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Treatment of traumatic disruption of the suspensory apparatus in Thoroughbred racehorses at risk of proximal interphalangeal joint subluxation using a locking compression-distal femur plate for double arthrodesis

David Orozco Lopez DVM[1,2] | **Jose M. Garcia-Lopez VMD, DACVS, DACVSMR[1]** | **Ryan Carpenter DVM, MS, DACVS (Large Animal)[3]** | **Jose J. Bras DVM, MS, DACVS (Large Animal)[4]** | **Dean W. Richardson DVM, DACVS[1]** | **Kyla F. Ortved DVM, PhD, DACVS (Large Animal), DACVSMR[1]**

[1]New Bolton Center, Department of Clinical Studies, University of Pennsylvania, Kennett Square, Pennsylvania, USA

[2]William R. Prichard Veterinary Medical Teaching Hospital, School of Veterinary Medicine, University of California-Davis, Davis, California, USA

[3]Southern California Equine Foundation, Arcadia, California, USA

[4]Rood and Riddle Equine Hospital, Wellington, Florida, USA

Correspondence
Kyla F. Ortved, New Bolton Center, Department of Clinical Studies, University of Pennsylvania, Kennett Square, PA 19348, USA.
Email: kortved@vet.upenn.edu

Abstract

Objective: To describe the outcome of metacarpophalangeal (MCPJ) and proximal interphalangeal joint (PIPJ) arthrodesis using a locking compression-distal femur plate (LCP-DFP) in Thoroughbred racehorses with traumatic disruption of the suspensory apparatus (TDSA) at risk of PIPJ subluxation.

Study design: Multicenter retrospective study.

Animals: Twenty-six Thoroughbred racehorses.

Methods: Records of Thoroughbred racehorses with TDSA that had undergone MCPJ and PIPJ arthrodesis using an LCP-DFP at three referral hospitals between 2020 and 2024 were reviewed for inclusion. The preoperative data collected included signalment, affected limb, and type of injury. All postoperative complications were recorded. Long-term outcomes were obtained from medical records and telephone interviews.

Results: Nine females, 14 geldings, and three intact males with TDSA were treated via double arthrodesis using an LCP-DFP. The most common postoperative complications included support limb laminitis, incisional drainage, implant

Abbreviations: CaSO4, calcium sulfate; CBS, cortical bone screw; CDET, common digital extensor tendon; DFTS, digital flexor tendon sheath; DIPJ, distal interphalangeal joint; DSL, distal sesamoidean ligaments; IVRLP, intravenous regional limb perfusion; LCP, locking compression plate; LCP-DFP, locking compression distal femur plate; LF, left frontlimbLHS, locking head screw; MC3, third metacarpus; MCPJ, metacarpophalangeal joint; MTPJ, metatarsophalangeal joint; OA, osteoarthritis; P1, proximal phalanx; P2, middle phalanx; PIPJ, proximal interphalangeal joint; PMMA, polymethylmethacrylate; PSB, proximal sesamoid bones; RF, right frontlimb; SLL, support limb laminitis; SSI, surgical site infections; TA, transarticular; TDSA, traumatic disruption of the suspensory apparatus.

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infection with osteomyelitis, and distal interphalangeal joint subluxation. No horses developed PIPJ subluxation. Twenty (76.9%) horses developed short-term complications. Thirteen (50%) horses survived long term (>6 months, range 6–32 months) and were reported to be pasture sound without receiving any analgesic or antiinflammatory medication.

Conclusion: Metacarpophalangeal and PIPJ arthrodesis using an LCP-DFP in racehorses resulted in a stable construct with no horses developing subluxation of the PIPJ joint postoperatively. Arthrodesis using an LCP-DFP was associated with a fair prognosis for pasture soundness.

Clinical significance: Application of an LCP-DFP may prevent subluxation of the PIPJ; however, the prognosis is still affected by the high prevalence of other complications and associated mortality among horses that suffer TDSA.

1 | INTRODUCTION

Catastrophic racehorse injuries require major medical interventions to save the horse's life, often causing severe loss of function and leading to euthanasia if immediate treatment is not available.[1,2] Musculoskeletal injuries are the leading cause of retirement and euthanasia among racehorses worldwide.[3–6] These injuries have been associated with 83% of Thoroughbred racehorse deaths,[3] causing understandable financial and welfare concerns within the racing industry.

Traumatic disruption of the suspensory apparatus (TDSA) can be secondary to fracture of the proximal sesamoid bones (PSBs), disruption of the distal sesamoidean ligaments (DSLs), or, less commonly, a complete tear of the body or both branches of the suspensory ligament.[1] Traumatic disruption of the suspensory apparatus has been described as the main catastrophic injury in Thoroughbred racehorses.[2,3,7–12] A number of studies have identified fracture of the proximal sesamoid bones as the most common cause of TDSA in Thoroughbred racehorses,[2,3,8–10,13–15] and its prevalence among catastrophic fractures has been reported to be up to 22%,[15] 55%,[5] 58%,[2] and 58.8%[13] in racetracks in Japan, South Africa, Hong Kong, and the United States, respectively. The most recent California Horse Racing Board Postmortem Program report identified TDSA in 46% of necropsied Thoroughbred racehorses with musculoskeletal injuries, making it the most common catastrophic injury despite a declining trend in fatalities.[16]

Horses with TDSA present with hyperextension of the metacarpophalangeal (MCPJ)/metatarsophalangeal (MTPJ) joints during weight bearing. Arthrodesis of the MCPJ/MTPJ is a salvage procedure with the long-term goal of re-establishing comfortable weight bearing and preventing overload laminitis on the contralateral limb.[1,17–19] The standard surgical approach for MCPJ/MTPJ arthrodesis includes a 10–14 hole, 4.5 or 5.5 mm broad locking compression plate (LCP) applied to the dorsal aspect of the limb along with a tension band on the palmar/plantar aspect of the joint.[17,19–21] The use of an LCP with a palmar/plantar tension band for MCPJ/MTPJ joint arthrodesis has been reported in Thoroughbred racehorses with TDSA[19] and horses with MCPJ/MTPJ osteoarthritis (OA).[21]

The DSL stabilize both the MCPJ/MTPJ and the proximal interphalangeal joint (PIPJ), preventing hyperextension. Additional PIPJ axial stabilization is provided by the scutum medium, which is located where the straight sesamoidean ligament and axial palmar pastern ligaments coalesce with the superficial digital flexor tendon prior to its insertion to the proximopalmar surface of the middle phalanx.[22,23] In racehorses with TDSA, disruption of the DSL and comminuted PSB fractures can result in instability of the PIPJ, leading to palmar/plantar subluxation of the PIPJ during the postoperative period (Figure 1).[17–19,24,25] Techniques to avoid this complication include the application of a palmar/plantar PIPJ tension band using high-tensile metal cable or more flexible high-density polyethylene.[18] Few reports describe the outcomes associated with these techniques; however, the authors' clinical experience suggests that PIPJ subluxation postoperatively is associated with a poor to grave prognosis.

