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Radiation exposure associated with percutaneous fluoroscopically guided lag screw fixation for sacroiliac luxation in dogs

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Abstract

Objective: To determine radiation exposure to surgical personnel and to evaluate the accuracy of a modified percutaneous lag screw fixation technique for sacroiliac luxation (SIL) under fluoroscopic guidance in dogs.

Study design: Cadaveric experimental study.

Sample population: Seventeen beagle cadavers with iatrogenic SIL.

Methods: Seventeen beagles with iatrogenic SIL underwent reduction and stabilization with 3.5-mm screws. Hypodermic needles (14 gauge) and fluoroscopy were used to orient two Kirschner wires for temporary stabilization and to guide drilling of glide and pilot holes using cannulated drill bits. Duration of surgery and radiation exposure were recorded. Postoperative computed tomographic evaluation of screw position and angulation was performed.

Results: Average time for fixation was 15.85 minutes (range, 6.37–33.5). Cumulative radiation doses of 0.4 mrem for the dominant arm of the assistant and 0 mrem for the primary surgeon were recorded. The mean dorsoventral and craniocaudal screw angles were $0.68^\circ \pm 3.4^\circ$ (range -5.4° to 9.5°) and $1.9^\circ \pm 3.2^\circ$ (range -4.3° to 9.1°), respectively. Sixteen of the 17 dogs had 100% sacral screw purchase, with the remaining case achieving 93.4% purchase.

Conclusion: Fluoroscopy-assisted percutaneous placement of 3.5-mm cortical screws in lag fashion performed with 14-gauge needles in conjunction with Kirschner wires and cannulated drill bits yielded repeatable accurate

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screw placement with low levels of ionizing radiation exposure to the surgical team.

Clinical significance: The described technique may be a viable method for minimally invasive osteosynthesis fixation of SIL with low levels of radiation exposure to the surgical team. These results provide evidence to support further evaluation of radiation exposure in clinical cases and can aid in study design and sample size determination.

1 | INTRODUCTION

Sacroiliac luxation (SIL) is the traumatic separation of the wing of the ilium from the sacrum without fracture of the adjacent ilium or sacrum[1] and is often secondary to motor vehicle accidents.[2,3] The decision to treat animals with medical or surgical management is determined by the severity of pain, pelvic instability, narrowing of the pelvic canal, alignment of the coxofemoral joint, neurological dysfunction, and potential for additional stress on concurrent fractures/fixations.[3-6] Guidelines for fixation include placing a screw in lag fashion centered on the sacral body perpendicular to the sagittal plane, achieving >60% screw purchase through the width of the sacrum, >90% reduction of the sacroiliac joint, and > 50% restoration of the pelvic canal.[1] Clinically, there is a low loosening rate when one screw is properly placed with >60% sacral purchase.[7,8]

Open reduction and internal fixation (ORIF) requires significant soft tissue dissection and retraction of the ilial wing to permit palpation and visualization to guide screw placement.[7,9,10] Accurate screw placement can be complicated by imperfect animal positioning, concurrent pelvic fractures, and obesity or swelling obscuring palpable landmarks.[1] No single safe angle has been found in dogs.[11] Minimally invasive osteosynthesis (MIO) has been shown to result in more accurate sacral screw placement, a lower incidence of screw loosening,[12,13] and quicker return to weight bearing compared with ORIF.[8] Minimally invasive osteosynthesis has become the standard of care in human traumatology for the treatment of SIL because of safer screw positioning and decreased blood loss, duration of surgery, hospitalization time, and postoperative pain.[10,14-17] Original descriptions of the MIO technique in dogs required that the surgeon hold a drill guide while using fluoroscopy to guide drilling of the pilot hole, exposing surgical personnel to ionizing radiation.[7,8] Methods to mitigate this include using elongated handheld aiming guides or table-mounted holding arms and aiming devices.[18] In man, surgeons who specialize in trauma and or deformity surgery are exposed to relatively high doses of radiation from intraoperative fluoroscopy, and junior surgeons received higher doses of radiation than senior surgeons.[19,20] Because the use of intraoperative imaging is becoming more commonplace in small animal orthopedics, it is important to understand the relative risks associated with fluoroscopically assisted procedures for operating room personnel. Hersh-Boyle and colleagues[21] documented radiation exposure to dogs and cats undergoing orthopedic and interventional procedures, but, to the best of the authors' knowledge, no published report has documented direct exposure levels for veterinary surgical personnel during MIO.

The objective of this study was to document radiation exposure to the primary surgeon and the surgical assistant and to evaluate the accuracy of a modified fluoroscopically assisted percutaneous MIO technique for lag screw fixation of artificially induced SIL in dogs. We hypothesized that this technique would achieve low levels of radiation exposure to the surgical team. We also hypothesized that this technique would achieve lag screw placement, as measured by screw angulation and sacral screw purchase, similar to previously documented MIO techniques.[12,22]

2 | MATERIALS AND METHODS

Performing power analysis for noninferiority tests, with Type I error rate (α) of .05 and power ($1 - \beta$) of 0.8, we set the noninferiority margin as the standard deviation for screw angulation and sacral screw purchase reported from a previous MIO study,[12] yielding a required sample size of 17. Seventeen adult laboratory beagles (body weight 6.2–18.8 kg) that had been humanely killed for reasons unrelated to this study and had been stored at −20 C° were obtained in accordance with the Iowa State University IACUC guidelines. Whole cadavers were thawed for 48 hours at room temperature prior inducing SIL. A luxation was induced by using a ventral approach to the pelvis, transecting the pubis and ischium by using an oscillating saw. The ipsilateral sacroiliac joint was luxated by using an osteotome and manipulated to displace and confirm mobility of the sacroiliac joint. The cadavers were refrozen at −20 C° and then thawed for 48 hours prior to MIO fixation.

