURE 6 Sacroiliac (SI) luxation (Group 1): Case example 2. Ventrodorsal radiograph of left unilateral sacroiliac luxation (A). Ventrodorsal radiograph demonstrating triangular external skeletal fixation (ESF) immediately postsurgery (B). Lateral radiograph demonstrating triangular ESF immediately postsurgery (C). Ventrodorsal radiograph after ESF removal 3 weeks postsurgery (D). The third connecting bar to complete the triangular frame has yet to be added to the construct.

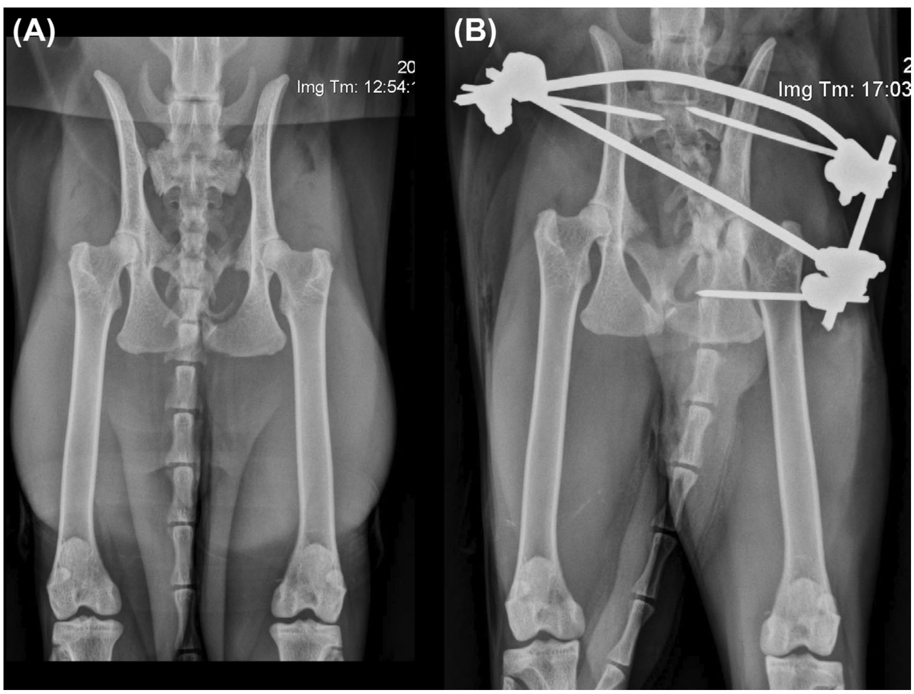

FIGURE 7 Sacroiliac (SI) luxation (Group 1): Case example 3. Ventrodorsal radiograph of bilateral sacroiliac luxation (A). Ventrodorsal radiograph demonstrating triangular external skeletal fixation (ESF) immediately postsurgery (B).

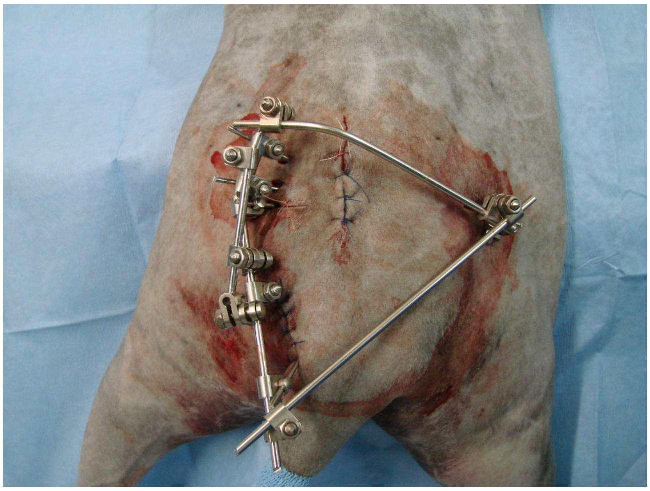

FIGURE 8 Photograph of postoperative appearance of triangular external skeletal fixation (ESF) frame configuration example (cranial is towards the top of the photograph) the tail has been partially amputated.

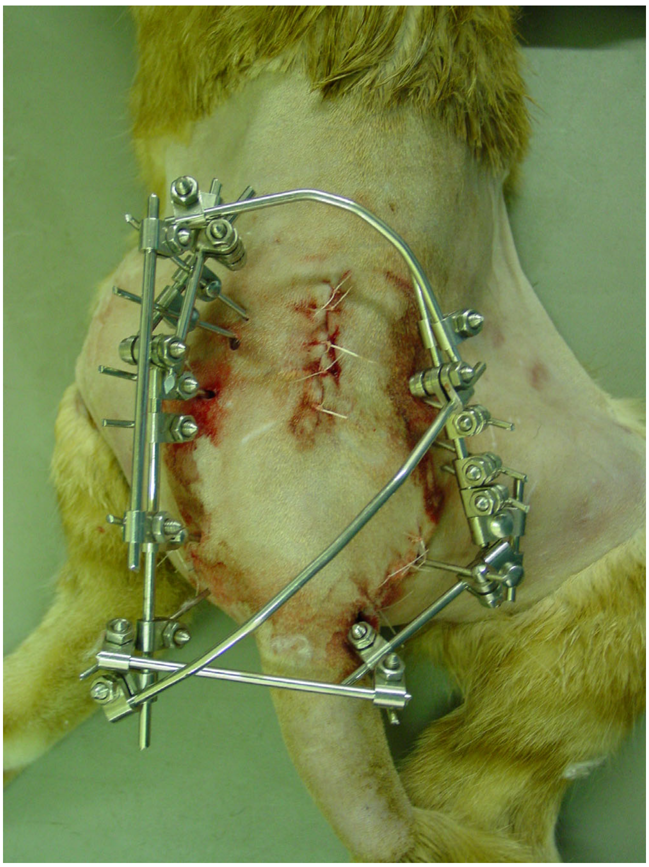

FIGURE 9 Photograph of postoperative appearance of quadrilateral external skeletal fixation (ESF) frame configuration example (cranial is towards the top of the photograph). An additional crossover connecting bar was placed to provide additional stability in this selected case.

segment. Adjacent segments were then connected using separate connecting bars (Figure 10). Realignment of the major fracture segments was performed using the ESF components anchored in each segment as handles for indirect reduction. After the primary surgeon had confirmed and maintained optimal fracture reduction, an assistant tightened the clamps connecting adjacent segments (Figure 11), thus stabilizing the fracture. The authors have termed this the "pin anchor realignment technique" (PART).

3.4 | Frame application for ilial fractures

A dorsal approach was made to the sacrum and ilial wings. A dorsal midline skin incision was centered on the median sacral crest. The length of the incision varied according to the fracture configuration but was always sufficient to allow direct visibility of the ilial and/or acetabular fracture(s). The surface of the wing of the ilium was exposed using sharp separation of the origin of the sacrospinalis muscle from the bone.

The triangular ESF configuration (Figure 12) was used for cases of isolated ilial body fractures and for ilial fractures with concurrent unilateral or bilateral sacroiliac luxation. It consisted of three pins placed cranial to the ilial fracture, and three placed caudal to it, with a single ilio-sacral pin positioned contralaterally. The three cranial pins consisted of a single ilio-sacral pin and two ilial pins, or two ilio-sacral pins and a single ilial pin in cases of cranial ilial fractures. In fractures immediately caudal to the sacrum, two ilio-sacral pins were used alone. Two ischial pins were placed in the caudal fragment, with a third pin in the ilium between the fracture line and the acetabulum. As with the standard ESF technique, the pins were spread evenly in a far-far-near-near configuration according to fracture location and configuration. In cases of supracotyloid fractures, the pin in the caudal segment closest to the fracture site was placed immediately cranial to the acetabular rim.

The quadrilateral frame was used for cases with bilateral ilial fractures. This frame consisted of bilateral ilio-sacral pins and bilateral ischial pins connected together in a quadrilateral construct (Figure 13). Additional pins were placed on either side of the fracture at the discretion of the surgeon. In cases with segmental fractures, one or preferably two pins were placed into the free segment to facilitate reduction and subsequent fixation to the major bone segment cranially or caudally depending on fracture configuration.

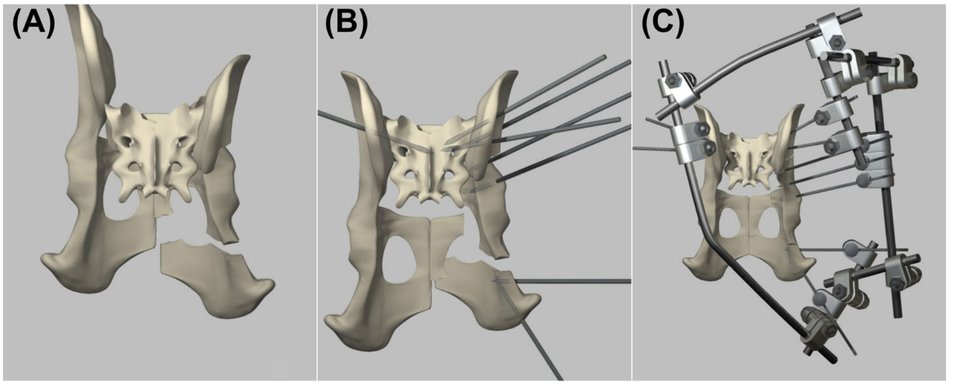

FIGURE 10 Pin anchor realignment technique (PART). Schematic image of pelvis with ilial body fracture, contralateral sacroiliac luxation, and pubic symphyseal fracture (A). Pins inserted into fracture fragments (B). Realignment of the fragments to reduce the fractures and secure position with clamps and connecting bars to complete the external skeletal fixation (ESF) construct (C).

