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PAPER

Repair of lumbosacral fracture–luxation with bilateral twisted string-of-pearls locking plates

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Objectives: To describe a surgical technique using bilateral twisted string-of-pearls locking plates for lumbosacral fracture–luxation in dogs and cats.

Materials and Methods: Twisted string-of-pearls locking plates were used to stabilise lumbosacral fracture–luxation between 2013 and 2017. Decompression of the *cauda equina* was achieved by dorsal laminectomy through a dorso-medial approach. Stabilisation was achieved using bilateral string-of-pearls plates attached to the lateral aspects of the vertebral body cranial to the fractured vertebra and the iliosacral joints. Reduction of the luxation was assessed under fluoroscopy. Outcome and complications were evaluated 24 hours, 6 weeks and 6 months postoperatively.

Results: Six animals (four dogs and two cats) were included. Five animals were presented with non-ambulatory paraparesis. Tail anaesthesia and severe lumbosacral pain was evident in all cases but one. Six weeks postoperatively, all animals improved to ambulation, and tail sensation recovered. The long-term clinical outcome was defined as excellent in five and satisfactory in the remaining case.

Clinical Significance: Bilateral twisted string-of-pearls locking plates can be associated with a satisfactory result in treating lumbosacral fracture–luxation.

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INTRODUCTION

Lumbosacral luxation and L7 fractures (LSFL) are relatively common traumatic spinal injuries in dogs and cats (Bali *et al.* 2009). This traumatic event most commonly combines a displaced cranial–ventral sacrum and an oblique caudal–ventral wedge fracture of the L7 vertebra body. A relatively fixed sacrum boundary with a moderately mobile caudal lumbar spine was suggested as an explanation for the liability of this location for traumatic damage (Scott & McKee 1999).

The functional spinal cord of most dogs terminates at, or slightly cranial to, the L6 to L7 vertebral junction, and so, the L7 to S1 region of dogs and cats contains the *cauda equina* (spinal nerves). Clinical signs associated with damage to this region include pain, sciatic neuropathy, urinary and faecal incontinence, perineal and tail anaesthesia and absent tail and anal tone (Bali *et al.* 2009). The goals of surgical management are: (1) to relieve the pain, (2) to decompress the nerve roots, (3) to stabilise and reduce the fracture or luxation and enable fracture healing and (4) to improve the overall neurological function. Satisfactory results have also been reported for spinal fractures treated with conservative management that included pain management and strict rest (Selcer *et al.* 1991).

Numerous different techniques have been described to stabilise LSFL, including transilial pinning, external fixator, spinal instrumentation, combined Kirschner-Ehmer/dorsal spinal plate, plastic plates and pins buried in polymethylmethacrylate (PMMA) (McAnulty *et al.* 1986, Lewis *et al.* 1989, Beaver *et al.* 1996, Harrington & Bagley 1998). These techniques have several limitations. One obvious practical difficulty stems from the fact that the approach to the lateral aspect of the L6 to L7 vertebral bodies is obscured by the wings of the ilium, making it challenging to access. Furthermore, this physical obstruction by the wings of the ilium makes it difficult to place implants while avoiding penetration of the vertebral canal.

The string-of-pearls (SOP) locking plates (Orthomed UK Ltd) have previously been used for thoracolumbar disc protrusions (McKee & Downes 2008), spinal fracture stabilisation (Tobias & Johnston 2011) and cervical distraction and stabilisation in dogs with cervical spondylomyelopathy (Solano *et al.* 2015). This interlocking plate system allows contouring in multiple planes. The objective of this study was to evaluate the use of SOP plates for the management of LSFL.

MATERIALS AND METHODS

Inclusion criteria

Medical records of dogs and cats diagnosed with LSFL in our referral practice between 2013 and 2017 were reviewed. The diagnosis was based on survey radiographs and neurological examination, followed by CT in all cases. All animals that had LSFL (Fig 1) and that were treated with the SOP technique described here were included in this report.