The use of a human locking compression-distal femur plate (LCP-DFP) (DePuy Synthes, Warsaw, Indiana) for double arthrodesis of the MCPJ/MTPJ and PIPJ was first introduced as an alternative to transfixation pin casting in the management of severely comminuted proximal phalangeal fractures using a bridge plating technique.[26] The LCP-DFP, which has a precontoured expanded head plate, designed to be applied to the human femur with the expanded head placed distally over the lateral condyle,

FIGURE 1 Lateromedial radiograph of a metacarpophalangeal joint arthrodesis with a 10-hole locking compression plate and 5.5 mm transarticular screws. A tension band was created with a figure-of-eight 1.7 mm stainless steel cable. Note the subluxation of the proximal interphalangeal joint characterized by palmar displacement of the distal end of the proximal phalanx.

was approved for use in equine patients in 2019. Left and right bent plates are available and are compatible with the 4.5−5.0 mm LCP systems. The expanded head contains seven threaded locking holes (stacked holes), which accept 5.0 mm locking head screws (LHS) and 4.5−5.5 mm cortex screws. The plate is available with 5, 7, 9, 11, or 13 combi-holes in the shaft, which accept 4.5−5.5 mm cortex screws and 5.0 mm locking head screws.[27] The use of an LCP-DFP for double arthrodesis of the MCPJ/MTPJ and PIPJ has been recently used following TDSA in racehorses with disruption of the DSL or comminuted medial and lateral PSB fractures to preemptively stabilize the PIPJ, thus preventing PIPJ subluxation. As far as the authors are aware, arthrodesis of the MCPJ/MTPJ and PIPJ joint using an LCP-DFP has not previously been evaluated clinically in racehorses with TDSA.

The objectives of this study were therefore to describe the surgical technique and report the short- and long-term outcomes of Thoroughbred racehorses with TDSA that were treated with arthrodesis using an LCP-DFP. We hypothesized that racehorses with TDSA due to disruption of the DSL or comminuted medial and lateral PSB fractures that were treated using an LCP-DFP would not develop subluxation of the PIPJ and that this treatment would provide a reasonable prognosis for unrestricted pasture activity for a broodmare, stallion, or valued retiree.

2 | MATERIALS AND METHODS

2.1 | Case selection

Medical records were reviewed for Thoroughbred racehorses that had TDSA due to DSL disruption or comminuted medial and lateral PSB fractures and underwent MCPJ/MTPJ and PIPJ arthrodesis using an LCP-DFP between 2020 and 2024 at three equine referral hospitals (Hospital 1 = New Bolton Center, University of Pennsylvania; Hospital 2 = Southern California Equine Foundation; Hospital 3 = Rood and Riddle Equine Hospital in Wellington, Florida). Preoperative, surgical, and postoperative data were retrieved.

Preoperative data included age, sex, breed, weight, affected limb, type of injury, method of limb stabilization between injury and surgery, and time to surgery. Surgical data included anesthesia and surgery time, implants used, locoregional antibiotic therapy, intraoperative complications, and anesthetic recovery. Postoperative data included analgesic and antibiotic protocols, cast management, contralateral hoof support, and postoperative complications. Short- and long-term outcomes were obtained from medical records and phone interviews.

2.2 | Surgical technique

Horses were placed under general anesthesia and positioned in lateral recumbency with the affected limb elevated. The limbs were clipped and aseptically prepared from the coronary band to the carpus and draped routinely, isolating the limb from the coronary band to the proximal metacarpus. Arthrodesis of the MCPJ was performed routinely with additional modifications.[21]

A longitudinal incision was made over the dorsal aspect of the affected limb extending from the proximal third of the metacarpus to the coronary band. The incision was extended down to the periosteum through the common digital extensor tendon (CDET), splitting it longitudinally. Following transection of the MCPJ capsule, the lateral and medial collateral ligaments of the MCPJ were sharply elevated from the surface of the distal third metacarpus (MC3) and proximal phalanx (P1), allowing disarticulation of the joint. At Hospital 2, the lateral collateral ligament of the MCPJ was transected to expose the joint, and the proximal dorsal aspect of P1 was chiseled to provide a better bone-plate interface.

The articular cartilage was removed using an oscillating saw (18–22 mm) in a paintbrush manner. Shallow (approximately 1 mm) sagittal and transverse cuts were then made with the oscillating saw to aid in subsequent placement of the 2.5 or 3.2 mm drill bit used to perform subchondral bone forage (2–3 mm deep) in a grid pattern on the articular surfaces of MC3 and P1.

2.3 | Palmar MCPJ tension band application

A 4.0 mm hole was drilled in the dorsal plane and parallel to the joint surface through the diaphysis of MC3 and P1 approximately 8–10 cm proximal and approximately 4 cm distal to the joint, respectively. A 1.7 mm stainless steel cable (DePuy Synthes) was passed from lateral to medial through the hole in MC3 and retrieved and directed toward the palmar joint surface. A wire passer was passed proximomedially from lateral P1 through a 1 cm incision just palmar to the sagittal groove of P1. The cable was passed through the wire passer, retrieved on lateral P1, and then passed from lateral to medial through the drilled hole in P1. The wire passer was then passed distomedially through the incision palmar to the sagittal groove, and the free end of the cable was retrieved and brought to the lateral aspect of distal MC3, where it was placed through the crimp. While maintaining the MCPJ in slight dorsiflexion (approximately 5–10°), the crimp was compressed with the aid of a crimping tool (DePuy Synthes). Depending on the surgeons' preference, a cable tensioner device (DePuy Synthes) was utilized in some cases with 40 kg of tension applied.

2.4 | Proximal interphalangeal joint

In all but one horse, the articular cartilage of the PIPJ was debrided using a 4 mm drill bit passed across the joint from lateral to medial and dorsal to palmar. In some horses, one or two 5.5 mm transarticular cortex screws were placed in lag fashion across the PIPJ from distodorsal P1 to the proximopalmar aspect of the middle phalanx (P2). The screws were placed abaxially to ensure that adequate room remained to accommodate the expanded head of the plate. At hospital 2, the LCP-DFP was placed prior to the PIPJ transarticular screws.