A single surgeon (J.H.N.) with limited experience with MIO fixation performed all procedures. The surgeon and assistant wore personal digital dosimeters (RADOS

RAD-50-R personal dosimeter; RADOS Technology, Oy Turku, Finland) on the wrist of their dominant hand and under a lead apron to measure extremity and whole-body radiation exposure, respectively. Dosimeter readings were recorded after each case, and per case and cumulative exposure levels were documented.

Cadavers were placed in lateral recumbency on a radiolucent motorized tilt table and secured with 2-in porous tape around the mid abdomen and around the leg nearest to the table to prevent cadaver movement when the table was tilted. The C-arm (Koninklijke Philips NV, Amsterdam, Netherlands) was positioned with the amplifier under the table. The radiographic beam was centered on the lumbosacral space to achieve a lateral projection. The table was adjusted to achieve superimposition of the L7 transverse processes and parallelism of the L7-S1 end plates.[12] A previously described surgical technique with cannulated drill bits[22] was modified by employing 14-gauge hypodermic needles as drill sleeves and aiming devices for initial Kirschner wire (K-wire) placement. A stab incision was performed over the ilial wing, and a 1/8-in partially threaded intramedullary pin (IMEX Veterinary, Longview, Texas) was placed into the ilium in a craniolateral to caudomedial direction, engaging both cortices. A Jacobs chuck was attached to act as a reduction handle and to distance the assistant from the primary radiation beam (Figure 1). The assistant reduced the SIL with their dominant hand while standing as far as possible from the radiographic beam, and reduction was assessed with the C-arm. A 14-gauge 1.5-in-aluminum hub hypodermic needle (Covidien, Mansfield, Massachusetts) was inserted percutaneously 0.5 to 1 cm caudal to the planned lag screw location over the ilium and sacral body (Figure 2A). The location and angle of the needle was assessed with the C-arm and adjusted as required. The needle trajectory was adjusted until the long axis of the needle was parallel to the radiographic beam. This is important to avoid iatrogenic trauma to the sciatic nerve and cauda equina. A 0.045-in (1.1 mm) K-wire (IMEX Veterinary, Longview, Texas) was driven through the ilium and sacrum by using the needle as a guide (Figure 2B). After this point, no surgical personnel were required in the vicinity of the cadaver during fluoroscopy. The surgical team took at least three steps away from the C-arm, which was operated by the surgeon using a foot pedal. The 1/8-in pin was removed, and a 14-gauge needle was inserted percutaneously over the center of the sacral body and manipulated until the shaft was centered within the radiopaque hub, indicating that the long axis of the needle was parallel to the x-ray beam (Figure 3). Manipulations were made without fully removing the needle whenever it was possible, and the needle was imbedded in the ilial periosteum to minimize movement. A 0.045-in K-wire was driven through the ilium and sacrum by using the needle as a guide. The position of the K-wire was assessed with the C-arm, and the needle was removed. A stab incision was performed adjacent to the K-wire, and a 3.5-mm drill guide (DePuy Synthes Veterinary, West Chester, Pennsylvania) was positioned over the K-wire. A 3.5-mm cannulated drill bit (Arthrex, Naples, Florida) was used to drill a glide hole through the ilial wing, feeling carefully to drill through only the two cortices of the ilium, leaving the guide wire embedded in the sacrum. A pilot hole through the sacrum and contralateral ilium was drilled by using a 2.5-mm cannulated drill bit (Arthrex). A K-wire was kept in the hole to maintain its location and orientation for tapping and screw placement. The pilot hole was tapped with a 3.5-mm tap. A 3.5-mm (32–36 mm long) titanium partially threaded cortical shaft screw (Synthes) was inserted to complete lag fixation. Titanium screws were used to lessen

FIGURE 1 Pelvis model with reduction pin. Threaded pin inserted into ilial wing with attached Jacobs chuck manipulated by an extended arm to distance the assistant from the radiographic beam

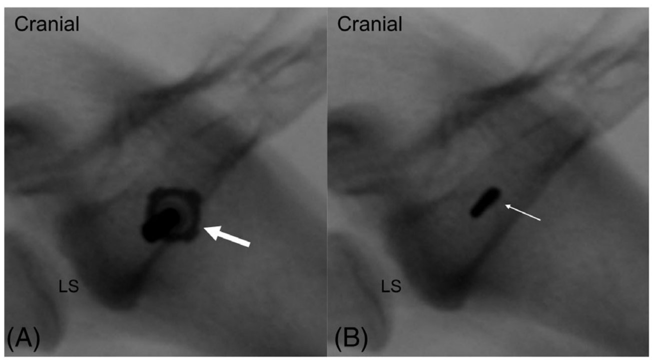

FIGURE 2 Intraoperative fluoroscopic images with the dog in lateral recumbency. A, 14-gauge needle (thick white arrow) in the planned temporary K-wire site. Minor deviation from parallelism with the radiographic beam is acceptable as in this case, but the needle should guide the K-wire through both the ilium and part of the sacrum distal to the planned site of screw placement. Planned K-wire trajectory can be inferred by assessing the position of the needle tip relative to the hub. B, Temporary K-wire (thin white arrow) placed just caudal to the planned lag screw fixation site engaging the ilium and sacrum. K-wire, Kirschner wire