Neurological and radiographic assessment

Neurological examination was completed by a neurologist in all cases. Dogs were assessed preoperatively, immediately postoperatively, daily until hospital discharge and for a minimum of 6 weeks postoperatively. At presentation, all non-ambulatory animals had undergone whole body CT-myelography (Philips CT Mx8000 IDT 16; Philips Medical Systems) that was assessed by a radiologist. The displacement of the fracture or the luxation and the degree of nerve compression were evaluated. The long axis, sagittal width and vertebral body height of L5 to L7 and the sacrum were measured. Intraoperative imaging was performed by fluoroscopic supervision of an OEC 9000 mobile C-arm (OEC-Diasonics Inc.). Orthogonal radiographs were taken immediately postoperatively.

Implants

The SOP locking plate was used with conventional cortical screws; 3·5, 2·7 or 2 mm plates were used depending on the animal's size and CT vertebral measurements to allow at least two screw holes *per* vertebra.

Surgical procedure

Animals were first medically stabilised, and life-threatening issues were addressed before surgery. For surgery, animals were positioned in sternal recumbency, including a ventral support with a sponge cushion, so that the vertebral column, pelvis and pelvic limbs were elevated from the table. In cases with radiological evidence of spinal nerve compression or penetration of bone fragments into the canal, a neurologist preformed a dorsal laminectomy. Care was taken to preserve the articular processes of L7 to S1. Reduction of the luxation was assessed under fluoroscopic supervision of a C-arm (General Electric). Reduction was achieved using two pointed bone reduction forceps placed on the spinal processes of L6 and the caudal sacrum. Adequacy of reduction was assessed by obtaining