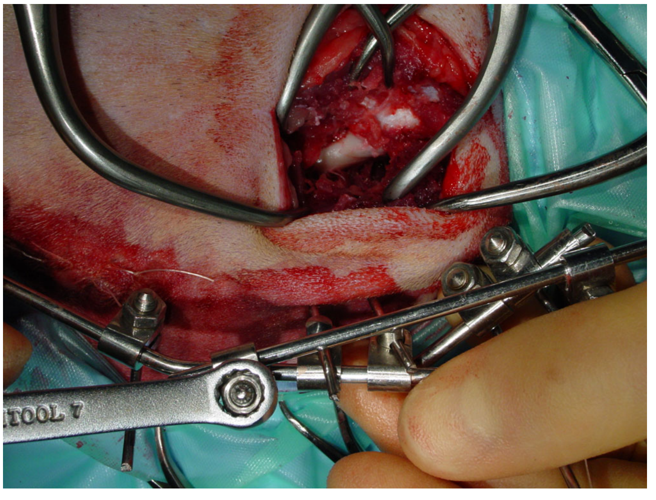

FIGURE 11 Pin anchor realignment technique (PART). The fracture is realigned by manipulating the pins anchored in each segment as handles for indirect reduction. Once optimal fracture reduction is confirmed, the clamps connecting adjacent segments are tightened to stabilize the fracture.

3.5 | Pin placement

Pin location was divided into three regions ilio-sacral, ilial (including the cranial acetabulum) and ischial (including the caudal acetabulum).

3.6 | Ilio-sacral pins

One or two ilio-sacral pins (Figure 14,B) were placed across luxated or non-luxated sacroiliac joints using the previously described PAST technique.

3.7 | Ilial pins

One or two ilial pins were placed in each ilial region at approximately 30° to the horizontal plane and 90° to the sagittal plane. Pins were placed to span the length of the major bone segments, no closer than 4 mm from any fractures to avoid iatrogenic fissures and to provide a longer lever arm for indirect fracture reduction. The tip of a 6 mm mini-Hohmann retractor was walked off the caudal aspect of the sacrum to act as a landmark to guide placement of the most cranial ilial pin. This pin was placed at the level of the caudodorsal iliac spine, 1–2 cm caudal to sacrum and was driven until two or three complete threads exited the medial cortex of the ilial body. In cases with supracotyloid fractures, the most caudal ilial pin was placed into the ilial body immediately cranial to the dorsal acetabular rim, angling slightly cranially to avoid the acetabulum.

3.8 | Ischial pins

A 2 cm longitudinal skin incision was centered over the ischiatic tuberosity. The caudal edge of the internal obturator muscle was elevated and the tip of a 6 mm mini-Hohmann retractor was inserted dorsal to the ischiatic ramus from caudal to cranial until it engaged the caudolateral extremity of the obturator foramen. Using the tip of the Hohmann retractor as a guide, the cranial ischial pin was inserted into the ischial spine through a small stab incision, approximately 2 cm cranial to the ischiatic tuberosity, and directed medially at a dorsoventral angle of 30° from horizontal until the tip entered the ischiatic notch. The caudal ischial pin was inserted through the initial 2 cm longitudinal skin incision. The caudal ischial pin was placed from the ischiatic tuberosity into the ischiatic ramus, exiting caudomedial to the acetabulum. This pin passed either dorsal or ventral to the cranial ischial pin, so that the two pins crossed over in the intercortical zone of the ischium.

3.9 | Group 3: Acetabular fractures

The triangular ESF was used solely in cases of unilateral simple, isolated fractures of the acetabulum. The

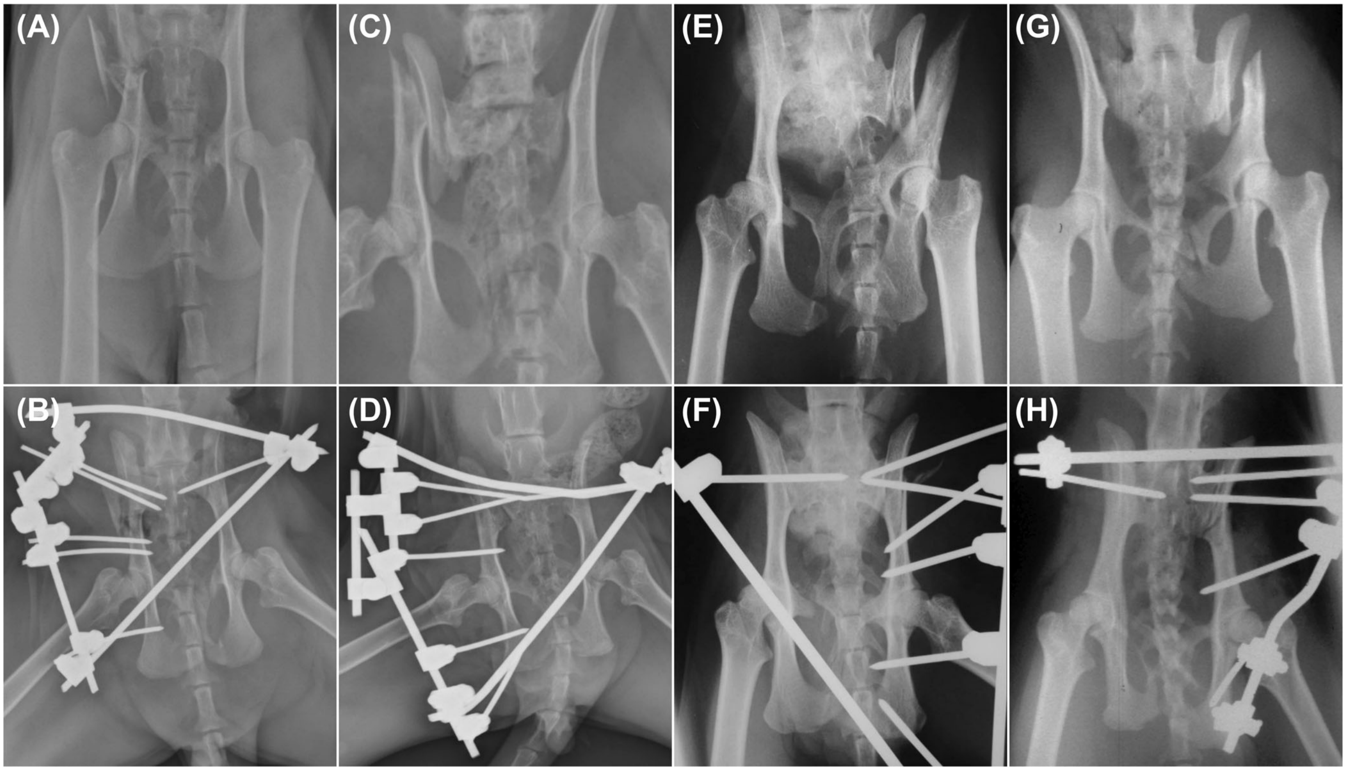

FIGURE 12 Ilial fractures (Group 2): Examples of triangular frame configurations. (A) Case example 1. Preoperative ventrodorsal radiograph of unilateral comminuted ilial body fracture. (B) Postoperative ventrodorsal radiograph of case example 1. (C) Case example 2. Preoperative ventrodorsal radiograph of unilateral ilial body fracture and contralateral sacroiliac luxation. (D) Postoperative ventrodorsal radiograph of case example 2. (E) Case example 3. Preoperative ventrodorsal radiograph of unilateral ilial body fracture and contralateral sacroiliac luxation. (F) Postoperative ventrodorsal radiograph of case example 3. (G) Case example 4. Preoperative ventrodorsal radiograph of unilateral ilial body fracture and contralateral sacroiliac luxation. (H) Postoperative ventrodorsal radiograph of case example 3 (third connecting bar yet to be attached).

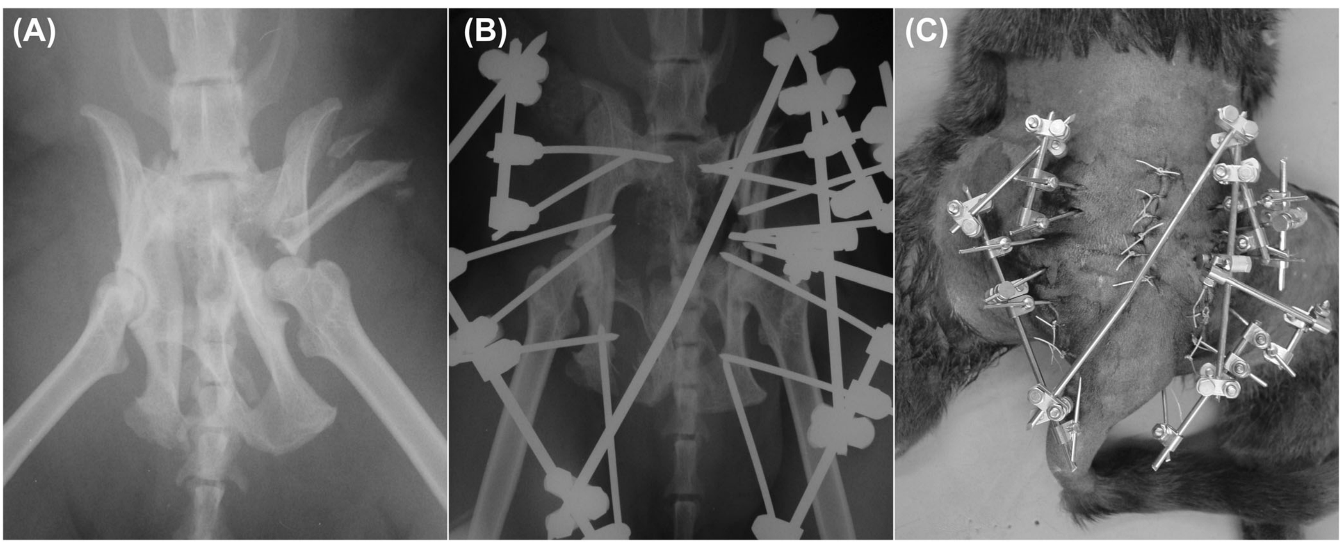

FIGURE 13 Ilial fractures (Group 2): Example of modified quadrilateral frame. (A) Preoperative ventrodorsal radiograph of bilateral comminuted ilial body fractures. (B) Postoperative ventrodorsal radiograph demonstrating modified quadrilateral frame. (C) Photograph of postoperative appearance of a modified quadrilateral external skeletal fixation (ESF) frame configuration example (cranial is towards the top of the photograph).