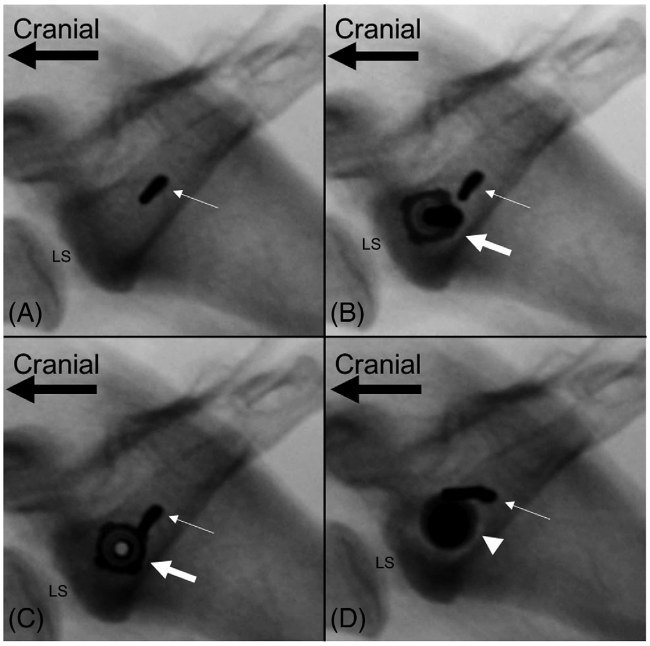

FIGURE 3 Intraoperative fluoroscopic images with the dog in lateral recumbency. A, Temporary K-wire (thin arrow; also in B,C,D) placed just caudal to the planned lag screw fixation site. B, 14-gauge needle (thick white arrow; also in C,D) in the planned screw fixation site. C, Ideal needle placement parallel to the radiographic beam. D, Final screw placement (arrowhead) with temporary K-wire. Thick black arrow, cranial. K-wire, Kirschner wire

computed tomography (CT) beam hardening artifacts at postoperative evaluation.[23]

2.1 | Measurement of operative variables

Surgical variables including the time required for cadaver positioning, duration of surgery for reduction and screw placement, and the number of times the needle or K-wire was placed were recorded. Any procedural complications were documented. Radiation exposure to both the primary surgeon and surgical assistant was recorded with a digital dosimeter for each case. Digital dosimeters were calibrated by the Iowa State University Environmental Health and Safety Radiation Safety Department and had a radiation detection range of 60 keV to 1.5 MeV and a measurement range of 0.1 mrem to 999 rem. The number of fluoroscopic images for each case was recorded.

2.2 | Postoperative evaluation

Postoperative CT was performed by using a dedicated algorithm with high kVp, high tube charge, low pitch, and narrow columniation.[23] All data were evaluated by one author (J.H.N.) experienced with CT image reconstruction and evaluation. In a radiographic imaging program (Horos v3.3.5; Horos Project, Annapolis, Maryland; https://horosproject.org/), each pelvis was evaluated by using three-dimensional multiplanar reconstruction (MPR) and orientated in accordance with a previously described protocol.[12] The dorsoventral screw angle (DVA) and craniocaudal screw angle (CCA) were measured in the transverse and dorsal planes, respectively. The DVA has previously been defined as the angle between the long axis of the screw and the dorsal plane.[12,18] The CCA has been defined as the angle between the long axis of the screw and the transverse plane.[12,18] Screws with dorsal angulation for DVA and cranial angulation for CCA were assigned positive screw angles, while ventral and caudal angulation were assigned negative screw angles.

2.3 | Sacral screw purchase evaluation

The pilot hole length to sacral width ratio (PL/SW-R) was calculated as a surrogate measurement for potential sacral screw purchase.[12,18] The mean sacral width was determined by averaging measurements through the center of the sacral body in both the transverse and dorsal planes. The shortest pilot hole in either the transverse or the dorsal plane was measured from the entry to exit points in the sacrum. Drill holes or screws with dorsal exit through the spinal canal floor or with cranial exit through the L7-S1 intervertebral disc space were recorded. A screw was considered properly placed when there was >60% PL/SW-R and no dorsal exit into the vertebral canal or cranial exit into the LS space.

2.4 | Sacral body diameter evaluation

The diameter of the sacrum at the level of the screw was recorded from a transverse cross-section centered on the screw on midline. The ratio of sacral body diameter to screw diameter (3.5 mm) was calculated.

2.5 | Evaluation of reduction and pelvic canal diameter

Reduction of the sacroiliac joint was assessed by comparing the percentage of the cranial to caudal length of the ilial joint surface in contact with the sacral joint surface. Measurements were recorded by using a dorsal MPR with the sacrum rotated to yield a cross-sectional image that included the full craniocaudal length of the sacrum at a level centered on the SI joint in the transverse plane.