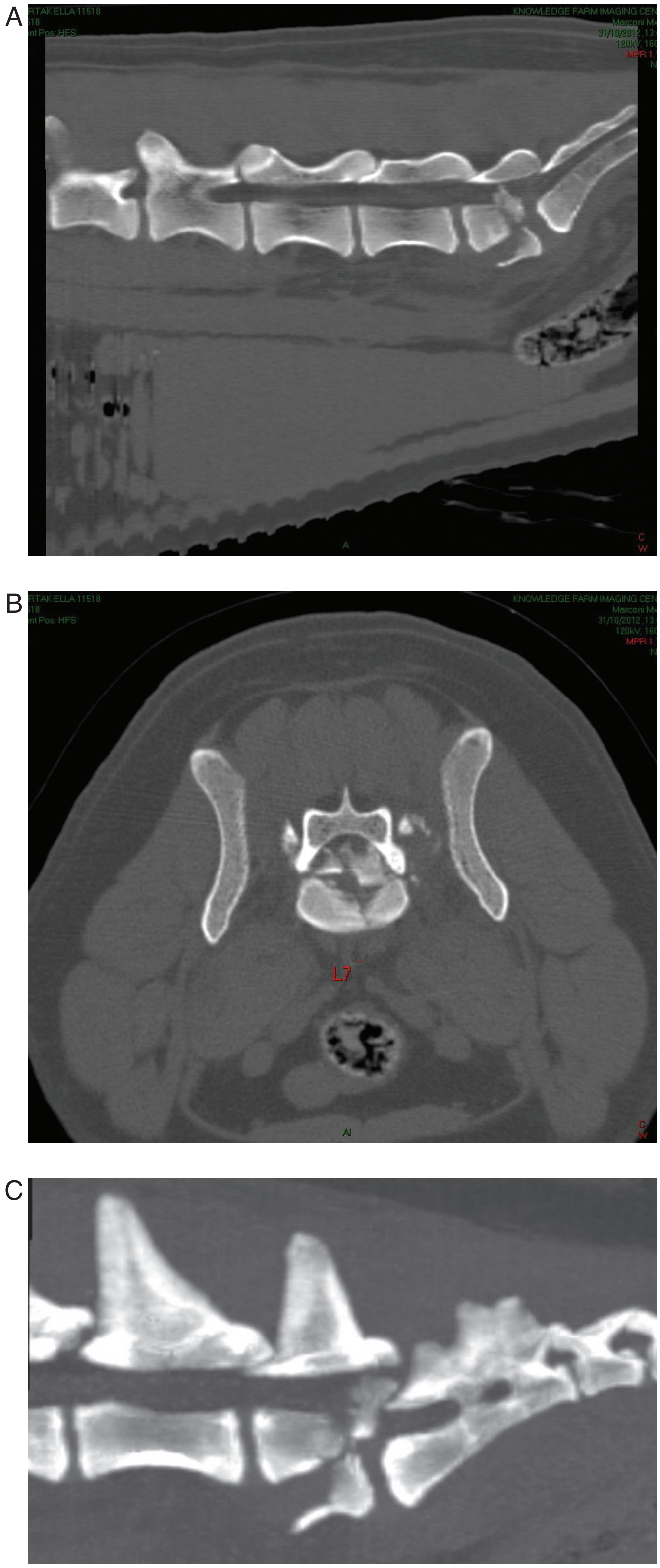


FIG 1. Sagittal (A) and transverse (B) view of a CT scan of a 6-year-old dog weighing 30 kg that was hit by a car (case I). Oblique fracture through the caudal half of L7 with a cranioventral displacement of the sacrum in relation to L7. The L/S zygapophysial joints are not luxated in this case. Displaced bone fragments are observed protruding into the L–S vertebral canal, impinging the dural sac (*cauda equina*). (C) sagittal view of an 18-month-old dog weighing 27 kg (case V) with an oblique fracture of L7 and luxation of L/S; the zygapophysial joints' displaced fragments are evident in the L–S vertebral canal

orthogonal fluoroscopic views and evaluation of the alignment of the facet joint. Anatomical alignment was temporarily maintained through the use of Miltex Stifle Retractor (Miltex), which was inserted through the laminectomy hatch. In cases with luxation of the zygapophysial joints at the lumbosacral junction, reduction was temporarily maintained by placing 0·062 in. Kirschner wires across the articulating facets of the luxated vertebra and sacrum (see black arrows in Fig 4A, B). These Kirschner wires were removed after final SOP plate stabilisation in some cases.

The surgical stabilisation of LSFL of all cases was performed by a single surgeon (US). Two SOP locking plates were cut to fit the length between the most cranial part of the intact vertebra cranially to a few millimetres caudal to the dorsal aspect of the sacroiliac articulation (Fig 2), one plate for each lateral aspect. Each plate was contoured to grossly fit the shape of the dorsolateral aspect of the L6 vertebra body just dorsal to the transverse process. The caudal part of each plate was contoured and bent to fit the dorsomedial part of the L7 to S1 articulation (Figs 2B and 4B). To achieve stabilisation, the plate was twisted between every two holes so that the proximal screw would be aimed ventromedially to engage the proximal vertebra body (approximately 45° measured from the vertical axis of L6) (Fig 3A), and about 35° ventrolaterally at the most caudal part of the plate so that the screws were aimed to penetrate the sacrum, sacroiliac articulation and the ilial wing (Fig 3B). The cumulative twisting angle throughout the plate length was approximately 70° to 80°. An SOP plate holder (Orthomed UK Ltd) was used to fix the plate to the lateral cortex of L6 and the dorsomedial aspect of the sacroiliac articulation. Two 0·062 Kirschner wires (K-wires) were inserted through the most proximal hole (into the L6 vertebra body) and the most distal hole (into the sacroiliac joint and ilial wing). Orthogonal fluoroscopic views were obtained to ensure proper implant positioning and vertebral canal avoidance. Drill holes were created through the second-most cranial and caudal holes of the plate (adjacent to the one with the K-wire). Hole depth was measured with a depth gauge. Self-tapping bicortical screws, 2 mm longer than the hole depth, were inserted through the drilled holes and were locked into the plate. The two K-wires were then removed and replaced by self-tapping bicortical screws. In two cases, the fractured vertebra was bridged, and in the four other cases, one or two additional screws were inserted into the fractured vertebral body. We aimed to achieve two screws *per* plate in the vertebra cranial to the fracture site and two screws in the sacroiliac region, altogether engaging at least eight cortices on each side of the fracture (Fig 2).