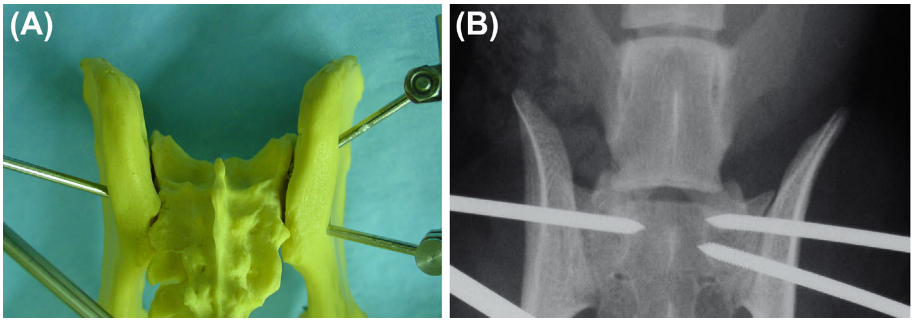

FIGURE 14 (A) Photograph of a model of a pelvis, demonstrating position of transfixing pins when one (left side of photograph) or two (right side of photograph) pins are placed across the sacroiliac joint. (B) Close up image of radiograph demonstrating position of one, and two pins, placed across the sacroiliac joint. These pin positions are used for *luxated* (with the pin anchor slide technique) and *nonluxated* sacroiliac joints.

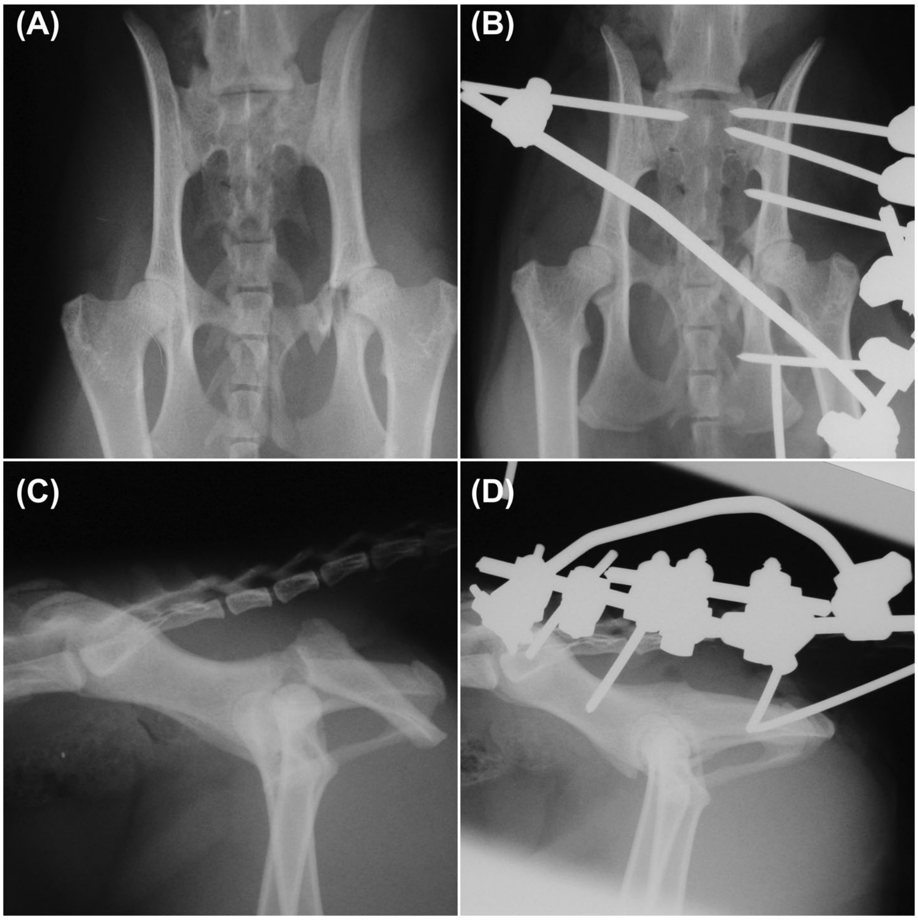

FIGURE 15 Acetabular fractures (Group 3): Triangular external skeletal fixation (ESF) configuration examples. Case example 1: Unilateral acetabular fracture. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs. Case example 2: Unilateral acetabular fracture and contralateral sacroiliac fracture-luxation. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs. Case example 3: Unilateral acetabular fracture and ipsilateral ilial fracture. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs. Case example 4: Unilateral acetabular fracture with ipsilateral ilial fracture and contralateral sacroiliac luxation. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs.

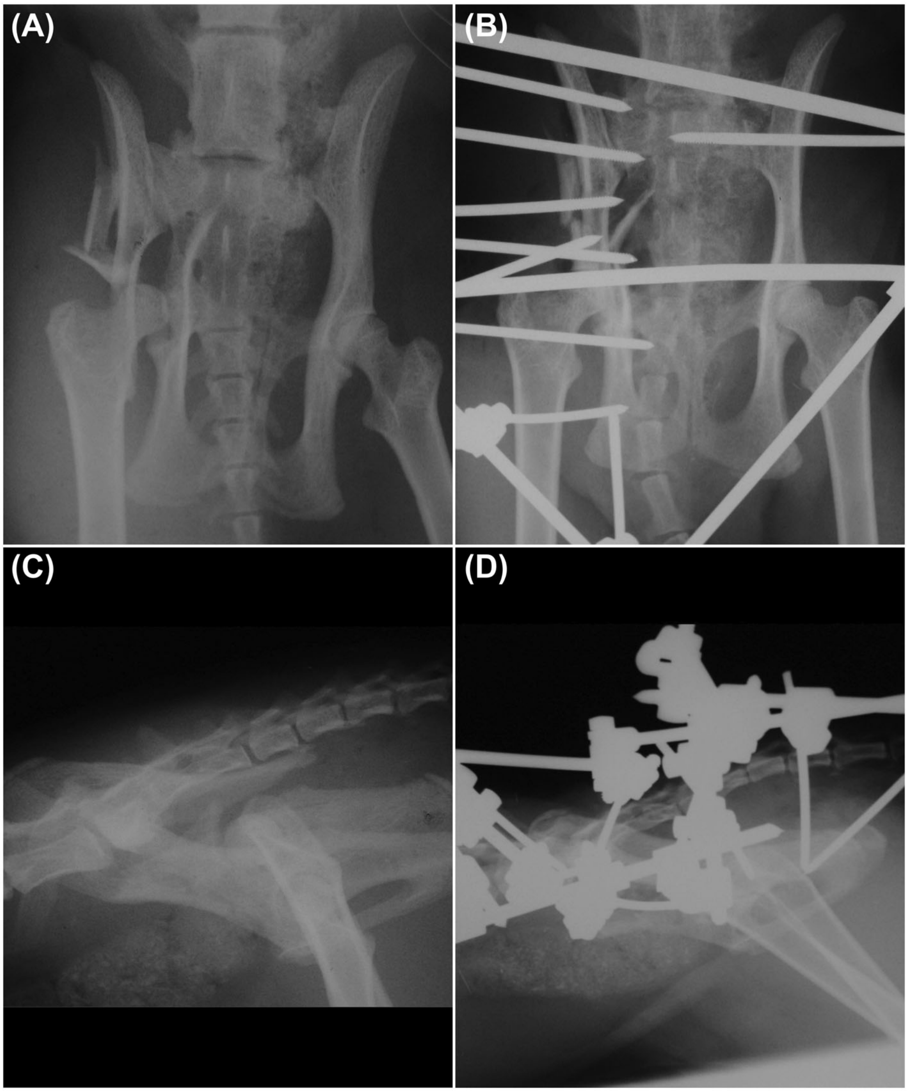

FIGURE 15 (Continued)

triangular ESF consisted of three pins placed cranial and two pins placed caudal to the acetabular fracture and a single ilio-sacral pin contralaterally (Figure 15). The three cranial pins consisted of a single ilio-sacral pin and two ilial pins. The caudal ilial pin was inserted approximately 4 mm cranial to the acetabular fracture (Figure 16). An additional ipsilateral ilio-sacral pin was added if there was a concurrent ipsilateral ilial fracture or if the acetabular fracture was comminuted. Two ischial pins were placed caudally, with an occasional third pin 4 mm caudal to the acetabular fracture in some cases. The third pin caudal to the acetabulum was placed via a separate stab skin incision and care had to be taken to avoid the sciatic nerve (Figure 17). All pins were spread evenly in a far-far-near-near configuration according to fracture location and configuration. The quadrilateral frame was used for cases with comminuted acetabular fractures, or in cases with bilateral injury to the weight-bearing axis, regardless of the fracture configuration. The quadrilateral ESF consisted of bilateral ilio-sacral pins and bilateral ischial pins connected together in a quadrilateral construct (Figure 18). Additional pins were placed on either side of the fracture at the discretion of the surgeon. Pins were placed using the same guidelines as we described for ilial fractures.