2.5 | Plate application

Following tension band placement, a 9-, 11-, or 13-hole left or right 4.5 mm LCP-DFP was placed on the dorsal midline of MC3, P1, and P2 with the plate contoured to approximately a 195° angle over the MCPJ. The expanded head of the LCP-DFP was positioned under the CDET at the dorsoproximal aspect of P2. The three most distal holes of the expanded head were filled with 5.0 mm LHS placed into proximal P2 just distal to the PIPJ. Next, a 5.5 mm cortical bone screw was placed in load in one of the screw holes in P1, providing axial compression of the PIPJ and compressing the plate to the surface of P1. The remainder of the holes over P1 were filled with 5.0 mm LHS.

Next, an articulated tension device (DePuy Synthes) was applied to the proximal end of the plate and fixed to MC3 using a unicortical 4.5 mm cortical bone screw. Following maximal tightening of the tension device, a 5.5 mm cortical screw was inserted through the second, third or fourth most proximal plate hole in load position. Most cases had a second 5.5 mm plate screw inserted and tightened prior to tension device removal. The rest of the plate holes were filled with 5.0 mm LHS (Figure 2). All plate screws were bicortical. Two additional 5.5 mm cortical screws were then placed in lag fashion from distodorsal to proximopalmar across the MCPJ. In some horses, the lateral PSB was incorporated using a 5.5 mm cortical screw in lag fashion through MC3. Intraoperative fluoroscopic or radiographic imaging guidance was used throughout the procedure.

The incision was closed routinely in three or four layers, and an antibiotic intravenous regional limb perfusion (IVRLP) was performed prior to placing a half-limb fiberglass cast in a neutral/weight-bearing position on all surgically treated limbs. Patients were assisted during anesthesia recovery via head and tail ropes or via a pool-raft recovery system. Radiographs of the affected limb were obtained postoperatively and when re-evaluations were warranted based on clinicians' preference and case progression (Figure 3).

2.6 | Outcome

Short- and long-term complications were recorded. Short-term success was defined as survival to discharge. A successful long-term outcome was defined as the horse being alive and pasture sound 6 months after surgery

FIGURE 2 An 11-hole locking compression-distal femur plate affixed to the dorsal surface of the third metacarpus, proximal, and middle phalanx.

without receiving any anti-inflammatory or analgesic medication. Long-term follow up was made via telephone interviews with owners.

2.7 | Statistical analysis

Descriptive statistics were performed in GraphPad Prism software v10.1.1 (San Diego, California). Continuous data was evaluated for normality using the Shapiro–Wilk test. Normally distributed data was presented as mean ± standard deviation (SD), and data that did not follow a normal distribution was presented as median and range.

3 | RESULTS

3.1 | Patient demographics

Twenty-six Thoroughbred racehorses with TDSA were included in the study (Table 1). There were nine females, 14 geldings, and three intact males with a median age of 4 years (range, 2–7 years) and a median weight of 499 kg (range, 450–590 kg). Radiographic confirmation of TDSA was obtained in all patients, characterized by comminuted medial and lateral PSB fracture ($n = 16$), rupture of DSL ($n = 7$), comminuted medial PSB fracture and midbody lateral PSB fracture ($n = 2$), rupture of DSL and comminuted fracture of the medial PSB ($n = 1$). No additional imaging was performed to assess the palmar soft tissues or digital blood flow in any horse. All injuries were closed, and limbs were stabilized immediately after injury using a Kimzey Leg Saver Splint (Kimzey Inc., Woodland, California). Upon initial physical examination, all horses were presented with severe lameness of the affected limb. The median time between injury and surgical treatment was 48 h (range, 6–96 h).

3.2 | Surgical treatment

At Hospital 1, once anesthetized, a high four-point nerve block was performed using 20 mL of bupivacaine 0.5% and 0.4 mL of dexmedetomine 0.05% in the affected limb in all horses. No nerve blocks were performed at hospitals 2 and 3. Arthrodeses were performed using a nine-hole ($n = 16$), 10-hole ($n = 1$), 11-hole ($n = 6$), or a 13-hole ($n = 3$) LCP-DFP. In all cases, a 1.7 mm stainless steel cable was used as a palmar MCPJ tension band. The lateral PSB was incorporated via a single transarticular screw from MC3 into the basilar fragment of the lateral PSB in four horses. Transarticular screws from P1 to MC3 were applied in all horses. Among these, two and three 5.5 mm screws were used in 18 and eight horses, respectively. Transarticular screws across the PIPJ were used in only 14 horses; two screws were placed in 12 horses and one screw was placed in two horses.

At Hospital 1, amikacin-impregnated polymethylmethacrylate (PMMA) (20 g polymer powder/10 mL monomer liquid/2.5 g amikacin) and amikacin-impregnated calcium sulfate ($CaSO_4$) beads (Kerrier, West Palm Beach, Florida) were placed around the plate in five and one horses, respectively. At Hospital 2, an antimicrobial-infused solution (cefazolin 1 g in 1 L of sterile saline) was used to lavage the surgical site throughout the procedure. At Hospital 3, all horses had amikacin-impregnated $CaSO_4$ beads placed around the plate. Intraoperative IVRLP was performed in all horses (2–3 g amikacin diluted to 20 ml with 0.9% saline, $n = 19$; 500 mg meropenem diluted to 60 ml with 0.9% saline, $n = 7$). A half-limb cast was placed on all treated limbs. Median surgery and anesthesia times were 155 (range, 110–285 min) and 200 min (range, 150–353 min), respectively. Anesthetic recovery was assisted with head and tail ropes in 25 horses and via a pool-raft system in one horse.