Orthogonal fluoroscopic views were obtained again to ensure maximal bone purchase of the screws in the pedicle and vertebral body, simultaneously making sure that the vertebral canal and disc spaces were intact (Fig 2A, B).

Follow-up

All dogs and cats were evaluated 24 hours and 6 weeks postoperatively, including physical and neurological examinations. Long-term follow-up was available in two of the six cases at 6 months postoperatively. In those cases, long-term follow-up included orthogonal radiographs under sedation.

Neurological examination included the following criteria:

1. Ambulation: scaled as ambulatory, ambulatory paraparesis, non-ambulatory paraparesis or plegia.
2. Sensation (tail, anal and perineum, limb): scaled as normal, weak or anaesthetic.
3. Reflexes (tail, withdrawal reflex): scaled as normal, weak or absent.
4. Bladder and/or bowel continence: scaled as normal or incontinent.
5. Postural reactions: scaled as normal, weak or absent.

Complications

All complications were documented and reviewed. Catastrophic complications were defined as associated with morbidity causing permanent unacceptable function, which constituted a reason for euthanasia. Major complications were defined as morbidity that

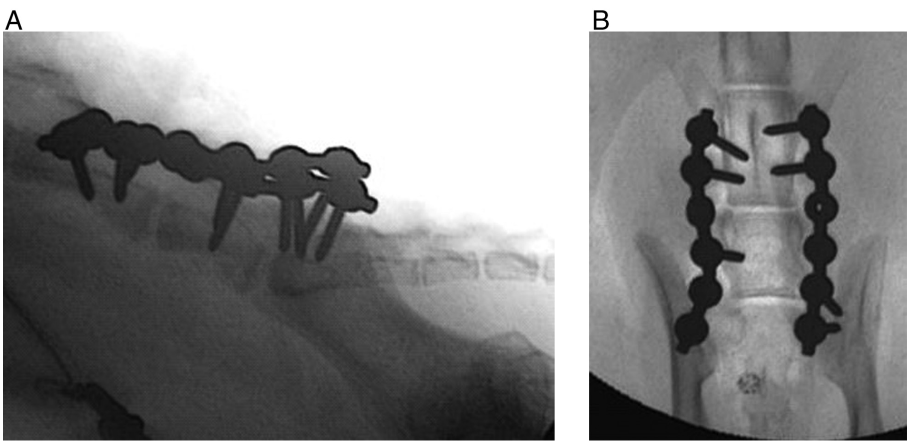
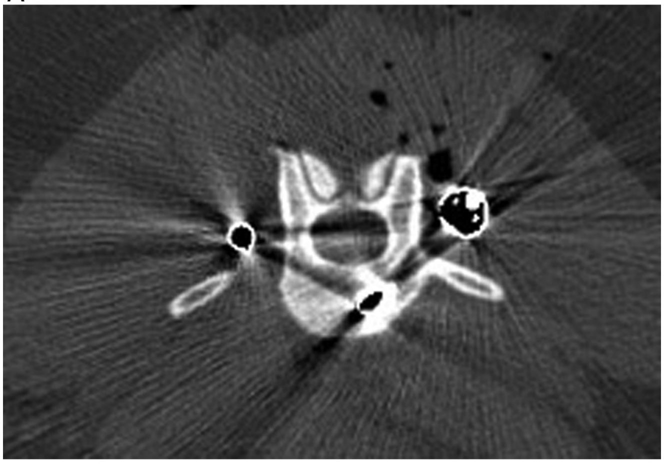


FIG 2. Lateral (A) and dorsoventral (B) intraoperative fluoroscopic view of a Himalayan cat, 12 months old, following a fall from the fifth floor (case III). The two string-of-pearls (SOP) plates are fixed to L6 with two bicortical screws each and to the sacroiliac region with two bicortical screws each. A single screw is also fixed to L7 in each plate. In this case, the third screw on the left plate is engaging the base of the transverse process because the fracture line on L7 body did not enable engaging the vertebral body. The cumulative twisting of the SOP plate is 70° to 80°