3.10 | "Drop pins"

In cases of highly comminuted acetabular fractures following application of a quadrilateral frame, a small hockey-stick-shaped "drop pin" was placed on the medial aspect of the acetabulum to act as a buttress

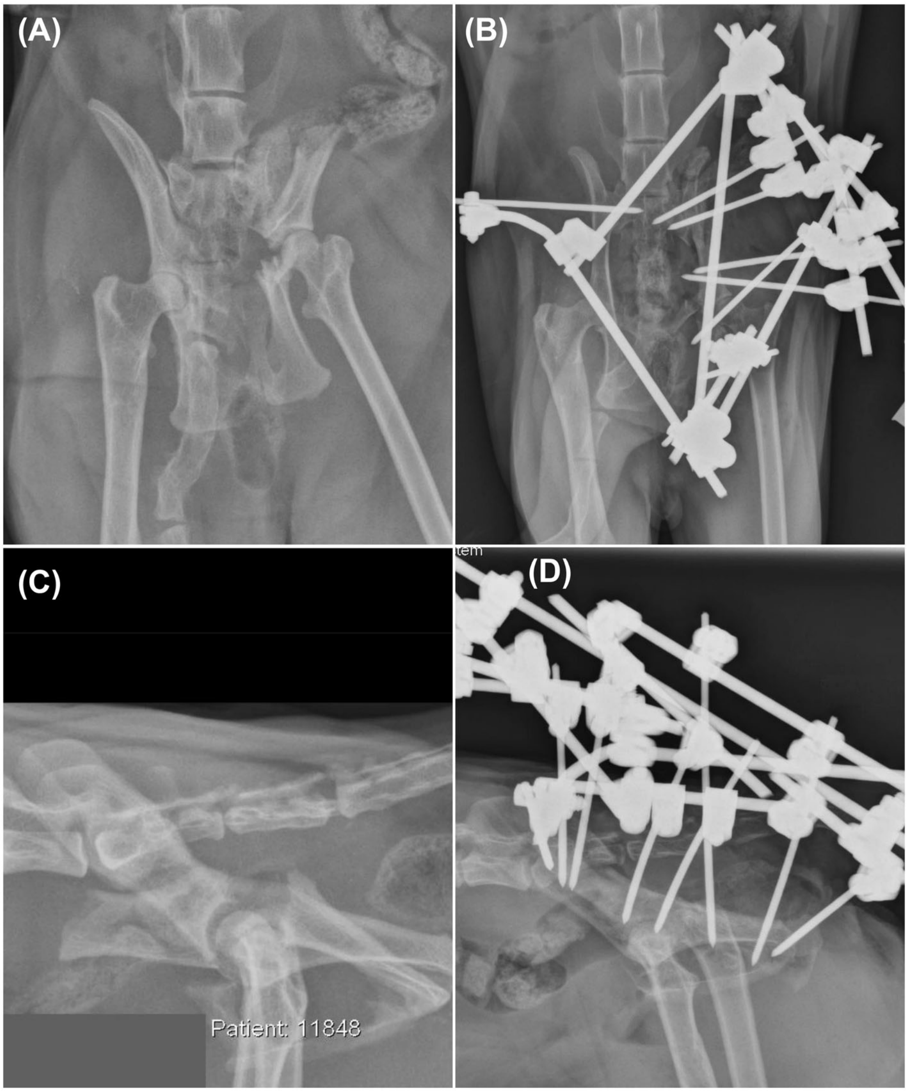

FIGURE 15 (Continued)

to the medial acetabular wall. The pin does not engage the bone but abuts the medial acetabular wall to counteract against implosion. This pin was made from a length of the nonthreaded end of 1.6 mm pin bent to 90° (Figure 19). The "drop-pin" was secured to a separate dorsal connecting bar.

3.11 | External skeletal fixation link assemblies

The transfixation pins in each major segment were connected to one another using KE clamps and 3.2 mm connecting bars (Steinmann pins). The connecting bars were left long, and one or more double clamps were interposed either between the single clamps or at one end of a row of clamps. The double clamps in the major segments cranial and caudal to the acetabular fracture were linked using a separate 3.2 mm connecting bar. The long ends of the connecting bars were used as handles for fracture reduction. These were manipulated until the fracture was visibly reduced (PART). If portions of the connecting bars interfered with reduction by impacting with one another they were shortened. Once satisfactory fracture reduction was achieved, the segments were locked in position by tightening of the clamps by a surgical assistant. For comminuted articular fractures, the major aim was anatomical alignment of the dorsal acetabular rim, which was established by achieving direct visibility of the dorsal acetabulum via a gluteal intramuscular window (and a dorsal arthrotomy). The triangular and quadrilateral frames were completed by using contoured segments of 3.2 mm Steinmann pins to link the ipsilateral ESF to the contralateral ilio-sacral pin (triangular ESF) or to the entire contralateral ESF assembly (quadrilateral ESF). Care was taken to ensure the caudal

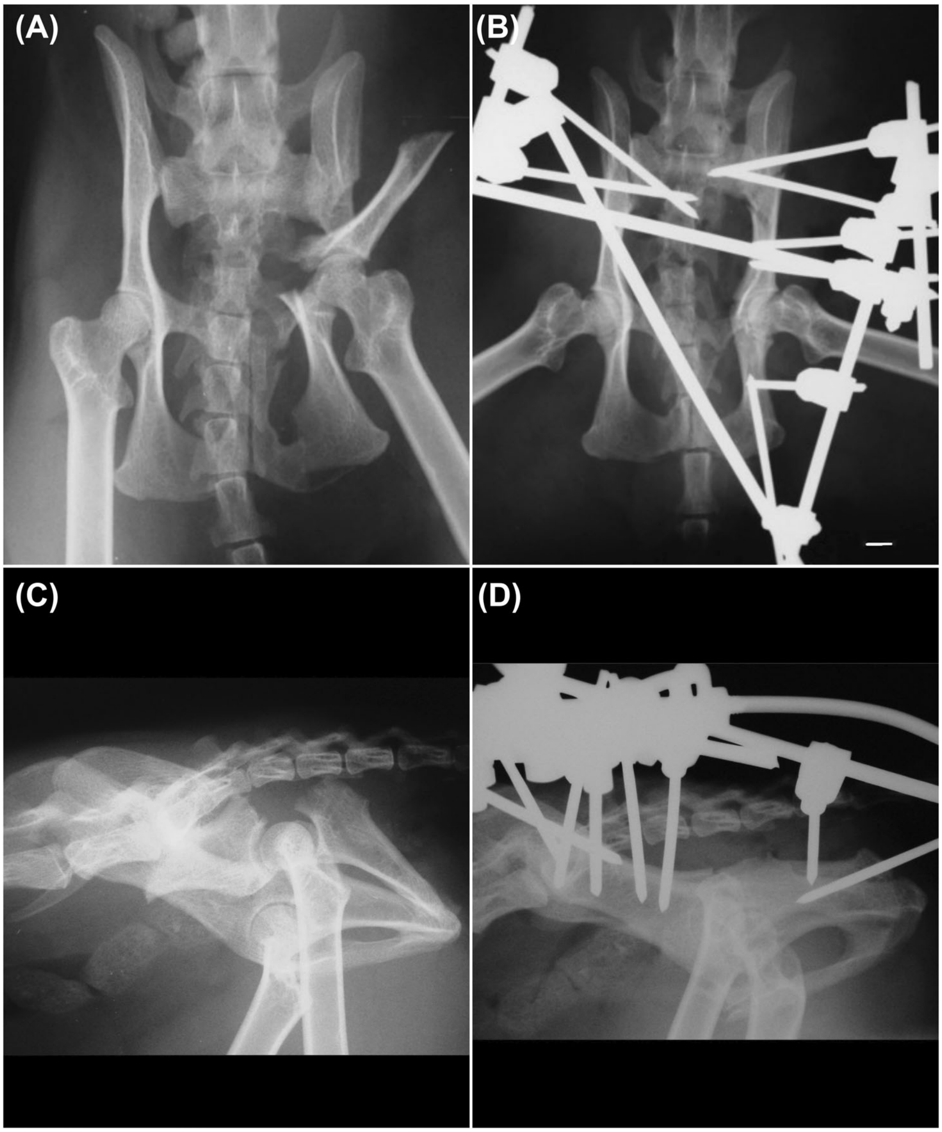

FIGURE 15 (Continued)

connecting bar of the quadrilateral frame (connecting the left and right ischial fragments) was contoured to allow sufficient elevation of the tail for defecation.

The skin incisions were closed routinely.