Pelvic canal diameter ratio (PCDR) was calculated by measuring the pelvic canal width at the cranial aspect of the acetabulum divided by the width of the sacrum, with a normal PCDR being ≥1.1.[8,13,24] Hemipelvic canal width ratio (HCWR) was measured by drawing a line from the sacral spine to the pubic symphysis and measuring from the medial aspect of the pelvis at the cranial aspect of the acetabulum to the midline. The HCWR was calculated by dividing the hemipelvic canal width of the surgically treated side by the contralateral hemipelvic width, with a value of 1 being symmetric.[8,13,24]

2.6 | Statistical analysis

Range, mean, and standard deviation were determined for duration of surgery variables, the number of fluoroscopic images acquired, the number of times the hypodermic needle or K-wire needle was replaced, CCA, DVA, and percentage sacral screw purchase. Statistical analysis was performed to evaluate cases that did and did not require intraoperative reduction in R 3.5.1 (R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/). Shapiro–Wilk tests were performed to check normality for total surgical duration and number of images. F tests were used to check for significant differences between reduced and nonreduced groups. $P \leq .05$ was considered significant. Linear regression analysis was used to determine a line of best fit for cumulative radiation exposure.

3 | RESULTS

3.1 | Operative values

The mean time for cadaver positioning was 2.16 minutes (range, 0.5–4.83). The average time for surgical fixation was 15.85 minutes (range, 6.37–33.5). The needle was placed an average of 14.25 times per case (range, 4–30). Kirschner wires were placed only twice for each case, once for the temporary reduction and once to guide the cannulated drill bit. Intraoperative complications were noted in four of 17 cases. Two complications resulted from

TABLE 1 Individual case and cumulative case radiation exposure levels

Case No.	Fluoroscopic images taken, n	Cumulative surgeon radiation exposure under vest, mrem	Cumulative surgeon radiation exposure dominant wrist, mrem	Cumulative assistant radiation exposure under vest, mrem	Cumulative assistant radiation exposure dominant wrist, mrem	C-arm examination dose, mGy	Cumulative C-arm examination dose, mGy
1	37	0	0	0	0	0.548	0.548
2	16	0	0	0	0	0.348	0.896
3	38	0	0	0	0	0.658	1.554
4	60	0	0	0	0	1.48	3.034
5	62	0	0	0	0	1.21	4.244
6	59	0	0	0	0	4.21	8.454
7	24	0	0	0	0	2.07	10.524
8	41	0	0	0	0.2	4.42	14.944
9	18	0	0	0	0.2	1.57	16.514
10	55	0	0	0	0.2	3.8	20.314
11	43	0	0	0	0.2	2.28	22.594
12	34	0	0	0	0.2	2.39	24.984
13	53	0	0	0	0.3	4.7	29.684
14	41	0	0	0	0.3	3.59	33.274
15	17	0	0	0	0.3	1.48	34.754
16	21	0	0	0	0.3	1.82	36.574
17	20	0	0	0	0.4	1.74	38.314

Note: Individual case and cumulative case radiation levels are listed for the surgeon and assistant's dominant arm and under the vest dosimeters. C-arm dose report data are also listed.

the K-wire becoming lodged in the 2.5-mm drill bit. In one case, the end-threaded reduction pin was driven through the transverse process of L7, requiring replacement of the pin. In the fourth case, the screw missed the glide hole, creating a new hole in the wing of the ilium. Final placement caused the screw head to pull through the wing of the ilium with subsequent loss of reduction. This case was included in the analysis of screw positioning within the sacrum but was excluded from the analysis of sacral reduction.

On average, 37.63 ± 16.2 (range, 16–62) fluoroscopic images were obtained per case. No detectable radiation readings were recorded from the dosimeters under the vest of the surgeon or surgical assistant for the cumulative amount after 17 cases. No detectable radiation exposure was recorded from the dosimeter on the dominant wrist of the primary surgeon (Table 1). Radiation exposure on the dominant wrist of the assistant was not detectable until a cumulative dose was acquired after eight cases (0.2 mrem), with a final cumulative dose of 0.4 mrem after 17 cases (Figure 4). This dose was associated with exposure to a total of 639 fluoroscopic images. The average examination dose reported by the fluoroscopy unit was 2.36 ± 1.39 mGy (range, 0.38–4.7), with a cumulative total of 29.86 mGy after 17 cases.