A



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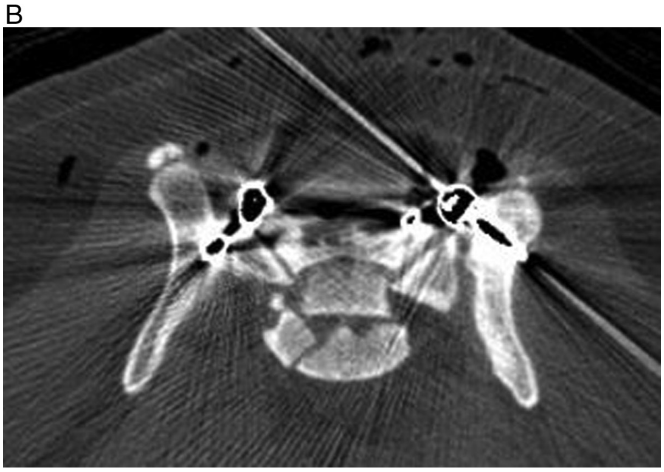

FIG 3. Postoperative CT scan of a dog, 11 months old, weighing 15 kg that was hit by a car (case II). Transverse views of the L6 vertebra (A) and lumbosacral joint (B) are shown. The twisted string-of-pearls plate allowed insertion of the proximal screws medially through the body of L6 and laterally at the distal part of the lumbosacral joint and into the ilial wing, allowing maximal bone purchase of the screws

required further surgical treatment. Minor complications were those not requiring additional surgical treatment.

RESULTS

Signalment and aetiology

Six animals (four dogs and two cats) with LSFL were included (Table 1). All but one were younger than 2 years at the time of presentation. All fractures were traumatic, and five of six animals had been hit by a motor vehicle. The animal weight distribution ranged from 4·9 to 30 kg (mean 17 kg) (Table 1).

Clinical presentation

Cases I and III had pneumothorax that was addressed before surgery. Case VI had ulna and radius fractures in the right limb (in addition to LSFL) that were treated with plates 3 days after spinal stabilisation. The neurological deficits that were detected when the animals presented are summarised in Table 1.

Imaging

No significant damage was evident in CT myelography of the spine cranial to the spinal fracture site in all of the cases. In five cases, the preoperative CT scan revealed compression of the dural sac resulting from a major fragment or chip fragments protruding into the spinal canal. The cranioventral displacement of the sacrum, in relation to L7, involved fracture of L7 with luxation of the zygapophyseal joints in two cases (cases IV and V) and fracture of L7 without luxation in four cases. Intraoperative orthogonal fluoroscopic views provided a convenient modality to ensure maximum bone purchase of the screws in the pedicle and vertebral body, as well as to properly identify the location of the spinal canal and avoid screw protrusion into the fracture site, vertebral canal or disc spaces. Orthogonal radiographs were taken immediately postoperatively to assess the position and length of the implants. Reasonable reduction and anatomic alignment were confirmed in all cases. Implant positioning was satisfactory in all cases, except for one dog, in which a screw penetrated the L5 to L6 intervertebral disc (case VI). In this case, the screw position was corrected *via* a minimal dorsal approach. Orthogonal radiographs at 6 months or more postoperatively were available for two cases (Fig 4A, B).

Intraoperative assessment

Mean surgery time was 3 hours and 9 minutes (sd 26 minutes). In one case (case VI), massive haemorrhage occurred during drilling of the screw hole in the L6 vertebra, which was controlled by tamponade and bone wax insertion. In one case, over-twisting of the SOP plate resulted in fracture of a plate before it was applied; this plate was replaced with a new one.

Outcome

Median duration of postoperative hospitalisation was 2 days (range: 1 to 4 days). Neurological evaluation at 24 hours identified improvement in tail sensation in two dogs that had complete tail anaesthesia before surgery, and one cat that was incontinent became continent. At 6 weeks postoperatively, all animals that were non-ambulatory had regained ambulation. The cat (case III) regained normal gait by 6 weeks. Three dogs (cases I, IV and V) had evident pelvic limb lameness and ataxia with conscious proprioceptive deficits but were able to go for short walks. These cases were evaluated again at 6, 4 and 6 months, respectively. At that time, case I improved from severe to mild pelvic limb lameness and very mild proprioceptive deficits; case IV had traumatic coxofemoral luxation and presented with severe right pelvic limb lameness; and case V had improved to normal gait.