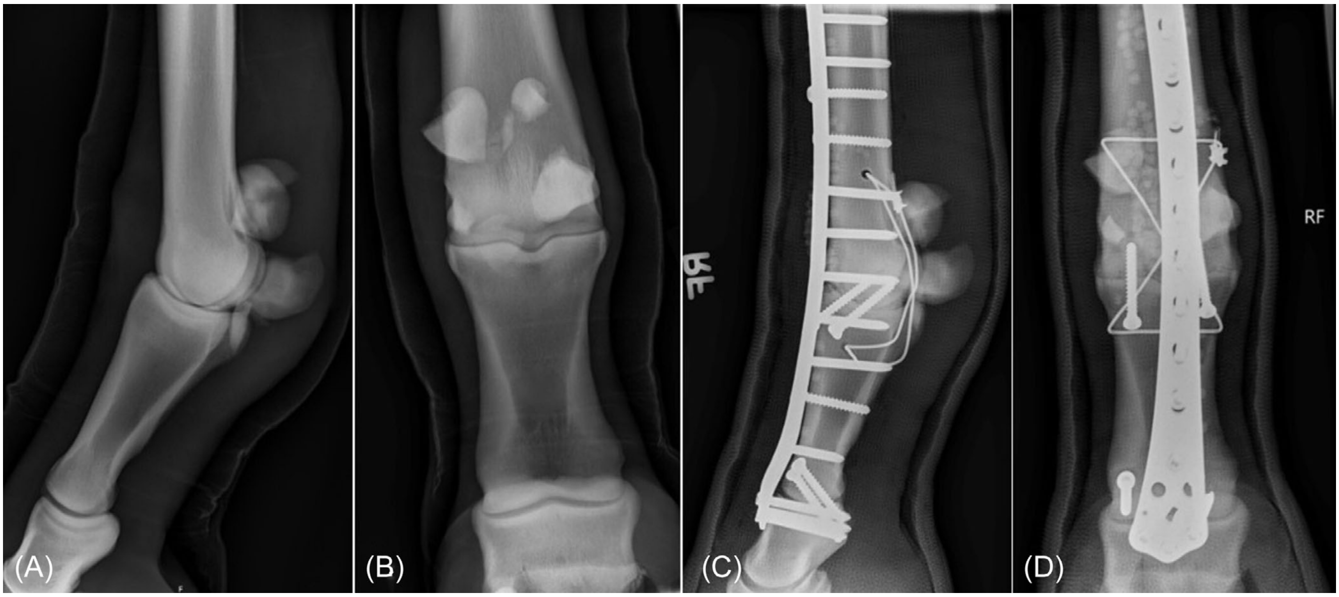

FIGURE 3 Preoperative lateromedial (A) and dorsopalmar (B) radiographs of a horse with traumatic disruption of the suspensory apparatus characterized by comminuted medial and lateral proximal sesamoid bone fractures. Postoperative lateromedial (C) and dorsopalmar (D) radiographs of the same horse following metacarpophalangeal and proximal interphalangeal joint arthrodesis via an 11-hole locking compression-distal femur plate and 5.5 mm transarticular screws in the metacarpophalangeal and proximal interphalangeal joints. A palmar tension band is created with a 1.7 mm cable.

3.3 | Postoperative management

Postoperative management varied depending on the case and the surgeons' preferences. Perioperative systemic antibiotics included penicillin (22 000 IU/kg; potassium penicillin G IV four times daily, or procaine penicillin G IM twice daily for 3–16 days) and gentamicin (6.6–8.8 mg/kg IV once daily for 3–11 days) or enrofloxacin (5 mg/kg IV once daily for 5–29 days) in all horses. Nineteen horses were transitioned to oral antibiotics, including minocycline (4 mg/kg orally, twice daily for 8–19 days; $n = 5$), doxycycline (10 mg/kg orally twice daily for 10–15 days; $n = 10$), chloramphenicol (50 mg/kg orally, four times daily for 21 days; $n = 2$) or trimethoprim sulfamethoxazole (30 mg/kg orally, twice daily for 10–13 days; $n = 2$). Two horses treated with minocycline and one treated with trimethoprim sulfamethoxazole were transitioned to chloramphenicol (50 mg/kg orally, four times daily for 27–29 days). Antibiotic therapy was transitioned empirically in most cases, regardless of signs of surgical site infection, with culture and antibiotic susceptibility testing conducted in only five horses (Table 2).

Serial IVRLP was administered in all horses. Six horses received amikacin (2.5 g amikacin diluted to 20 mL with 0.9% saline) once daily for 3 to 6 days. Thirteen horses received amikacin (3 g amikacin diluted to 60 mL with 0.9% saline) once daily for 3 days, followed by 3 more treatments every 48 h. Seven horses received meropenem (500 mg meropenem diluted to 60 mL with 0.9% saline) once daily for 1 to 8 days; four of these horses were transitioned to amikacin (2.5 g amikacin diluted to 60 mL with 0.9% saline) for an additional 3 to 11 days. Anti-inflammatories including phenylbutazone (2.2–4.4 mg/kg IV or orally, daily to twice daily) or flunixin meglumine (1.1 mg/kg IV twice daily) were administered throughout hospitalization and the dose was tapered based on patients' comfort. Additional analgesic medications included morphine (0.1 mg/kg IM daily for 1–2 days; $n = 2$), pregabalin (4 mg/kg orally, twice daily for 31 days; $n = 1$), gabapentin (10 mg/kg orally, twice daily for 14 days; $n = 1$), butorphanol (0.015 mg/kg/h. IV, constant rate infusion for 1 day; $n = 3$), lidocaine (0.05 mg/kg/min IV constant rate infusion for 3–8 days; $n = 6$), and fentanyl (200–300 μg/h transdermally for 3 days; $n = 2$). All horses received omeprazole (1–4 mg/kg orally, daily) throughout hospitalization. Three horses received enoxaparin (0.5 mg/kg subcutaneously, daily) for 3–4 days; among these, two horses also received clopidogrel (4 mg/kg orally once, then 2 mg/kg orally, daily) for 3–4 days. Six additional horses received only clopidogrel (2 mg/kg orally, daily) for 1–16 days.

The contralateral foot was kept in an orthotic boot (Soft Ride Boots, Bacliff, Texas; $n = 17$) or had a cast-on orthotic shoe (SoftRider, Soft Ride Boots; $n = 2$) or cuffed shoe (Nanric Ultimate, Lawrenceburg, Kentucky; $n = 7$) throughout hospitalization. Following cast removal

TABLE 1 Summary of clinical attributes, implants used, and outcome for horses with traumatic disruption of the suspensory apparatus undergoing metacarpophalangeal and proximal interphalangeal joint arthrodesis with a locking compression-distal femur plate (LCP-DFP).