3.12 | Aftercare

Following immediate postoperative radiographs, the protruding ends of the pins and connecting bars were cut short (Figure 20). Any sharp cut pin ends were covered by wrapping a self-adhesive bandage (Vetrap, 3 M, Saint Paul, Minnesota) around them. Small sections of nonadherent primary dressing material (Zorbapad, Millpledge Veterinary, Nottinghamshire, UK) were placed around the pin entry points. Mild compression was provided by the placement of small sections of sterilized surgical preparation sponge between the connecting bars and skin. Patients were hospitalized for 2–5 days postoperatively. Dressings over the pin entry incisions were removed prior to discharge. In hospital, analgesia was provided with methadone (0.3 mg/kg q4h) or buprenorphine (0.02 mg/kg q6h), and oral meloxicam (0.05 mg/kg q24h; Metacam; Boehringer Ingelheim, Bracknell, UK). All cats were discharged with instructions to administer oral meloxicam (0.05 mg/kg q24h) for a minimum of 10 days. Instructions were given for cage rest, with 10–15 min of supervised daily activity in a small room during the 4–8 weeks postoperative period. Follow-up radiographs were scheduled 6 weeks postoperatively, with a view to remove all implants at this time. The ESF was only removed if bridging osseous callus was noted on orthogonal projections (Figure 21). For cases with solely sacroiliac luxation; radiographic follow up and frame

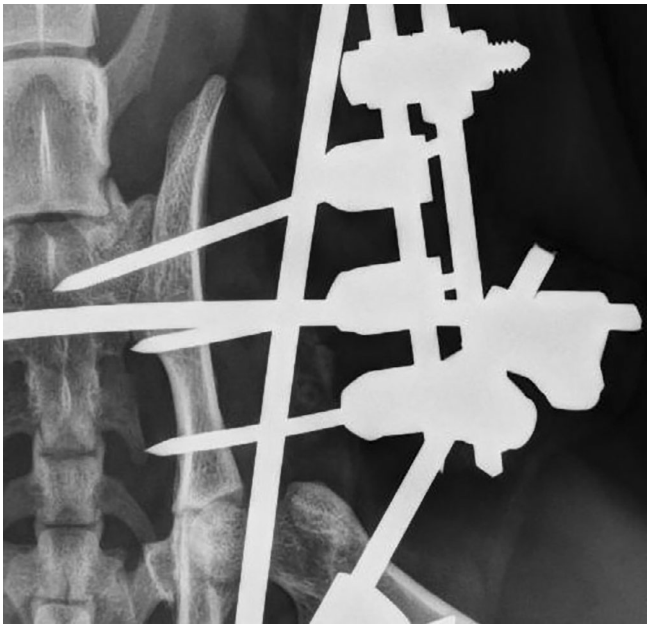

FIGURE 16 Ilial pin placement location for acetabular fracture. Close up image of radiograph demonstrating the typical position of three ipsilateral pins cranial to the acetabular fracture. One iliosacral pin and two ilial pins. The cranial ilial pin is placed just caudal to the level of the caudal aspect of the sacrum; the caudal ilial pin is placed approximately 5 mm cranial to the acetabulum.

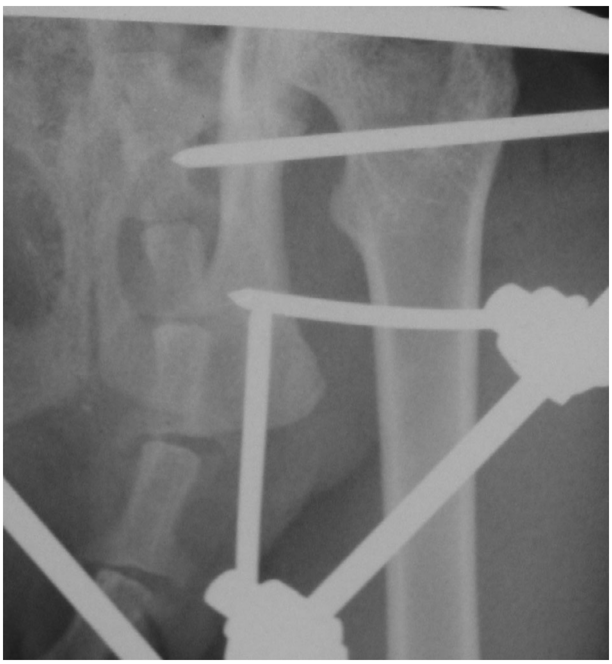

FIGURE 17 Ischial pin placement location for acetabular fracture. Close-up image of radiograph demonstrating the typical position of three ipsilateral pins caudal to the acetabular fracture. The two caudal ischial pins cross within the intercortical zone of the ischium. The third pin is placed approximately 5 mm caudal to the acetabulum.

removal was advised after 4 weeks. "Drop" pins were removed by pulling them out in a curved motion in the direction of the bend in the pin to avoid ensnaring of soft tissues. Following ESF removal, a further week of cage rest was advised, followed by a further 2 weeks of confinement to one room. Normal activity resumed thereafter.

3.13 | Radiographic measurements

For cases in group 1, the percentage of sacroiliac reduction was measured as previously described.[10] In cases with bilateral luxation, the mean percentage reduction was calculated. In cases of type II sacral fractures, the percentage reduction was calculated in a similar manner from measurements of the fracture surfaces. The length of the fracture surface on one side of the sacral fracture was measured from cranial to caudal on the ventrodorsal radiograph (measurement A). The length of the fracture surface in contact with the opposite side of the fracture was measured (measurement B). The percentage of measurement B relative to measurement A was calculated in order to determine the percentage of fracture reduction.

For cases in group 2; fracture reduction was classified as anatomic, near anatomic, good, fair, or poor.[6] For cases in group 3; fracture reduction was classified as anatomic, near anatomic, or nonanatomic, as previously described.[39] Follow-up radiographs were evaluated for evidence of osseous healing, implant failure, and any progression of pelvic canal narrowing or loss of fracture reduction.

As previously reported, the sacral index (SaI) was used to measure the degree of pelvic canal narrowing for all cases in the study population.[28] The mean SaI has previously been reported as 0.97 ± 0.025 for a normal feline pelvis and was thus used to estimate the pelvic canal diameter prior to injury by calculating the product of the cranial sacral width and the SaI.[28] The degree of pelvic canal narrowing could then be calculated as a percentage of the original pelvic canal width. In cases of sacral fracture where the cranial aspect of the sacrum could not be measured, this width was estimated by measuring the hemisacral width from the sacral spine to the cranial abaxial margin of the intact portion of sacrum and doubling this value. All measurements were made by the same surgeon (MH).

3.14 | Outcome

Short-term outcome was based on examination at the time of follow-up radiography and ESF removal.

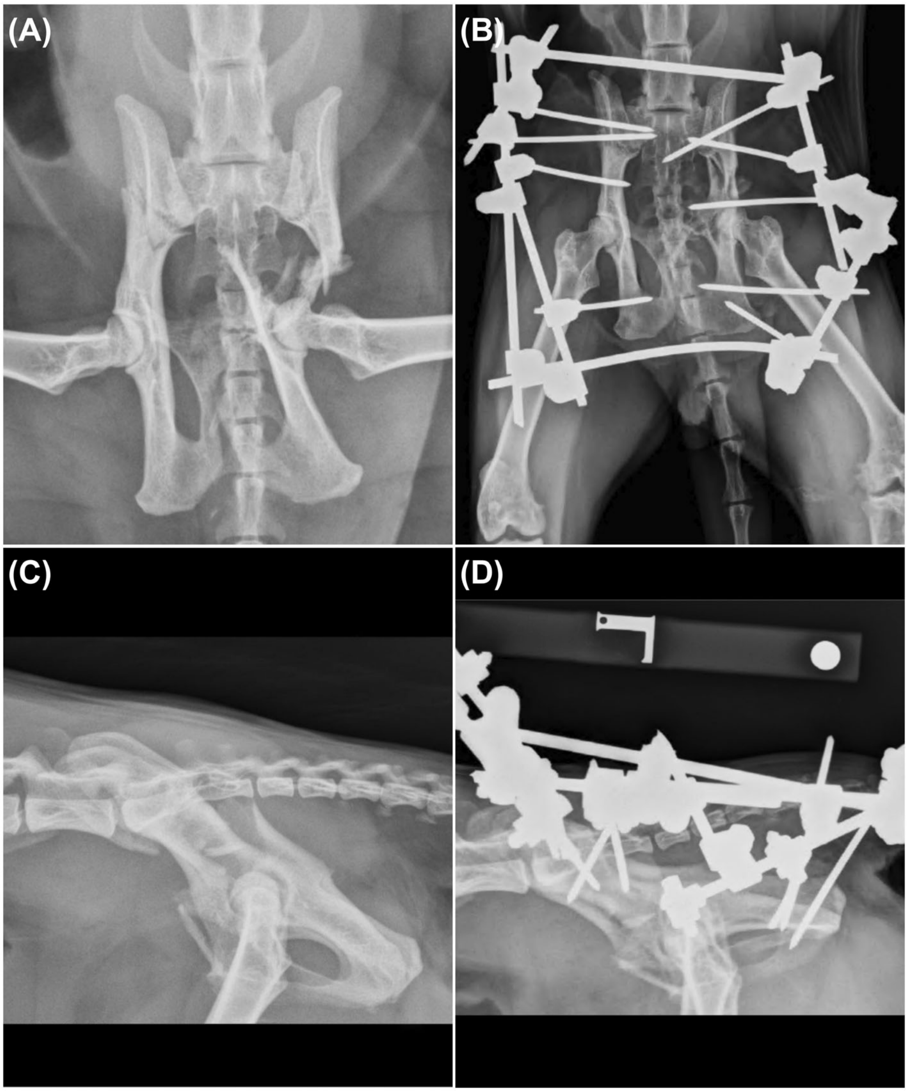

FIGURE 18 Acetabular fractures (Group 3): Quadrilateral external skeletal fixation (ESF) configuration examples. Case example 1: Unilateral acetabular fracture and contralateral ilial fracture. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs. Case example 2: Unilateral acetabular fracture with ipsilateral sacroiliac luxation and contralateral ilial fracture. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs. Case example 3: Unilateral acetabular fracture with ipsilateral ilial fracture and contralateral sacroiliac fracture-luxation. Preoperative (A) and immediate postoperative (B) ventrodorsal radiographs, and preoperative (C) and immediate postoperative (D) lateral radiographs.

Lameness was graded as 0–5.[7] The presence of neurological deficits was recorded. Long-term outcome was by owner postal questionnaire. Information about the cats' mobility (ability to run and jump) was graded on a visual analogue scale (VAS) of 1–100, where 1 = poor activity and 100 = excellent activity. Owners were also asked to grade to the presence of any observed lameness from 0 to 5 as previously described.[7] Information regarding the presence of specific neurological deficits (knuckling, plantigrade stance, low tail carriage, ataxia) and the incidence of any clinical signs related to constipation was also requested.