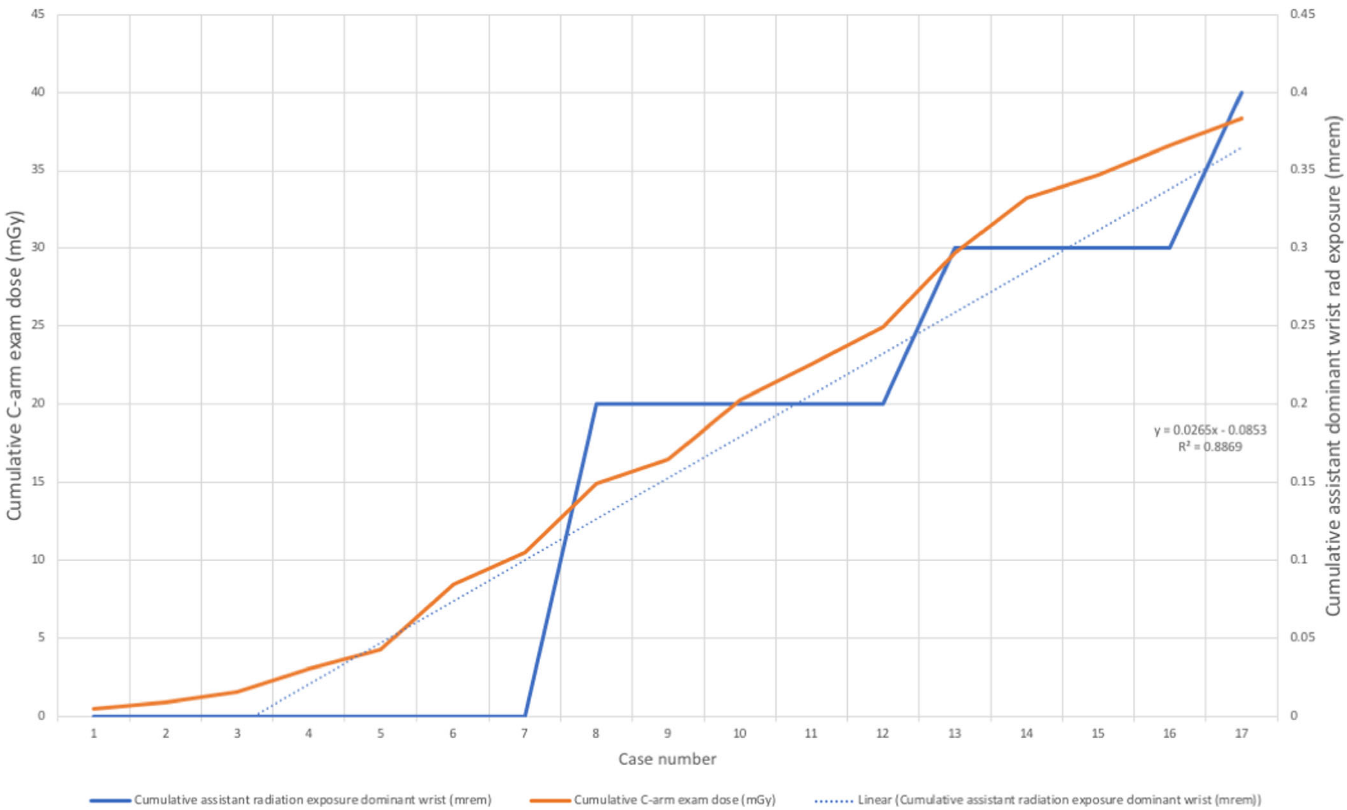

FIGURE 4 Graph of C-arm and dosimeter radiation levels. Cumulative C-arm examination dose (red line) and cumulative radiation exposure to the surgical assistant are plotted for the 17 cases. A linear regression line for exposure to the assistant's arm has been plotted

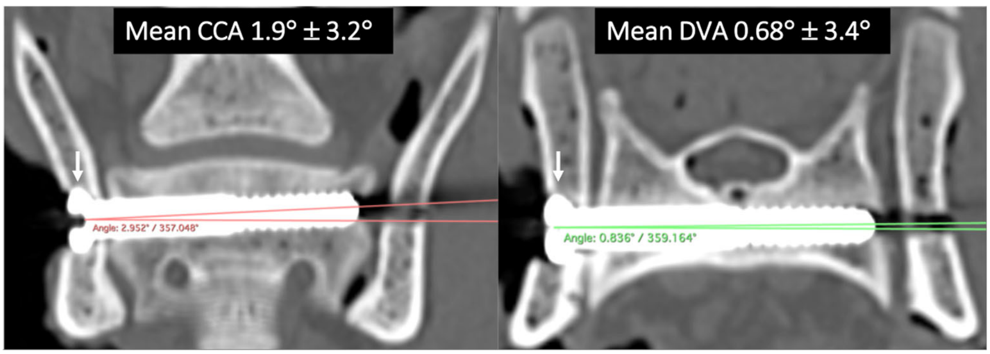

FIGURE 5 Postoperative CT MPR views. Dorsal (image at left) and transverse (image at right) MPR illustrating mean and SD for the CCA and DVA. Partial screw head pull through is present (white arrows). CCA, craniocaudal screw angle; CT, computed tomography; DVA, dorsoventral screw angle; MPR, multiplanar reconstruction

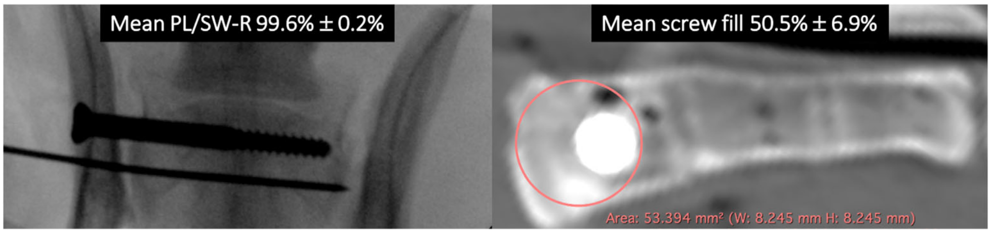

FIGURE 6 Intraoperative fluoroscopic image and postoperative sagittal CT MPR. Image at left, Dorsoventral projection illustrating the mean and SD for the PL/SW-R. Image at right, Midline sagittal multiplanar reconstruction illustrating the mean screw fill with a 3.5-mm screw. This screw was placed slightly caudal to the ideal location in the center of the circle. CT, computed tomography; MPR, multiplanar reconstruction; PL/SW-R, pilot hole length to sacral width ratio