All six animals that were presented with tail anaesthesia had recovered sensation within 6 weeks. One dog (case V) had persistently dropped tail carriage. In our study, only one dog (case V) presented with urinary incontinence preoperatively. This dog became continent 24 hours postoperatively.

Complications

Complications and the associated treatments are summarised in Table 2. One minor complication was observed. Superficial incisional site infection was documented in one dog (case VI) that

Table 1. Characteristics of animals included in the report

		Signalment				Aetiology	Clinical presentation-neurologic deficits	Evaluation				Implant
Case	Sp	Breed	Gender	Age	Weight (kg)			Radiologic presentation	24 hours postoperative	6 weeks	More	
I	C	MB	F	6 years	30	HBC	Non-ambulatory paraparesis Tail anaesthesia Weak withdrawal reflex	CT – comminuted fracture of L7 with chip fragments within the spinal canal, without LS zygapophysial joints luxation	Non-ambulatory paraparesis with voluntary pelvic limb movement, some tail sensation	Ambulatory, severe rear limb lameness, marked CPD. Normal tail sensation	6 month mild pelvic limb lameness. Very mild CPD	Two 3·5 mm SOP
II	C	MB	M	11 monmths	15	HBC	Ambulatory Severe lumbar pain Tail anaesthesia	CT – comminuted fracture of L7, without luxation of LS the zygapophysial joints, chip fragments within the spinal canal	No change	Normal gait Normal tail sensation	—	Two 2·7 mm SOP
III	Fe	Himalayan	M	12 months	6·2	HRS 5th floor	Non-ambulatory paraparesis Tail anaesthesia Weak anal reflex and sensation Continence status unclear	CT – L7 compression fracture without luxation of LS the zygapophysial joints, leading to dorsal elevation of the vertebral fragment, leading to compression of the dural sac	No change, normal continence	Normal gait Normal tail sensation	—	Two 2 mm SOP
IV	C	MB	F	4 months	16	HBC	Ambulatory paraparesis Lumbar pain Tail anaesthesia	CT – L7 oblique fracture of the vertebra body and fracture of the R transverse process, LS zygapophysial joints luxation	No change Mild tail sensation and motion	Ambulatory Mild pelvic limb lameness and CPD Normal tail sensation	4 month Severe R pelvic limb lameness secondary to hip luxation	Two 2·7 mm SOP
V	C	MB	F	18 months	27	HBC	Non-ambulatory paraparesis Voluntary hind limb movement Tail anaesthesia Very weak anal reflex and sensation Incontinence	CT – oblique fracture of L7 with luxation of LS the zygapophysial joints, leading to cranioventral displacement of the sacrum, displaced fragment (and several smaller fragments) into the LS vertebral canal impinging on the dural sac (*cauda equina*)	No change normal continence	Ambulatory Mild pelvic limb lameness Marked CPD Normal tail sensation Normal anal reflex and sensation	6 month: normal gait	Two 3·5 mm SOP
VI	Fe	DSH	M	12 months	4·9	HBC	Non-ambulatory paraparesis Tail anaesthesia Weak anal reflex and sensation	CT – comminuted fracture of L7 without luxation of LS the zygapophysial joints, chip fragments within the spinal canal	No change	Ambulatory Normal tail sensation	—	Two 2 mm SOP

C Canine, CPD Conscious proprioceptive deficits, DSH Domestic shorthair, HBC Hit by car, HRS High-rise syndrome, Fe Feline, Fleur Fluoroscopy, MB Mixed breed, PO Postoperative