3.15 | Statistical analysis

Data were visually assessed graphically for normality and mean, median, and range reported as appropriate for each outcome measure. A one-way analysis of variance was performed to detect differences in pelvic canal diameter and fracture reduction between immediate postoperative and follow-up measurements. Fisher's exact test was used to detect differences in outcome measures in cases with and without clinical evidence of pin loosening. Data were analyzed using statistical software (SAS version 8.0; SAS Institute,

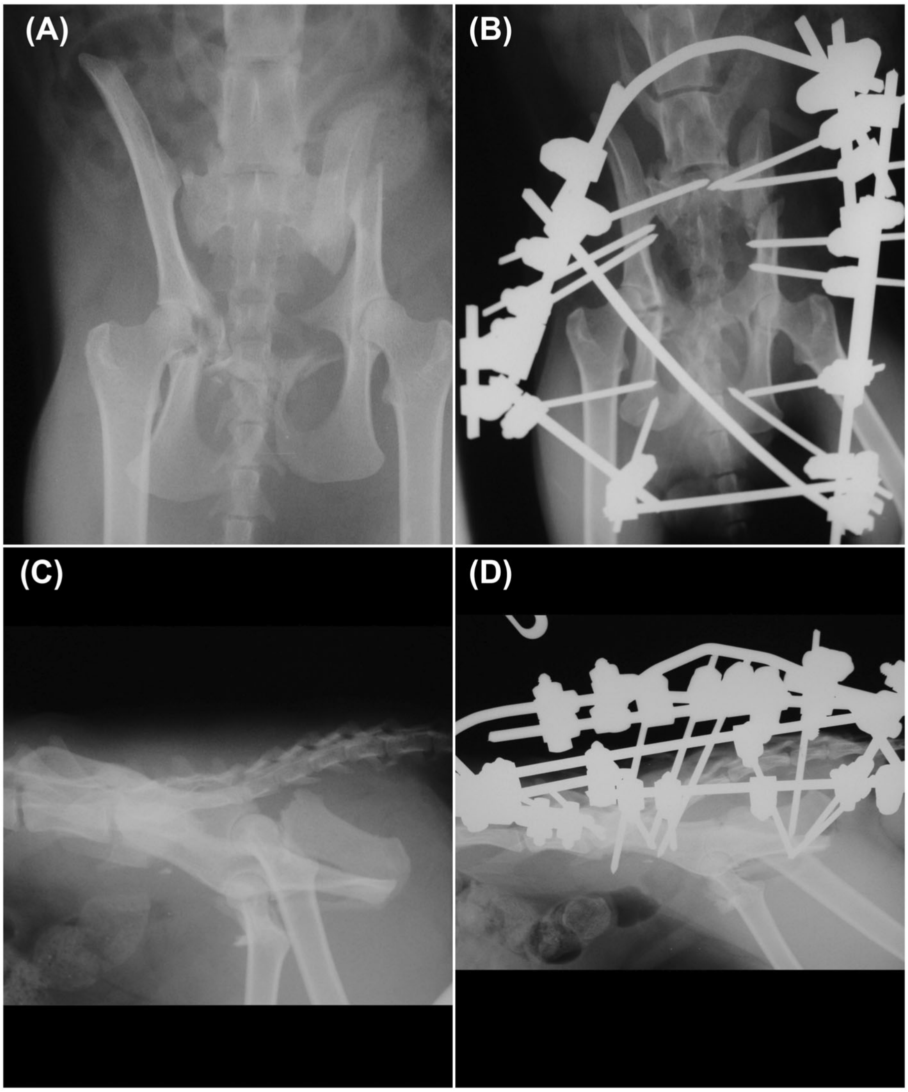

FIGURE 18 (Continued)

Cary, North Carolina). $p < .05$ was considered significant.

4 | RESULTS

4.1 | Presenting features

One hundred and twenty-five cases satisfied the inclusion criteria. There were 28 cases in group 1, 62 cases in group 2, and 35 cases in group 3. The mean age was 33 ± 24 months (range: 4–192 months) and the mean weight was 4.2 ± 1.1 kg (range: 1.9–7.3 kg).

Data concerning fracture configuration are detailed in Table 1. Concurrent musculoskeletal injuries were present in 17/125 (14%) cats. Data concerning these injuries are recorded in Table 2. Thoracic radiographs had been performed in all cases and pneumothorax was present in 11/125 (9%); cats all resolved with conservative management.

4.2 | Fracture reduction and pelvic diameter

There was no meaningful change ($p = .16$) in the reduction of sacroiliac luxation between immediate postoperative (92%; range 75–100) and follow-up radiographs (91%; range 70–100). The accuracy of fracture reduction for groups 2 and 3 are shown in Tables 3 and 4 respectively. There was no noteworthy change in the diameter of the pelvic canal between immediate postoperative and follow-up radiographs of all cases

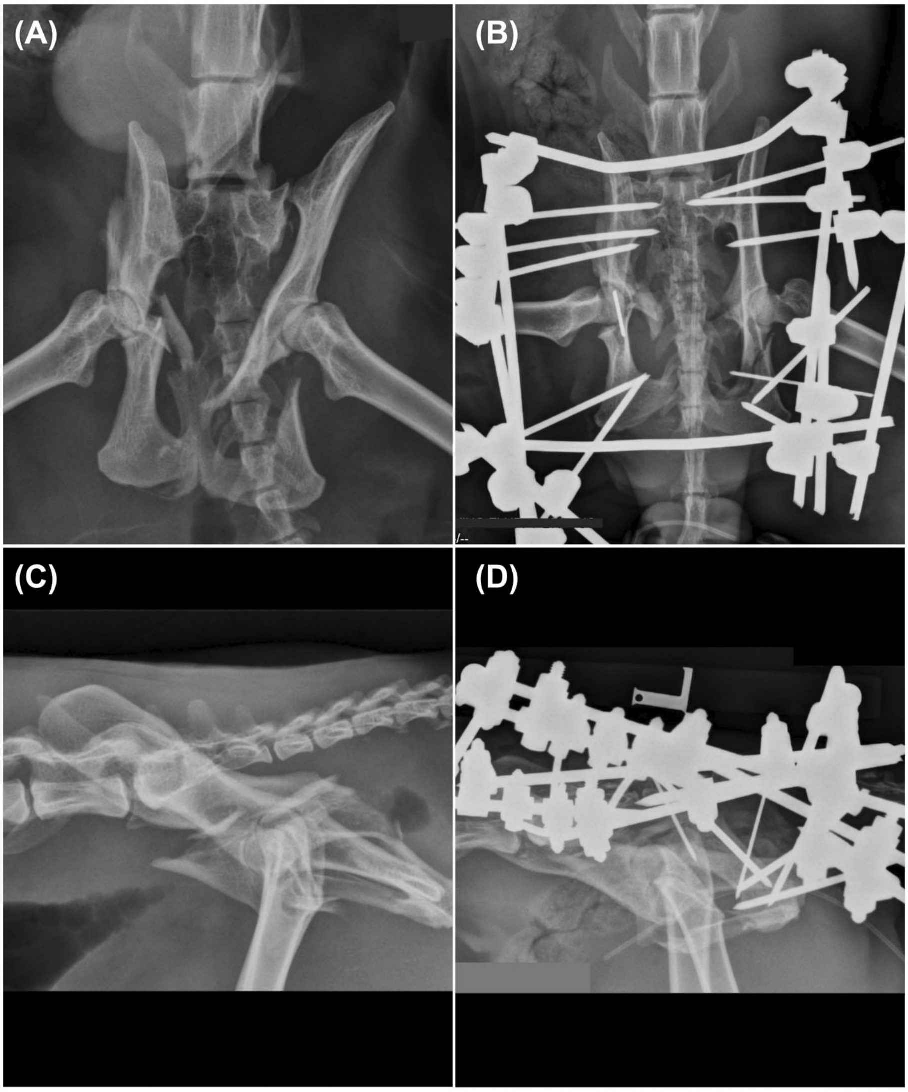

FIGURE 18 (Continued)

(Table 5) (p = .11, .29, and .19 respectively for groups 1, 2, and 3).

4.3 | Short-term outcome

For group 1, excluding the two type II sacral fractures and one case with a concurrent contralateral femoral neck fracture, the mean time to frame removal was 26 ± 2 days (range: 23–29). The mean time to frame removal for the three other cases was 42 ± 2 days (range: 40–43). For group 2, the mean time to frame removal was 42 ± 2 days (range: 36–50), and for group 3 it was 44 ± 3 days (range: 37–61). Radiographic union was confirmed in all fractures prior to frame removal.

Implant loosening was noted on follow-up radiographs in 0/28 (0%) of cases from group 1, 11/62 (18%) of cases from group 2, and 5/35 (14%) of cases from group 3.

During frame removal some pins were palpably loose. From group 1 there was 5/84 (6%) pins palpably loose, 34/396 (9%) from group 2, and 28/323 (9%) from group 3.

At the time of frame removal, the median lameness score for groups 1 and 2 was zero (range: 0–2); for group 3 the median score was 1 (range: 0–3). There was no correlation between the incidence of pin loosening and lameness scores (p = .25). The null hypotheses can be accepted.

Neurological deficits associated with the sciatic nerve were noted in one cat from group 1, seven cats from group 2, and four cats from group 3. All had neurological deficits prior to surgery and these were associated with either sacral fractures or comminuted ilial fractures. There were no reported cases of constipation.