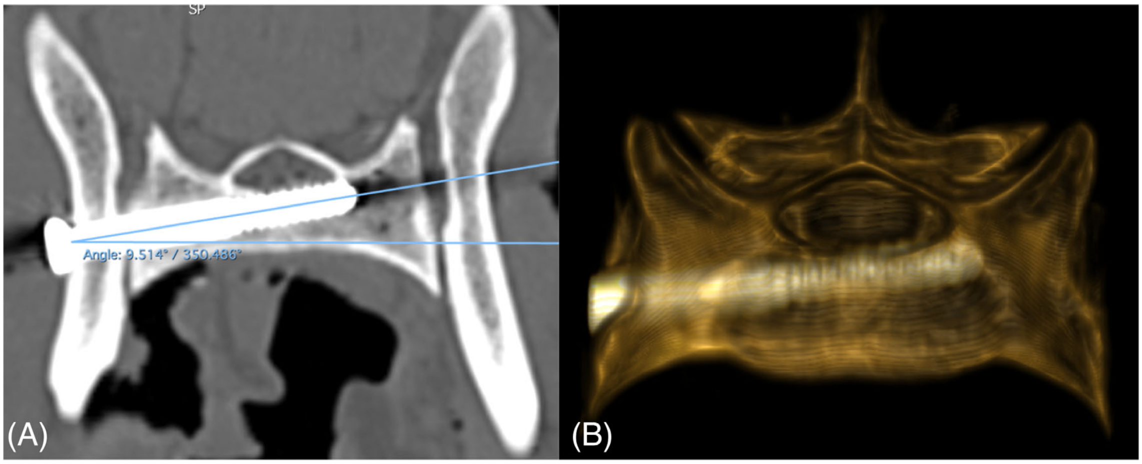

FIGURE 7 High dorsoventral screw angulation. Multiplanar (A) and three-dimensional (B) reconstructions of the sacrum illustrating screw threads engaging the ventral cortex of the spinal canal without associated impingement or compression of the nerve roots. This case had a DVA of 9.5°

3.2 | Screw angles and sacral screw purchase

The mean ± SD screw angle was 0.68° ± 3.4° (range, −5.4° to 9.5°) for the DVA and 1.9° ± 3.2° (range, −4.3° to 9.1°) for the CCA (Figure 5). Sixteen of seventeen (93.75%) cases had a PL/SW-R of 100%, and the remaining case had a PL/SW-R of 93.4%. The mean PL/SW-R was 99.6% ± 1.4%. (range, 93.4%–100%; Figure 6).

3.3 | Pilot hole exit point and screw placement evaluation

Pilot holes were properly oriented in 16 of 17 cadavers, achieving a PL/SW-R > 60%, without cranial exit into the L7-S1 intervertebral disc space and without dorsal exit into the spinal canal. The one case that did not meet this criterion had a screw placed with a DVA of 9.5°, causing the screw threads to engage the ventral bony margin of the spinal canal without screw penetration into the spinal canal (Figure 7). While no compression or impingement was noted, this was considered to be improper placement because of engagement of the screw threads in the ventral floor of the vertebral canal. This case was still considered to have a PL/SW-R of 100% because the pilot hole did not penetrate the vertebral canal, and there was less than 0.5 mm of thread extension into the canal, which is the difference in the radius of the pilot hole and outer screw threads.

3.4 | Sacral reduction and pelvic canal diameter

Sixteen pelves were evaluated for sacral reduction and pelvic canal diameter. One case was excluded because the screw head pulled through the ilial wing, resulting in loss of reduction. An additional case had partial screw head pull-through that did not impact further evaluation. Among the16 pelves evaluated for sacral reduction, 15 had >90% cranial/caudal reduction (mean, 97%; range, 78.6%–100%). Despite confirming mobility of the ilial wing relative to the sacrum in all cases prior to operation, six of 17 cases were assessed to be adequately reduced on the basis of fluoroscopy results prior to stabilization and did not require further reduction at the time of surgery. Shapiro–Wilk tests confirmed normality, and F tests provided evidence that the variance between the two groups was not different for number of fluoroscopic images and surgical duration variables. These cases were associated with a lower number ($P = .0019$) of fluoroscopy images (mean, 22.67 ± 8.04) compared with those that required reduction (mean, 46.60 ± 13.88). Total duration of surgery was also shorter ($P = .014$) for these cases (mean, 10.78 ± 3.65 minutes) compared with those that required reduction (mean, 20.22 ± 7.3 minutes). The mean $\pm$ SD for PCDR and HCWR were 1.14 ± 0.09 (range, 0.95–1.26) and 0.91 ± 0.14 (range, 0.75–1.21), respectively.

3.5 | Sacral diameter and percentage screw fill

The mean $\pm$ SD sacral diameter measured at the level of the screw was 7.04 ± 0.89 mm (range, 5.37–8.33). The actual mean $\pm$ SD percentage screw fill based on the sacral diameter at the level of the screw was 50.5% $\pm$ 6.9% (range, 42.1%–65.2%).

4 | DISCUSSION

Low levels of radiation exposure to the surgical team were noted with the technique used in this study. To the best of our knowledge, this report is the first to document radiation exposure to the surgical team during MIO fixation of SIL in dogs. Using the modified technique in which 14-gauge needles and fluoroscopy were employed to guide initial K-wire placement and to facilitate the placement of an iliosacral lag screw, we were able to maintain intraoperative reduction of the SI joint, facilitate accurate and timely localization of the center of the sacral body for screw placement, and achieve accurate screw orientation within a narrow safe corridor.