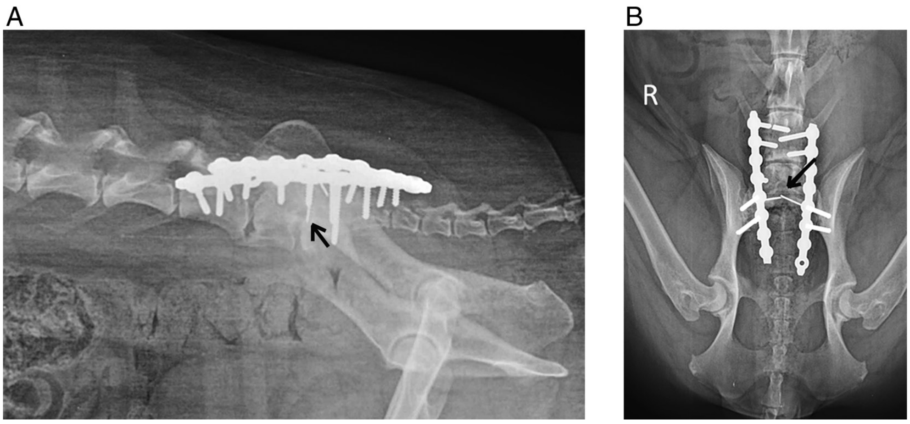

FIG 4. Long-term (8 month post-operative) radiographs of a dog, 18 months old, weighing 27 kg (case V). This lumbosacral luxation and L7 fracture (LSFL) was stabilised with two 3·5 mm twisted string-of-pearls plates. Lateral view (A) showing partial osseous union of L7 and sacrum and spondylosis of L6 to L7. In this case, the most caudal plate hole of the left plate seen in the ventro-dorsal view (B) was left unoccupied at the initial surgery because the plate was cut too long. The black arrows points to the 0·062 in. Kirschner wires that were inserted across the mutual articulating facet of L7 and sacrum to maintain temporary reduction until plates were applied. At that stage, the cranial-most right screw found to be fractured (B), but the spondylosis of L6 to L7 and the contralateral plate appears to provide enough rigidity and stabilisation

Table 2. Complications and the associated treatments

Case	Complications	Grade	Time from surgical procedure	Treatment
I	Draining tract	Major	3 months	Implants removed. Antibiotics.
II	None			
III	None			
IV	Coxofemoral luxation	Major	4 months	Open reduction and stabilisation by iliofemoral suture
V	Screw malposition	Major	Immediately	Screw repositioning by minimal surgical approach
VI	Superficial incisional site infection	Minor	7 days	Broad-spectrum antibiotics

resolved with 12·5 mg/kg broad-spectrum antibiotics (Synulox; Pfizer) twice daily for 10 days. Three major complications were observed:

1. In one dog (case V), a screw malposition was detected on the postoperative radiographs, penetrating the L5 to L6 intervertebral disc space. The dog was brought to the surgery table again, and a minimal dorsal approach was taken to modify the screw by replacing it with a 4 mm shorter screw.
2. In case I, a draining tract was noted 3 months postoperatively. Orthogonal radiographs detected implant loosening and suspected discospondylitis. All of the metallic implants were removed, bacterial culture and sensitivity was collected, and the dog was treated with 12·5 mg/kg potentiated amoxicillin (Synulox; Pfizer) twice daily and 10 mg/kg enrofloxacin (Baytril) once daily for 10 days. Culture and sensitivity results were positive for *Staphylococcus intermedius* sensitive to amoxicillin–clavulanic acid, so treatment was prolonged for an additional 20 days. The draining tract resolved after 14 days.
3. Case IV presented 4 months postoperatively with acute and severe right pelvic limb lameness. Orthogonal radiographs identified coxofemoral luxation. Although this traumatic event could have occurred independently, this major complication was considered related to LSF because this particular dog was ataxic at the time of occurrence, presumably contributing to luxation. The dog was treated by open reduction and stabilisation by iliofemoral suture.

DISCUSSION

In this retrospective study, we present an SOP plate-based technique for caudal spinal fracture stabilisation, aimed to address the vertebral instability and nerve compression that is inherent to LSFL. We found that this technique resulted in satisfactory clinical improvement in all cases treated.