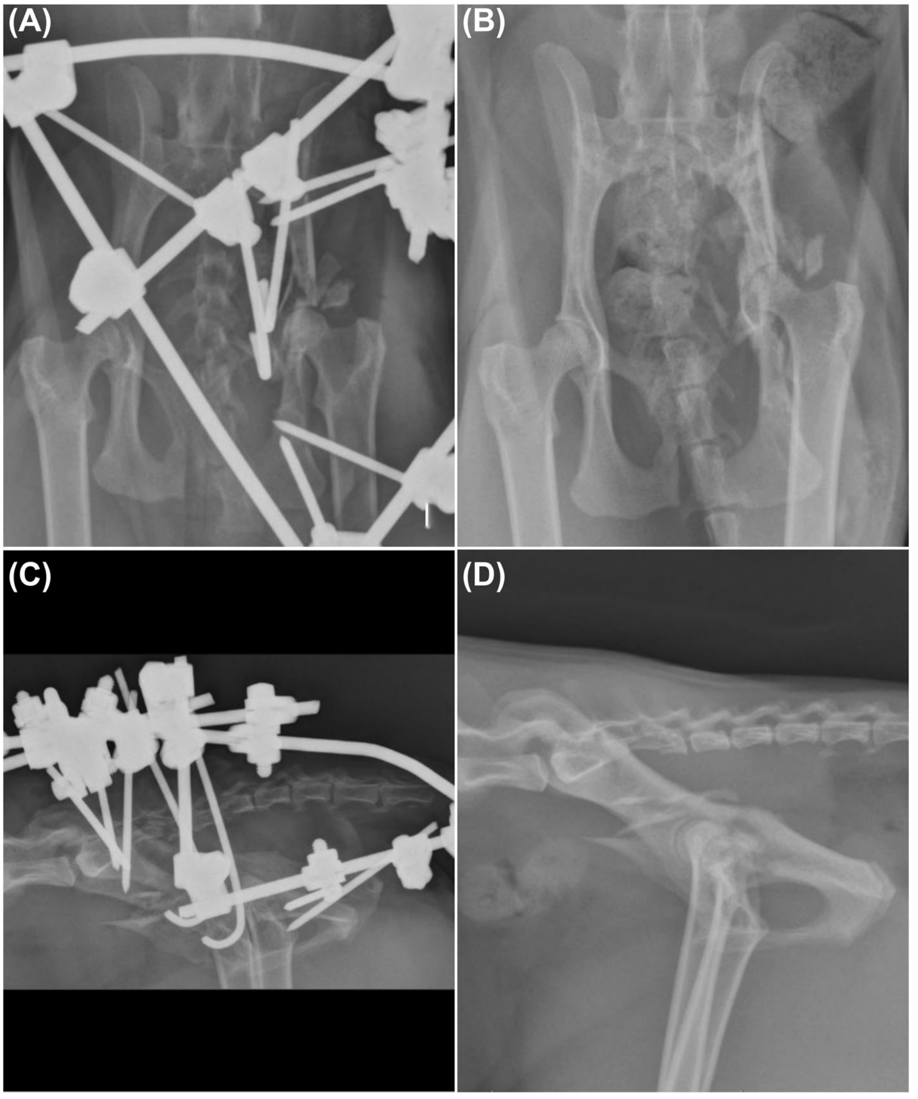

FIGURE 19 Drop pins. Immediate postoperative ventrodorsal (A) and lateral (C) radiograph demonstrating the use of two "drop pins" to buttress the medial side of the acetabulum. Ventrodorsal (B) and lateral (D) radiographs following ESF removal.

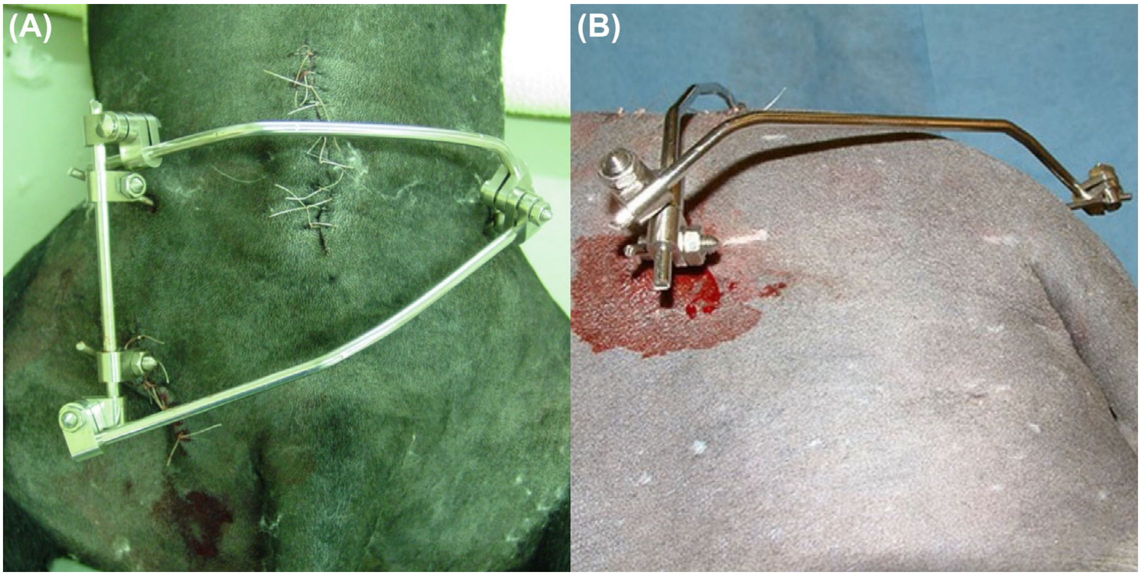

FIGURE 20 Dorsal (A) and lateral (B) photographs following triangular external skeletal fixation (ESF) application for sacroiliac (SI) luxation.

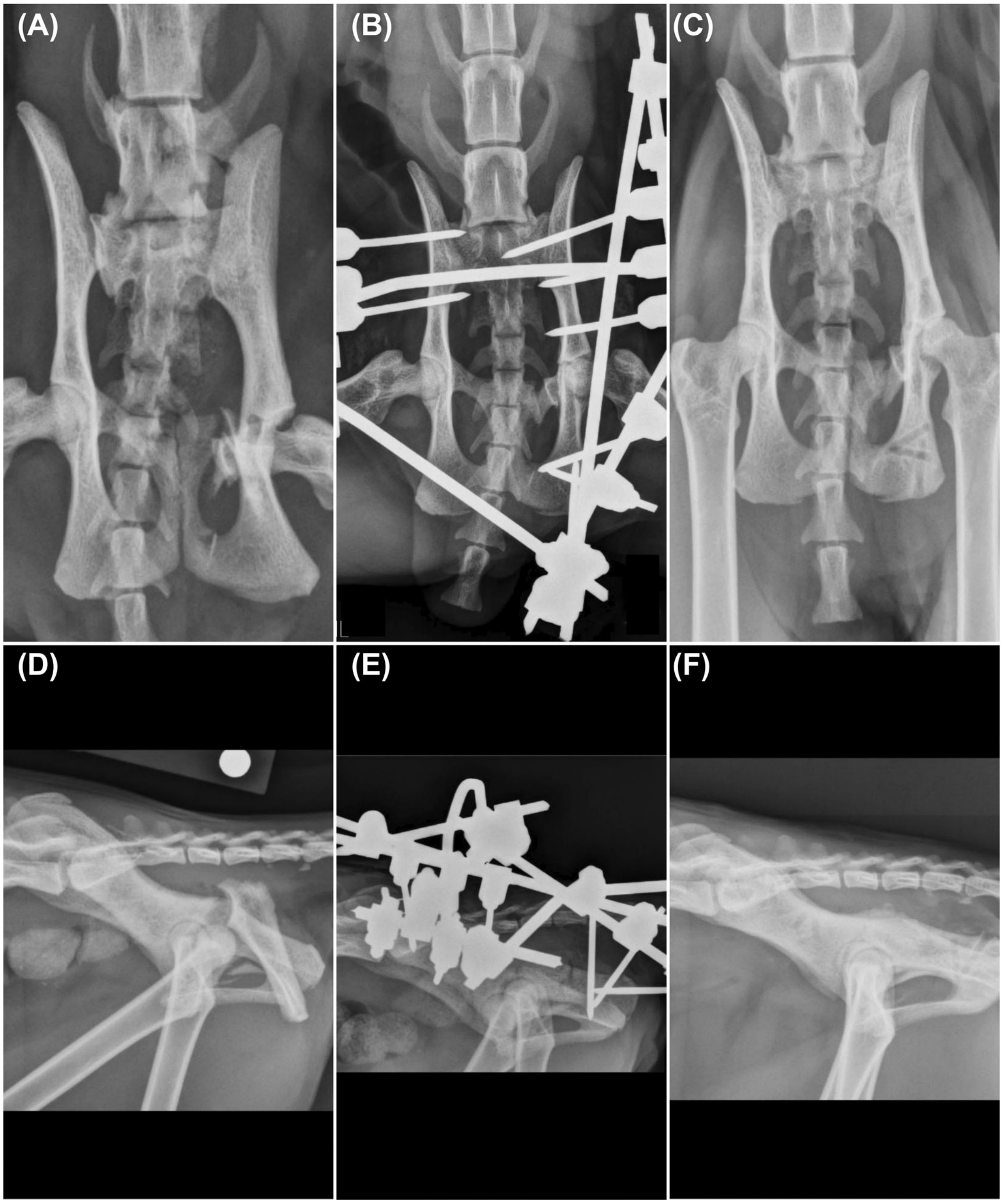

FIGURE 21 Case progression. Acetabular fracture with contralateral sacroiliac luxation repaired with triangular external skeletal fixation (ESF) configuration. Ventrodorsal radiographs preoperative (A), immediate postoperative (B), and immediately following ESF frame removal (C). Lateral radiographs preoperative (D), immediate postoperative (E), and immediately following ESF frame removal (F).