Horse	Limb	Injury	Time between injury and surgery (h)	LCP-DFP length	# PIPJ TA 5.5 mm CBS	Surgery time (min)	Cast duration (days)	Outcome
1	RF	DSL rupture	24	9 hole	0	160	14	Excellent[a]
2	RF	DSL rupture	6	9 hole	0	225	10	Euthanized
3	LF	DSL rupture, comminuted fracture medial PSB	48	9 hole	0	180	15	Excellent[a]
4	LF	Comminuted medial and lateral PSB fracture	24	11 hole	2	130	10	Euthanized
5	RF	Comminuted medial and lateral PSB fracture	48	11 hole	2	235	15	Excellent[a]
6	LF	Comminuted medial PSB fracture, midbody lateral PSB fracture	24	9 hole	2	190	9	Euthanized
7	RF	DSL rupture	24	11 hole	0	165	15	Euthanized
8	RF	DSL rupture	48	11 hole	0	130	6	Excellent[a]
9	LF	Comminuted medial and lateral PSB fracture	72	9 hole	0	120	5	Excellent[a]
10	RF	Comminuted medial and lateral PSB fracture	72	9 hole	0	150	7	Excellent[a]
11	LF	Comminuted medial and lateral PSB fracture	48	9 hole	0	140	9	Excellent[a]
12	RF	Comminuted medial PSB fracture, midbody lateral PSB fracture	48	9 hole	2	150	10	Excellent[a]
13	LF	Comminuted medial and lateral PSB fracture	48	9 hole	2	120	7	Euthanized
14	LF	Comminuted medial and lateral PSB fracture	48	9 hole	2	135	5	Euthanized
15	LF	Comminuted medial and lateral PSB fracture	24	9 hole	2	140	1	Euthanized
16	LF	Comminuted medial and lateral PSB fracture	24	9 hole	1	120	7	Euthanized
17	LF	Comminuted medial and lateral PSB fracture	48	9 hole	2	110	7	Excellent
18	RF	Comminuted medial and lateral PSB fracture	48	9 hole	2	130	7	Euthanized
19	LF	Comminuted medial and lateral PSB fracture	24	9 hole	2	120	6	Excellent[a]
20	LF	DSL rupture	96	11 hole	0	223	4	Euthanized
21	LF	DSL rupture	48	13 hole	0	245	12	Excellent[a,b]
22	LF	Comminuted medial and lateral PSB fracture	48	11 hole	0	285	15	Excellent[a,b]
23	RF	DSL rupture	48	13 hole	0	222	12	Euthanized
24	RF	Comminuted medial and lateral PSB fracture	48	13 hole	2	273	12	Euthanized
25	RF	Comminuted medial and lateral PSB fracture	12	10 hole	1	273	17	Euthanized

(Continues)

TABLE 1 (Continued)

Horse	Limb	Injury	Time between injury and surgery (h)	LCP-DFP length	# PIPJ TA 5.5 mm CBS	Surgery time (min)	Cast duration (days)	Outcome
26	LF	Comminuted medial and lateral PSB fracture	48	9 hole	2	273	5	Euthanized

Abbreviations: CBS, cortical bone screw; DSL, distal sesamoidean ligaments; LF, left front limb; PIPJ, proximal interphalangeal joint; PSB, proximal sesamoid bone; RF, right front limb; TA, transarticular.
[a]Unrestricted pasture exercise.
[b]Tack walking.

(mean 9 ± 4.2 days), the affected limb was placed in an orthotic boot (Soft Ride Boots; $n = 19$) or a cuffed shoe (Nanric; $n = 7$). Four horses had a bandage cast placed following cast removal for 7 to 15 days, and the rest of the horses had a modified Robert Jones bandage for the entirety of hospitalization.

3.4 | Short-term outcome

Fourteen (53.8%) of 26 horses with TDSA treated with LCP-DFP MCPJ arthrodesis were discharged from the hospital with a median time to discharge of 30 days (range 14–230 days). Short-term complications were reported in 20 horses (76.9%) (Table 3) and included support limb laminitis (SLL) ($n = 7$), incisional drainage ($n = 7$), implant infection with osteomyelitis ($n = 5$), distal interphalangeal joint (DIPJ) subluxation ($n = 3$), avascular hoof necrosis of the affected limb ($n = 3$), incision dehiscence ($n = 2$), fever (temperature ≥ 38.5°C; $n = 3$), facial nerve paralysis ($n = 1$), large colon impaction ($n = 1$), left dorsal displacement of the large colon ($n = 1$), cecal rupture ($n = 1$), antibiotic-induced colitis ($n = 3$), digital flexor tendon sheath septic tenosynovitis ($n = 1$), segmental small intestinal infarct and septic peritonitis ($n = 1$), and acute kidney injury ($n = 1$). No horses developed subluxation of their PIPJ postoperatively. Implant removal was performed at days 53 and 65 postoperatively in two horses with implant infection and osteomyelitis.

Of the 20 horses with short-term complications, eight (40%) recovered uneventfully and 12 (60%) were euthanized at a median of 22 days (range, 5–115 days) after surgery.

3.5 | Long-term outcome

Long-term follow up was available for all horses that survived to discharge. One horse sustained a proximal MC3 fracture of the affected limb after getting cast in a stall 5 months after surgery. Thirteen horses (50%) survived long term (> 180 days; median 759 days, range 180–880 days) and were reported to be pasture sound without receiving any analgesic or anti-inflammatory medication. At the time of writing, an additional horse was euthanized 15 months after surgery due to severe hind limb lameness secondary to PIPJ osteoarthritis. Serial follow up radiographs of the affected limb yielded progressive bone bridging of the MCPJ in all horses at 169 days postoperatively (median, range 56–430), whereas bone bridging of the PIPJ was noted on five horses at 224 days (median, range 72–430) (Figure 4). All horses developed some degree of PIPJ osteoarthritis and proliferative new bone formation associated with the dorsal aspect of the PIPJ (Figure 5).

4 | DISCUSSION

This case series describes an alternative surgical technique and clinical outcome for arthrodesis of the MCPJ and PIPJ in Thoroughbred racehorses with TDSA presumed to be at risk of PIPJ subluxation due to their injury. Loss of DSL support associated with rupture of the DSL or comminuted medial and lateral PSB fractures has been associated with future subluxation of the PIPJ following arthrodesis of the MCPJ.[19,24] As hypothesized, horses treated with double arthrodesis using an LCP-DFP did not develop subluxation of the PIPJ; however, the prognosis for pasture soundness was still affected by the high prevalence of complications and mortality among horses that suffer TDSA.