The most common neurological clinical sign observed in all the LSFL animals in our study was tail anaesthesia. Recovery of this function was achieved in all animals by 6 weeks. Only one dog showed incontinence at presentation, and two dogs had impaired anal reflex and sensation. It has been suggested that intact tail base sensation predicts control of urination in cats with sacrocaudal fracture–luxation (Tatton *et al.* 2009). In the same study, only about half (10/21) of the cats did not have tail base pain sensation. The relative low case number and the participation of dogs in our study may explain the difference in prevalence of tail anaesthesia.

In fractures occurring in the more cranial part of the vertebral column, the degree of vertebral displacement is negatively correlated with the expected prognosis (Ullman & Boudrieau 1993, Bali *et al.* 2009). In our study, despite displacement or luxation of the L7 sacrum, the outcome was favourable. This may be explained by the fact that the vertebral canal is relatively large at that level and contains nerve roots of the *cauda equina* (and not spinal cord). Nerves tolerate more deformation and recover better following contusive injury than spinal cord parenchyma (Sharp & Wheeler 2005). However, recovery may be dependent on the severity of the initial lesion of the peripheral nervous system.

Twisting and bending the SOP plate to properly interface with the L6, sacrum and sacroiliac articulation was initially challenging. Because the screws must be inserted perpendicular to the SOP socket holes, the plate needs to be significantly twisted so that the holes will properly align with the L6 body on one side and the sacroiliac region on the other. This dictated twisting the plate to a cumulative twisting angle of 70° to 80°. In one case, over-twisting the SOP plate resulted in fracture of the plate before it was applied to the patient. This can be prevented by gradual twisting throughout the whole plate length (about 15° between every two plate holes). Significant twisting and bending can result in implant weakening, leading to implant failure. According to the manufacturer notes, SOP plates can be bent through 40° and remain almost (96%) as stiff as an untouched 3·5 mm dynamic compression plate (DCP) (Kraus & Ness 2007). Comparison of twisted DCP and SOP plates demonstrated diminished SOP stiffness and strength, but the contoured SOP remained at least as stiff and strong as the untouched DCP (Ness 2009). We assumed that the use of two (bilateral) plates may compensate for the diminished strength and will provide a relatively rigid construct to maintain spinal canal alignment and reduction of fracture fragments. The fact that no case of implant failure was documented in our report may support this assumption.

In this study, we used the SOP locking system as a 'buttress' system to bridge over the fractured L7 vertebra. Mechanically, it can be considered an internal/external fixator. One of the major practical disadvantages of this system is the fact that the screws must be inserted perpendicular to the SOP socket holes. In some cases, this disadvantage forces percutaneous predrilling and screw insertion (mostly in the L6 vertebra).

Intraoperative orthogonal fluoroscopic views were of great orientational aid during screw insertion. Consequently, we had a relatively low rate of postoperative screw malposition, with only one screw penetrating the L5 to L6 intervertebral disc. In contrast, studies of human spinal surgery report a high prevalence of pedicle wall violations secondary to screw malposition, ranging from 15·9 to 54·7% when intraoperative imaging was not in use (Vaccaro *et al*. 1995, Xu *et al*. 1998). However, in a more recent report of 4600 screws that were inserted under the supervision of intraoperative imaging, malpositioned screw rates decreased to only 1·5% (Suk *et al*. 2001).

The presented method may have some obvious advantages over alternative procedures. Unlike the use of pins and PMMA, plate and screws are more compact and therefore less prone to seroma formation (Weh & Kraus 2007). A transilial pin placed across the iliac wings prevents the sacrum from displacing ventrally and cranially but does not rigidly stabilise the fracture or luxation (Ullman & Boudrieau 1993), as compared with the rigid stabilisation of a locking system. Our approach also has an advantage over the Lubra dorsal plates technique because it permits decompression by dorsal laminectomy, which is not possible in the Lubra dorsal plates technique, which requires intact spinous process. Although this study shows promising results, it was not conducted in comparison with alternative methods. In addition, an obvious limitation of the current study is the lack of long-term radiological follow-up. Further studies are necessary to shed more light on the long-term healing process of LSFL cases treated with the SOP technique.

In summary, we have demonstrated that the use of twisted SOP locking plates under fluoroscopic guide is an effective treatment for LSFL with relatively few complications and a generally favourable outcome.

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Conflict of interest

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

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