The concept ALARA (as low as reasonably achievable) is employed to minimize occupational and environmental radiation exposure by decreasing exposure time, increasing distance from the radiation source, and using shielding to block or reduce ionizing radiation.[25] Exposure time was limited in this study through the use of image acquisition in a still shot rather than cine mode. This was performed at the expense of speed and ease of assessment because cine mode would have allowed assessment of structures in real time during cadaver positioning and SI reduction. Researchers evaluating the use of MIO for SIL in cats using a cannulated screw system reported a mean fluoroscopic screening time of 44 $\pm$ 6 seconds per procedure.[26] Hersh-Boyle and colleagues[21] documented patient radiation exposure for a variety of orthopedic and interventional procedures in dogs and cats using C-arm dose reports, but no report has documented direct exposure levels for veterinary surgical personnel. In small animals, radiation dose was reported to be lower for orthopedic procedures than for any other procedure type evaluated. Fluoroscopy unit dose for the 37 orthopedic cases, of which three were SIL, was reported to yielded a mean of 2.27 mGy (range, 0.14–74.33), which is similar but has a much wider range compared with the present study of 17 SIL cases with a mean of 2.36 ± 1.39 mGy (range, 0.38–4.7). The previous report[21] described median fluoroscopic screening time (1.71 minutes), while, in the present study, we used only still shot mode and reported a mean of 37.63 shots, which makes comparing these results difficult. Over the course of 17 cases and 639 acquired images, only the assistant had detectable exposure on the wrist of their dominant arm, with a cumulative dose of 0.4 mrem. Neither the surgeon nor the assistant had any detectable radiation exposure measured by the digital dosimeter under their lead apron/vest, which is a measure of whole-body radiation exposure. For comparison, orthopedic surgery residents in one study in man received mean radiation exposures of 0.2 to 79 mrem/month, and those who specialize in trauma or deformity surgery were exposed to 53 mrem/month.[19] On the basis of a linear regression model from the exposure levels to the assistant, 0.2 mrem was reached after 10.8 cases, and 79 mrem would not be reached until after 2984 cases. Linear regression analysis could not be performed for the exposure to the under-the-vest measurements from the surgeon or the assistant or from the dominant wrist of the surgeon because no detectable readings were present after a total of 17 cases. The low levels of exposure to both the surgeon and the assistant in our study are promising, and may serve to determine sample size requirements for future studies in a clinical setting.

It has been previously documented that, in human medicine, senior orthopedic surgeons used less fluoroscopic screening time and, as a result, were exposed to lower radiation levels compared with junior surgeons.[19,20] All procedures in this study were performed by a novice surgeon, and inexperience may have contributed to increased fluoroscopic shot acquisition. Additional veterinary studies in which novice and experienced surgeons are compared are required to validate the difference in exposure noted in human medicine. Strategies to increase the distance from the radiographic beam in this study included the use of extended instruments and taking three steps away from the C-arm whenever possible during image acquisition. A proprietary system in which two MIO reduction handles were used in conjunction with table-bound articulated arms and a minimally invasive lucent aiming device has been described for temporary reduction and drill guidance while minimizing radiation exposure, but this system is not widely available at the time of writing.[18] The modified technique used in the current study does not require custom elongated drill guides, a specialized table-mounted holding jig, or an aiming device, and eliminates the requirement for the surgical team to be near the patient during all stages except the initial reduction. To mitigate radiation exposure during the reduction period, the end-threaded pin used for manual reduction was inserted in a craniolateral to caudomedial orientation, and a Jacobs chuck was attached to the pin as a handle to further distance the assistant from the x-ray source. Manipulation of the ilium may have been easier than in a clinical setting due to the cadaveric nature of this study. The use of hypodermic needles to identify the appropriate location and angle for K-wire placement allowed the surgeon to avoid being in the vicinity of the radiation field during the entirety of the procedure and allowed the assistant to avoid being in proximity after the initial reduction and temporary K-wire placement. It has been recommended to stand at least 36 in away during fluoroscopy operation to minimize exposure.[27] In our study, the surgeon and assistant took three steps away from the C-arm when images were being acquired after temporary K-wire placement. The traditional method of MIO for SIL requires the surgeon or assistant to hold a drill guide centered within the primary beam to guide drilling of the pilot and glide holes.[8]

Using the modified MIO technique with 14-gauge hypodermic needles to guide initial K- wire placement to facilitate the use of cannulated drill bits, we were able to achieve results with respect to screw angle and PL/SW-R similar to previously published MIO data and superior to previously published ORIF data.[12,17] We were able to achieve an adequate degree of accuracy and precision, with mean DVA and CCA of $0.68^\circ \pm 3.4^\circ$ and $1.89^\circ \pm 3.2^\circ$, respectively. We achieved appropriate screw placement in 16 of 17 cases, with >60% PL/SW-R and lack of exit either cranially into the LS space or dorsally into the vertebral canal. The single case that failed to meet these criteria had screw threads that engaged the ventral floor of the vertebral canal without apparent compression or impingement on the tissues within the canal. While it is unlikely that this screw would have caused issues in a clinical animal, it fell outside of the variables established for appropriate screw placement for this study. Dejardin and colleagues[12] achieved mean PL/SW-R of 67.2% ± 19.4% for ORIF and 97.1% ± 2.3% for MIO. Our results closely match these MIO values, with a mean PL/SW-R of 99.6% ± 1.4%. Researchers in a retrospective clinical study evaluating the use of 2.4-mm cannulated screws for MIO fixation in cats achieved satisfactory screw placement in 11 of 12 cases (92%), with a mean screw purchase of 73%.[26]