The overall short-term and long-term success rates were 58.3% (14/26) and 50% (13/26). Among the 13 horses that survived long term, one was euthanized for causes unrelated to the surgical procedure 15 months after surgery. At the time of writing, only 46.15% (12/26) of the horses were alive and reported to be pasture sound without receiving any analgesic or anti-inflammatory medications. Similar reports of horses treated with MCPJ arthrodesis have described successful outcomes of 51.16% (22/43)[28] and 67% (4/6)[19] of horses. Conversely, a study with 17 horses with OA of the MCPJ/MTPJ treated with arthrodesis using an LCP and a tension band reported a

TABLE 2 Results of bacterial culture and antibiotic susceptibility and case management in patients with surgical site infection.

Horse	Isolates identified	Antibiotic susceptibility	Antibiotic resistance	Prophylactic IVRLP	Systemic antibiotic treatment
2	*Staphylococcus aureus* ssp *aureus*	Amikacin, azithromycin, ceftiofur, chloramphenicol, imipenem, trimethoprim/ sulfamethoxazole	Ceftiofur, gentamicin, tetracycline	Amikacin	Potassium penicillin, gentamicin; minocycline
6	*Streptococcus equi* ssp *zooepidermicus*	Ampicillin, azithromycin, ceftiofur, chloramphenicol, erythromycin, penicillin, imipenem	Amikacin	Amikacin	Potassium penicillin, gentamicin; minocycline; chloramphenicol
24	*Proteus mirabilis*	Amikacin, ceftiofur	Ampicillin, chloramphenicol, doxycycline, enrofloxacin, gentamicin, tetracycline, trimethoprim/ sulfamethoxazole	Meropenem	Potassium penicillin, enrofloxacin; chloramphenicol
	Escherichia coli	Amikacin	Ampicillin, ceftiofur, chloramphenicol, doxycycline, enrofloxacin, gentamicin, tetracycline, trimethoprim/ sulfamethoxazole		
25	*Staphylococcus epidermidis*	Amikacin	Ampicillin, ceftiofur, chloramphenicol, enrofloxacin, erythromycin, gentamicin, imipenem, trimethoprim/ sulfamethoxazole	Meropenem	Potassium penicillin, enrofloxacin; amikacin; sulfadiazine/ trimethoprim; chloramphenicol; doxycycline.
26	No growth	N/A	N/A	Meropenem	Potassium penicillin; enrofloxacin

Abbreviations: IVRLP, intravenous regional limb perfusion; N/A, not applicable.

success rate of 100%.[21] This marked difference in prognosis is thought to be associated with the severe vascular and structural damage that occurs in horses with TDSA, which likely increases the risk of postoperative complications.

There is no consensus on which horses are at greater risk for developing PIPJ subluxation after MCPJ arthrodesis. Horses selected for this procedure had disrupted DSL or comminuted fractures of the PSBs, and their incorporation into the construct to restore palmar support was not possible. Although no soft tissue imaging was performed preoperatively to assess the palmar soft tissues of the PIPJ, proximal migration of the PSBs noted on radiographs confirm disruption of DSL support. It is unclear how accurate ultrasonographic examination would be in a non-weight-bearing horse with TDSA, particularly given the presence of extensive tissue swelling and edema. Nonetheless, the authors agree that ultrasonographic imaging could be valuable.

Plate length was chosen at the surgeon's discretion, with the shorter nine-hole plate being preferred. This was due to the difficulty of achieving proper alignment with longer plates, the premade curved shaft of the LCP-DFP could cause the proximal end of the plate to misalign from the MC3 axis. Similar to previous reports, the plate was contoured to an approximate 195° angle over the MCPJ,[19,21] although some joints were fixed at an angle less than 195°. Anecdotally, a straight MCPJ following arthrodesis could increase mechanical stress through the PIPJ, potentially raising the risk of subluxation. This complication was avoided with the present double arthrodesis technique but constructs that result in a straighter MCPJ and PIPJ could theoretically increase mechanical stress on the DIPJ, thereby increasing the risk of subluxation of this joint.

The prevalence of surgical site infections (SSI) in horses undergoing MCPJ/MTPJ arthrodesis for the

TABLE 3 Distribution of short-term complications and outcome for 20 horses treated with metacarpophalangeal and proximal interphalangeal joint arthrodesis using a locking compression distal femur plate.

Horse	Short-term complications	Outcome	Survival after surgery (days)
1	Incisional drainage	Discharged	...
2	Incisional drainage, implant infection, osteomyelitis proximal P1—distal MC3	Euthanized	55
4	Incisional drainage, support limb laminitis, implant infection, osteomyelitis distal P1—proximal P2 (implant removed 54 days after surgery), peritonitis	Euthanized	55
5	Fever	Discharged	...
6	Incision drainage, incision dehiscence, fever, support limb laminitis, DFTS septic tenosynovitis, antibiotic induced colitis, avascular hoof injury (affected limb)	Euthanized	40
7	DIPJ subluxation (affected limb), facial nerve paralysis	Discharged	455
9	Fever, incisional drainage	Discharged	...
11	Support limb laminitis	Discharged	...
13	Support limb laminitis, antibiotic induced colitis, DIP joint subluxation (affected limb)	Euthanized	25
14	Incisional drainage, incision dehiscence, DIPJ subluxation (affected limb), avascular hoof injury (affected limb)	Euthanized	19
15	Avascular hoof injury (affected limb)	Euthanized	7
16	Support limb laminitis	Discharged	146
17	Left colon impaction	Discharged	...
18	Antibiotic induced colitis, acute kidney injury	Euthanized	7
19	Incisional drainage	Discharged	...
20	Cecal rupture	Euthanized	4
23	Incision drainage, left colon displacement, repeated colic following celiotomy	Euthanized	18
24	Support limb laminitis, implant infection, osteomyelitis distal P1—proximal P2	Euthanized	90
25	Implant infection, osteomyelitis P1—proximal P2 (implant removed 65 days after surgery)	Euthanized	115
26	Support limb laminitis, implant infection, osteomyelitis P1—proximal P2	Euthanized	92

Abbreviations: DFTS, digital flexor tendon sheath; DIPJ, distal interphalangeal joint; ..., alive at the time of writing.