4.4 | Long-term outcome

4.4.1 | Group 1

Completed questionnaires were obtained for 18/28 (64%) cats with a median follow up of 35 months (range: 5–78). Mean mobility score was 97 ± 3 and median lameness score assessed by owners was zero (range: 0–1). There were no problems related to constipation or neurological deficits.

4.4.2 | Group 2

Completed questionnaires were obtained for 42/62 (68%) cats with a median follow up of 32 months (range: 4–76). The mean mobility score was 96 ± 4 and median lameness score was zero (range: 0–2). No owners reported any symptoms of constipation in their cats. Of the seven cases with neurological deficits at short-term follow up, questionnaires were returned in five cases. Two cases were reported by

TABLE 1 Fracture configurations.

Injury	No. of cats (% in parentheses)
Sacroiliac luxation (Group 1)	
Unilateral SI luxation	16 (13)
Bilateral SI luxation	8 (6)
Unilateral SI luxation and contralateral type II sacral fracture	2 (2)
Unilateral type I sacral fracture	1 (1)
Unilateral SI luxation and contralateral type I sacral fracture	1 (1)
Ilial Fractures (Group 2)	
Unilateral ilial fracture and contralateral SI luxation	37 (30)
Unilateral ilial fracture	21 (17)
Unilateral ilial fracture and ipsilateral SI luxation	3 (2)
Bilateral ilial fracture and unilateral SI luxation	1 (1)
Acetabular Fractures (Group 3)	
Unilateral acetabular fracture and ipsilateral ilial fractures and contralateral SI luxation	8 (6)
Unilateral acetabular fracture	7 (6)
Unilateral acetabular fracture and ipsilateral SI luxation	4 (3)
Unilateral acetabular fracture and ipsilateral SI luxation and contralateral ilial fracture	4 (3)
Unilateral acetabular fracture and contralateral SI luxation	3 (2)
Unilateral acetabular fracture and contralateral ilial fracture	2 (2)
Unilateral acetabular fracture and ipsilateral ilial fracture	2 (2)
Bilateral acetabular fractures	2 (2)
Bilateral acetabular fractures and unilateral SI luxation	1 (1)
Unilateral acetabular fracture and ipsilateral SI luxation and contralateral type 2 sacral fracture	1 (1)
Unilateral acetabular fracture and bilateral SI luxation	1 (1)

TABLE 2 Concurrent injuries.

Injured structure(s)	Specific injury	No. of cases
Surgically repaired		
Radius and ulna	Comminuted distal fractures	1
	Comminuted proximal fractures	1
Mandible	Segmental fracture	1
Femur	Salter–Harris type II distal physeal fracture	1
	Capital physeal fracture	2
Tibia	Comminuted distal fracture	1
	Medial malleolar fracture	1
	Spiral diaphyseal fracture	1
Tail	Sacrococcygeal luxation	3
Coxofemoral joint	Unilateral luxation	2
	Bilateral luxation	1
Stifle	Luxation	1
Body wall	Lateral abdominal body wall rupture	1
Conservatively Managed		
Thorax	Pneumothorax	11

the owners to have neurological deficits; each case exhibiting some degree of plantigrade paw positioning and a delayed postural reflex as compared to the contralateral limb. For these latter two cases, lameness scores were 1 and 2; mobility scores were 72 and 84 respectively.

4.4.3 | Group 3

Completed questionnaires were obtained for 21/35 (60%) cats (median follow-up duration of 42 months (range: 6–80)). Mean mobility score was 89 ± 9 and median lameness score was 1 (range: 0–2). No specific neurological deficits were or signs of constipation were reported.

5 | DISCUSSION

We have described the use of external skeletal fixation for the treatment of various pelvic fracture configurations in 125 cats. Pelvic ESF was uncomplicated to apply, using well-defined corridors and landmarks for transfixation pin application. Indirect fracture reduction was facilitated by the use of the ESF components as handles. Tolerance of the ESF was excellent, and all fractures healed within 9 weeks of surgical intervention. This healing occurred with a low complication rate, allowing a return to normal or near normal activity for all operated cats in the long term.

TABLE 3 Ilial fracture configuration and quality of postoperative fracture reduction.

Fracture classification	Number of fractures (% in parentheses)	Quality of postoperative ilial fracture reduction (% in parentheses)				
		Anatomical	Near anatomical	Good	Fair	Poor
Simple	37 (59)	22 (59)	11 (30)	4 (11)	0	0
Mildly comminuted	16 (25)	2 (13)	4 (25)	8 (50)	2 (13)	0
Highly comminuted	10 (16)	0	0	7 (70)	1 (10)	2 (20)
Overall	63	24 (38)	15 (24)	19 (30)	3 (5)	2 (3)

TABLE 4 Acetabular fracture configuration and quality of postoperative fracture reduction.

Fracture classification	Number of fractures (% in parentheses)	Quality of postoperative acetabular fracture reduction (% in parentheses)		
		Anatomical	Near anatomical	Nonanatomical
Simple	15 (39)	12 (80)	3 (20)	0
Mildly comminuted	10 (26)	3 (30)	6 (60)	1 (10)
Highly comminuted	13 (34)	0	5 (38)	8 (62)
Overall	38	15 (39)	14 (37)	9 (24)

TABLE 5 Pelvic canal diameter immediately postoperative and at follow-up radiographs.

Fracture classification	Pelvic diameter (%) (percentage of the original pelvic canal width; mean and range values)		
	Immediate postoperative	Follow up	p
Group 1 (SI luxation)	96 (77–136)	95 (77–136)	.11
Group 2 (Ilial fracture)	100 (64–114)	96 (57–114)	.29
Group 3 (Acetabular fracture)	96 (64–115)	93 (53–115)	.19

An advantage of the ESF technique is that pins can be placed with almost limitless versatility to accommodate the configuration of the fracture(s) being stabilized. The frames described are merely a guideline to achieve stabilization; the authors recommend at least two, preferably three fixation pins should be placed in each major segment of bone cranial and caudal to the fracture; however, single pins may be used to secure smaller segments and facilitate their reduction. Single pin placement is not to be encouraged, however, and spatial alignment of the major fragments should be the main objective. It is important to adhere to the far-far-near-near principle of external fixator application to ensure that the fracture fragments are adequately stabilized, as failure to do so may result in rotation around two fixation points if they are placed too close together.[34] This is particularly pertinent to the stabilization of supracotyloid and caudal ilial fractures where it is essential that the most cranial pin in the caudal bone segment is inserted adjacent to the fracture line, as the entry points of the two caudal pins in the ischium are relatively close together.

With external fixation, the fixation pins themselves are used to manipulate the bone fragments, reducing the risk of nerve injury, although care must be taken to ensure the nerve does not become entrapped within the fracture gap itself. Care should be taken when inserting pins through a limited exposure to avoid iatrogenic trauma to neurovascular structures and intrapelvic organs. We saw no evidence of iatrogenic neurological injury. The ability to realign major bone segments using the transfixion pins as levers and the ability to manually hold the fracture in reduction without the need for reduction forceps across the fracture is another major advantage of using external fixation to treat these fractures.

Postoperative adjustment of the frame is feasible; however, we did not perform any postoperative adjustments in our patients. One aspect considered a contraindication for the use of ESF in the pelvis has been concerns using ESF in a well-muscled area. We did not see problems associated with the pins and morbidity was similar to what would be expected with ESF application to long bones. The smaller muscle mass in feline patients and the short time the frame was in place may reduce pin tract morbidity when applying pelvic ESF to cats.

Previous recommendations for articular fracture repair have emphasized the requirement for rigid internal fixation in order to provide the best environment for primary osseous healing. Pelvic ESF represents a deviation from recommended technique; however, the rate of uncomplicated healing seen in this series does not suggest that the healing environment was suboptimal. In some cats with comminuted acetabular fractures there would have been a degree of fibro-osseus union at the fracture site. The good functional outcomes of this case series as a result of a fibro-osseous union warrants consideration. No cases had revision surgery (femoral head and neck ostectomy, or hip replacement).

A benefit of pelvic ESF when compared to plate and screw fixation is the ability to treat concurrent ipsilateral or contralateral pelvic injuries using the same apparatus, and without repositioning the patient. Concurrent acetabular and ilial body fractures are relatively common, and treatment using plates and screws requires either two independent plates or a single plate contoured across both fractures. Mechanical challenges during multiple plate fixation of concurrent pelvic fractures are compounded by the biological compromises that are necessitated when making a wide approach to the entire hemipelvis.

Given the retrospective nature of this study there are inherent limitations including incomplete medical records, surgeon bias towards the fixation technique used, patients lost to follow up, and reliance on owners for follow-up data.

In conclusion, ESF may be applied successfully for stabilization of various pelvic fractures in cats. The technique can be performed through a limited open approach and multiple pelvic injuries can be treated concurrently. The technique facilitates accurate realignment of displaced segments and provides satisfactory stability to maintain reduction and prevent collapse of the pelvic canal. In the absence of substantial neurological dysfunction, a satisfactory return to function return can be expected, even in cases of highly comminuted fractures.

AUTHOR CONTRIBUTIONS

All authors fulfill the criteria for authorship by providing a substantial contribution to the design of the work; the acquisition, analysis, and interpretation of data; drafting the work; revising it for important intellectual conten, and; making final approval of the version to be published. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

FUNDING INFORMATION

No funding was received for this report.

CONFLICT OF INTEREST

The authors have no conflicts of interest related to this study.

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How to cite this article: Fitzpatrick N, Guthrie JW, Hamilton MH. External skeletal fixation for the treatment of pelvic fractures in cats. *Veterinary Surgery*. 2024;53(7):1196-1218. doi:10.1111/vsu.14132