Lag screw fixation with mean screw size relative to the sacral diameter at the level of the screw of 50.5% was achieved in this study. The use of a screw with a diameter of 40% relative to the bone diameter has been suggested.[28] Researchers in a study comparing the use of 2.0 to 2.7-mm screws in feline sacra found that, while the 2.7-mm screws often exceeded this size recommendation, they were associated with a decreased likelihood of implant loosening.[26] Increasing the screw size results in increased resistance to bending and shearing compared with a smaller screw alone or combined with an antirotational pin.[29] While the placement of a second screw has been shown to be stronger than a single screw and to increase resistance to torsional loads, this is not clinically required.[7,8,28]

Similarly to other studies,[7,8,12,26] we were able to achieve adequate sacroiliac reduction with a mean reduction of 96.8%. One case was excluded from the sacroiliac reduction evaluation because of loss of reduction after the screw head pulled through the ilium. Tonks et al[7] reported a mean postoperative SI joint reduction of 91%, and Tomlinson et al[8] reported a mean of 92% reduction for clinical cases treated with closed reduction techniques. These results are similar to those reported by DeCamp and Braden[1] (mean 94%) for open reduction. The mean PCDR was ≥1.1, which provided evidence of adequate restoration of pelvic canal diameter and was in line with results from previous reports.[8,13,24] We achieved a (HCWR) of 0.91. Tomlinson et al[8] reported a mean HCWR of 1.09, and Rollins et al[13] reported a mean of 0.99 in clinical cases of MIO fixation. Hemipelvic canal width ratio is a measurement of variance from 1, and, therefore, our mean of 0.91 is in line with prior studies. The referenced clinical studies calculated PCDR and HCWR on the basis of radiographic measurements, while CT MPR was used in this study. All cadavers in the current study had simple unilateral SIL without concurrent pelvic trauma or muscle contraction. As a result, six of 17 cases had adequate reduction and did not require additional manipulation at the time of fixation. These cases also had shorter surgical durations compared with the remaining 11 procedures. Surgical reduction may be more challenging in a severely traumatized animal or one with muscle contraction and fibrosis associated with a chronic luxation, which may result in a longer surgical duration or require conversion to an open procedure. In larger or more muscled animals, reduction may be enhanced by using a firmer grip on the Jacobs chuck and by providing additional caudal traction to the femur or a reduction forceps applied to the ischial tuberosity.[22]

Previously documented methods of MIO for SIL involve fluoroscopically guided insertion of a K-wire through the ilium and sacrum for temporary fixation.[8] With fluoroscopically guided insertion, repositioning of the K-wire is often required to achieve sufficient stability while avoiding adjacent neurovascular structures.[18,26] Kirschner wire placement was the most challenging step when MIO was performed in cats, requiring multiple attempts in 58% of cases.[26] The use of a 14-gauge needle to guide K-wire placement in the study reported here eliminated the requirement for K-wire replacement, resulting in decreased risk of iatrogenic trauma. The needle was repositioned an average of 14.25 times per case; however, these were often fine adjustments that did not require complete needle removal or additional puncturing of the skin.

Intraoperative complications were encountered during four of 17 procedures. In one case, the end-threaded reduction pin engaged the transverse process of L7. Postoperative CT revealed a nondisplaced fracture of the transverse process of L7. In two cases, partial or complete screw head pull-through was noted. Washers were not used in this study to minimize CT artifacts but are routinely used in our institution to lessen the risk of screw head pull-through. In two cases, the K-wire became lodged within the cannulated drill bit. If it had not already been fully drilled, the pilot hole was completed by using a standard 2.5-mm drill bit. Considerable time was required to remove the K-wire, and the authors recommend having a second cannulated drill bit available during clinical cases.

This study had several limitations. This was a descriptive cadaveric study in which we documented the accuracy and degree of radiation exposure with the described modified technique, but a direct comparison to ORIF or other MIO techniques was not performed. In addition, because this was a cadaveric study, results should be interpreted with caution because this technique has not been evaluated in clinical animals. Reduction of the SIL was not required in six cases and was easily performed in the remaining 11 cases. Reduction would likely be more difficult in clinical cases with more muscle contraction, variability in animal size, degree of polytrauma, and duration of time between trauma and surgery. The six cases that did not require reduction required acquisition of fewer fluoroscopic images and took less time to complete, thus skewing the results of this study. Fluoroscopic use was limited to still shots rather than cine mode, as has been described in other reports.[21,26] Use of cine mode may have decreased cadaver positioning and surgical durations, but at the cost of increased radiation exposure. Additional studies are required to compare differences in duration of surgery and radiation exposure between still shot and cine modes. After temporary K-wire placement, the surgeon and assistant took at least three steps away from the C-arm rather than the recommended 36 in.[27] Variability in the distance could have affected dosimeter readings. In addition, some operating rooms may not have sufficient room to allow for such distancing. All procedures were performed by a single surgeon (J.H.N.) to limit variability; however, several surgical residents assisted, which could have introduced variability in duration of surgery and SIL reduction. All postoperative measurements were performed by a single surgeon, which may be a source of bias. Having multiple people perform these measurements would have allowed us to evaluate for interobserver variability. Metal washers were not used in an effort to limit CT beam hardening artifact, and this may have contributed to screw head pull through in two cases. The use of a washer in clinical cases is expected to lower this risk by increasing the area of contact on the ilial wing.

Our results provided evidence that fluoroscopic percutaneous-assisted placement of 3.5-mm cortical screws in lag fashion performed with 14-gauge needles in conjunction with K-wires and cannulated drill bits yielded repeatable accurate screw placement with minimal ionizing radiation exposure to the surgical team. Data from this study may aid in the design of future studies of radiation exposure in a clinical setting.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

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