treatment of TDSA has been reported to be as high as 50%.[25] In contrast, when a similar surgical technique was applied for the treatment of MCPJ/MTPJ OA, no incisional or implant infections were described.[21] The proportion of horses that developed SSI in this case series was similar to previous long bone fracture repair and arthrodeses in horses reports, ranging from 14.2% to 32%.[20,29,30] SSI in horses with TDSA has been associated with the vascular damage that occurs during hyperextension of the digit, severe soft tissue trauma, and swelling, osseous fragmentation of fractured PSB, and external trauma from the MCPJ/MTPJ collapsing onto the racing surface as the horse gallops.[18] These factors can result in poor distal limb perfusion, impairing local defense mechanisms and compromising the achievement of therapeutic antimicrobial levels via regional limb perfusions.[31] All horses with implant infection and osteomyelitis were euthanized. Deep SSI can impair healing and lead to progressive instability of the repair, which not only affects the functional and cosmetic outcome of the affected limb but also results in intractable pain, increasing the risk of developing SLL, and ultimately euthanasia.[29]

Surgery time, which ranged from 110 to 285 min, likely also plays a role in the prevalence of SSI in horses with TDSA. Ahern et al. reported that surgical times greater than 180 min significantly increased the infection rate in orthopedic procedures.[29] A more recent study did not find longer surgical time to be associated with increased SSI in equine patients undergoing orthopedic procedures using metallic implants, although the mean surgical time was only 120 min.[30] Using an LCP-DFP for a double arthrodesis requires more extensive soft tissue dissection and placement of additional screws, which can be more time consuming than MCPJ arthrodesis alone. While a more minimally invasive approach might reduce

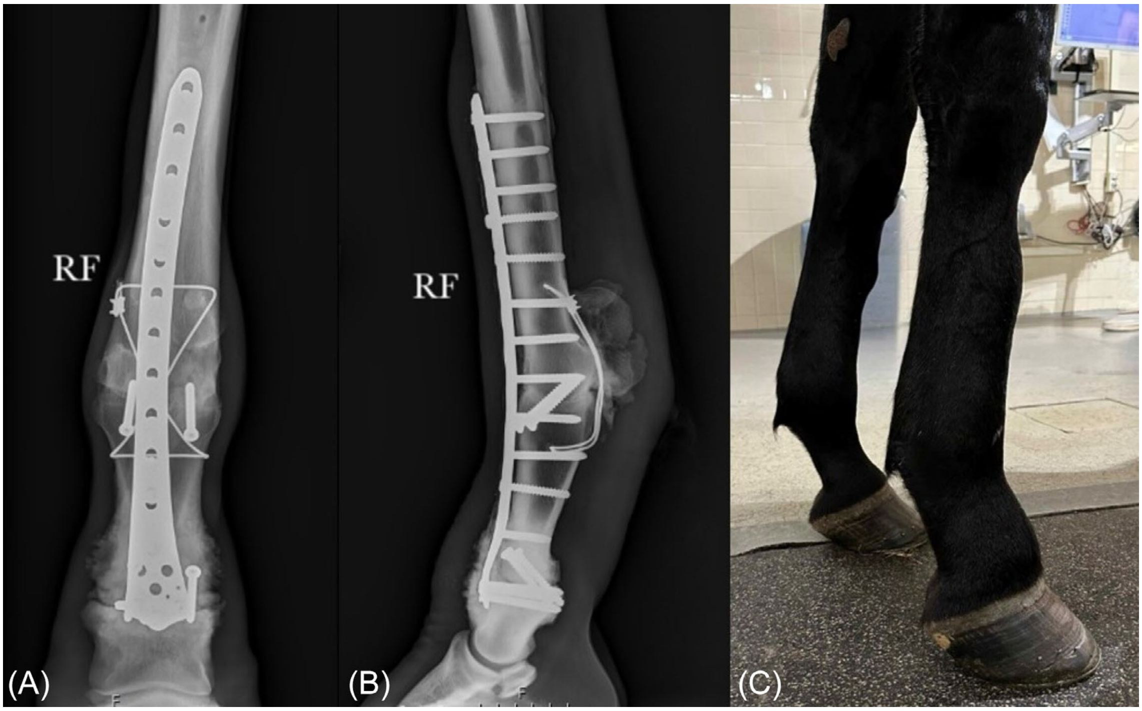

FIGURE 4 Dorsopalmar (A) and lateromedial (B) 3 year postoperative follow-up radiographs in a Thoroughbred racehorse that suffered comminuted medial and lateral PSB fractures in the right front limb. Metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joint arthrodeses were performed with an 11-hole locking compression-distal femur plate, 5.5 mm transarticular MCP and PIP joints, screws, and a palmar 1.7 mm cable tension band. (C) Appearance of the surgically treated limb on the same horse.

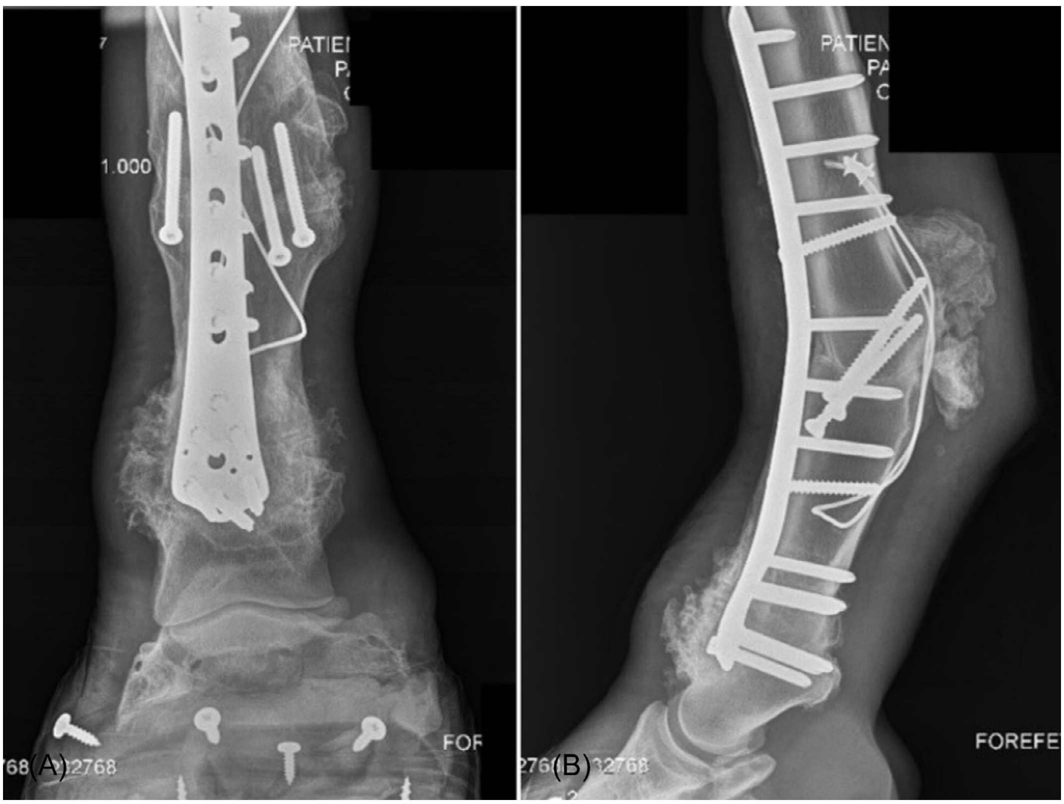

FIGURE 5 Dorsopalmar (A) and lateromedial (B) follow-up radiographs 3 months postoperatively in a Thoroughbred racehorse with traumatic disruption of the suspensory apparatus (TDSA) treated with a nine-hole locking compression-distal femur plate, 5.5 mm transarticular metacarpophalangeal screws, and a palmar 1.7 mm cable tension band. No transarticular proximal interphalangeal (PIP) screws were placed; note the marked proliferative exostosis around the proximal interphalangeal joint.

surgical site contamination and postoperative infection, the length, angle, and expanded head of the plate make minimally invasive approaches more difficult. Moreover, the cartilage debridement of the MCPJ would be decreased substantially using a minimally invasive approach.[32] Adequate preoperative planning and surgeon experience may aid in reducing surgical time.

Support limb laminitis has been described as the most serious complication associated with MCPJ arthrodesis in horses with TDSA.[20,28,30] The proportion of horses that developed SLL (26.9%) was lower than that previously reported (50%).[25] Although SLL was initially thought to be associated with mechanical overload of the support limb, recent research indicates that SLL is initiated by reduced lamellar blood flow due to the lack of normal cyclic loading of the foot.[33,34] Even with successful surgical repair of the limb with TDSA, horses can experience reduced cyclic loading of the contralateral foot due to persistent pain, surgical site infections, and vascular or reperfusion injuries. It should also be noted that 11.5% (3/26) of horses in this study developed laminitis of the affected limb, presumed to be secondary to vascular injury. Avascularity of the affected limb has been associated with injury of the digital arteries secondary to hyperextension of the digit, resulting in immediate avascular necrosis or transient avascularity, which can lead to reperfusion injury to the foot following injury.[24]

In a comparable case series involving Thoroughbred racehorses with TDSA that underwent a MCPJ arthrodesis using an LCP, 33.3% (2/6) horses were euthanized due to PIPJ subluxation.[19] Proximal interphalangeal joint subluxation results from the structural loss associated with the disruption of the suspensory apparatus, particularly when the distal sesamoidean ligaments are no longer able to provide support to the middle scutum and the PIPJ joint.[18,24] Although no horse in the present study developed PIPJ subluxation, three horses did develop DIPJ subluxation and were euthanized. As far as the authors are aware, this complication has not yet been reported following MCPJ or PIPJ arthrodesis. Anecdotally, racehorses that suffer TDSA may present partial or complete rupture of the DDFT associated with the traumatic event (Ortved, personal communication, October 26, 2024). Soft tissue evaluation of the palmar structures was not performed at the time of injury nor was there a postmortem in any of the cases; it is therefore possible that these horses had traumatic injury of the deep digital flexor tendon associated with the original injury leading to subluxation of the DIPJ.

All horses developed extensive proliferative new bone formation over the dorsal aspect of the PIPJ joint and delayed bone bridging of the PIPJ when compared to the MCPJ. Interestingly, all horses demonstrated radiographic evidence of concurrent bony fusion of the MCPJ along with limited periarticular new bone formation at 169 days postoperatively (median, range 56–430). This finding suggests that the articular cartilage debridement and stability of the construct in the MCPJ was effective at facilitating rapid fusion of the joint with limited periarticular new bone formation. In contrast, observations in the PIPJ suggest a potential lack of stability and/or slow bony fusion due to the limited ability to remove articular cartilage via a minimally invasive approach, which led to insufficient bone contact and inadequate compression across the joint.[35,36] Proximal interphalangeal joint transarticular screws were not placed in horses treated early in this case series in any of the hospitals, and horses were noted to develop large amounts of proliferative new bone over the PIPJ. Following this cohort of horses, transarticular screws were added to the PIPJ in an attempt to increase postoperative stability. Transarticular screws placed in lag fashion in addition to a plate affixed over the joint for PIPJ arthrodesis have been shown to be associated with less proliferative bone formation compared to using lag-fashion transarticular screws alone, supporting the efficacy of stronger constructs for arthrodeses.[36] Despite the addition of transarticular screws, PIPJ proliferative new bone continued to be a postoperative finding, which could be associated with a lack of adequate cartilage debridement. Although joint fusion without cartilage debridement has been reported in other species,[37,38] a pilot study that compared two PIPJ arthrodesis techniques in horses demonstrated that stabilization with an LCP with no cartilage debridement resulted in no bone fusion after 4 months.[35] Further, the specific amount of articular cartilage required to be debrided for rapid and functional bone fusion in the distal limb has not been defined. Reports have recommended removing at least 60% of the joint surface for effective arthrodesis of the distal tarsal joints,[39–43] but transarticular drilling of the PIPJ cartilage has achieved varying degrees of cartilage removal, ranging from 24% to 45%.[44] Given our findings, it is possible that more intensive drilling of the articular surface or possibly open debridement of the PIPJ will be necessary to limit the apparent delayed fusion of the PIPJ.

This study had limitations associated with its retrospective and multicenter nature, including variability in the completeness of medical records, limited sample size, and lack of a control group of cases treated via MCPJ arthrodesis alone. There were also slight inconsistencies in the surgical procedures and considerable variability in postoperative management among different surgeons and referral institutions.

Based on our results, no Thoroughbred racehorses with TDSA at risk of PIPJ subluxation developed this complication following the use of an LCP-DFP for double MCPJ/PIPJ arthrodesis, and this technique can be offered as a salvage procedure for racehorses with TDSA. However, postoperative complications and long-term success were similar to those previously described. More extensive debridement of the PIPJ cartilage could potentially lead to faster bony fusion of the PIPJ, less proliferative bone formation, and increased comfort, improving the outcomes reported in this study.

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CONFLICT OF INTEREST

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

ORCID

David Orozco Lopez https://orcid.org/0000-0001-6912-8908

Kyla F. Ortved https://orcid.org/0000-0003-0398-2444

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