

## CLINICAL RESEARCH

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## Minimally invasive tarsal arthrodesis in 15 dogs

Federico Longo DVM, PhD<sup>1</sup>  | Emanuele Castelli<sup>2</sup> |  
 Daniel Dean Lewis DACVS<sup>3</sup> | Caleb C. Hudson DVM, MS, DACVS (Small Animal)<sup>4</sup> |  
 Stanley Eunwoo Kim BVSc, MS, DACVS (Small Animal)<sup>2</sup> |  
 Antonio Pozzi MedVet, MS, DACVS (Small Animal)<sup>1</sup>

<sup>1</sup>Clinic for Small Animal Surgery,  
University of Zurich, Zürich, Switzerland

<sup>2</sup>Small Animal Surgery, Marigin—Zentrum  
für Tiermedizin, Feusisberg, Switzerland

<sup>3</sup>Department of Small Animal Clinical  
Sciences, College of Veterinary Medicine,  
University of Florida, Gainesville,  
Florida, USA

<sup>4</sup>Small Animal Surgery, Nexus Veterinary  
Specialists, Victoria, Texas, USA

## Correspondence

Federico Longo, Clinic for Small Animal  
Surgery, University of Zurich, 8006,  
Zürich, Switzerland.  
Email: [federico.longo2@uzh.ch](mailto:federico.longo2@uzh.ch)

## Abstract

**Objective:** The aim of the present study was to report the outcomes and complications of minimally invasive tarsal arthrodesis (MITA) in dogs.

**Study design:** Bi-institutional retrospective study.

**Sample population:** A total of 15 client-owned dogs.

**Methods:** Medical records of dogs undergoing MITA were reviewed to determine outcome and complications. Radiographs were recommended every 4 weeks until clinical union and reviewed to evaluate tibiotarsometatarsal alignment, implant position, subsequent osseous union of the debrided articulations. Time to clinical union and complications were recorded. Clinical union was defined as functional weightbearing limb use with at least 50% of osseous union. Final limb function was defined as full, acceptable, or unacceptable.

**Results:** Partial tarsal arthrodesis was performed in 10 cases and pantarsal arthrodesis in five cases. Postoperative swelling was minimal. Most complications, 26% major and 40% minor, were implant-related, and explant was required in three dogs. No catastrophic complications occurred. Mean ( $\pm$ sd) radiographic follow-up was 11.4 ( $\pm$ 13.1) months. Mean ( $\pm$ sd) time to radiographic osseous union was 1.8 ( $\pm$ 0.5) months. Mean ( $\pm$ sd) time to clinical union was 3.7 ( $\pm$ 0.8) months. Physiological alignment was restored in 12/15 dogs. Complete radiographic union occurred in 46% while in the remaining 54% obtained partial radiographic union, but clinical instability was not observed. Limb function was considered full in six and acceptable in eight dogs. Function was unacceptable in one dog, but the cause was not related to MITA.

**Conclusion:** MITA resulted in restoration of alignment, which was accomplished using MITA techniques. Furthermore, MITA appeared to result in faster healing times and reduced soft tissue complications compared to conventional open approach arthrodesis.

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**Clinical significance:** MITA may be considered as an option to obtain functional arthrodesis in dogs.

## 1 | INTRODUCTION

Pantarsal and partial tarsal arthrodesis are elective orthopedic procedures used to salvage limb function by promoting permanent osseous fusion of the debrided articulations.<sup>1,2</sup> Pantarsal arthrodesis involves the fusion of talocrural, intertarsal, and tarsometatarsal articulations, while a partial tarsal arthrodesis involves fusion of the intertarsal and tarsometatarsal joints.<sup>1-4</sup> Traditionally, tarsal arthrodeses have been performed using an open debridement approach and stabilized with plates,<sup>3,5-8</sup> external fixators,<sup>9-16</sup> pinning without or with tension band fixation,<sup>12</sup> or lag screws.<sup>13</sup>

Complication rates associated with tarsal arthrodesis using plate fixation range from 25% to 75%.<sup>5-8,12</sup> Severe postoperative swelling combined with excessive wound tension, vascular compromise, and cast-associated soft tissue injury<sup>14</sup> can result in substantial necrosis of the pes, which in extreme cases can necessitate either limb amputation or, in the most serious cases, euthanasia.<sup>15</sup> Plantar necrosis has been described as a specific major postoperative complication of tarsal arthrodeses with the reported incidence ranging from 8%<sup>16</sup> to 15%.<sup>8</sup> Implant failure is another common complication of tarsal arthrodesis with the reported incidence ranging between 7%<sup>16</sup> and 36%,<sup>17</sup> including screw loosening, breakage or bending.

The past three decades have seen a paradigm shift emphasizing minimally invasive techniques in small animal orthopedics.<sup>18-27</sup> Minimally invasive osteosynthesis principles can be applied when performing tarsal arthrodeses and may afford advantages over traditional open approaches.<sup>2</sup> Minimally invasive tarsal arthrodesis (MITA)<sup>2,28</sup> may decrease soft tissue complications by utilizing small skin portals and limiting soft tissue dissection, while providing the mechanical benefit of stable internal fixation.<sup>19,22,28</sup> However, extensive cartilage debridement, especially of the more distal joints, may not be possible via this approach. Furthermore, assessment of limb segment alignment and implant application may be more difficult due to the limited exposure. The outcome and risks associated with MITA should be analyzed in comparison to the reported results from traditional open techniques.

The purpose of this study was to report the clinical outcomes and complications associated with MITA in dogs. We hypothesized that MITA is a feasible and safe surgical technique which may result in a functional

arthrodesis with a low incidence of complications, particularly soft tissue and vascular complications.

## 2 | MATERIALS AND METHODS

### 2.1 | Case selection and inclusion criteria

The computerized surgical database at two institutions was searched from January 2007 to January 2017 to identify dogs that underwent a minimally invasive partial or pantarsal arthrodesis. The selection criteria for performing a minimally invasive arthrodesis was influenced by surgeon preference, as well as the type and location of pathology necessitating the procedure. The presence of concurrent orthopedic abnormalities at locations other than the involved tarsus did not exclude dogs from inclusion in the present study. Dogs were included in this study if immediate postoperative, and follow-up radiographs were available for review, and follow-up examinations were performed by the (primary) surgeon until healing of the arthrodesis.

### 2.2 | Medical record review

Information regarding each dog's signalment, age at time of surgery, bodyweight, type and etiology of the tarsal injury necessitating arthrodesis, concurrent musculoskeletal injuries and details of the surgical procedure including the number and location of incisions, the type of implants placed, and use of the bone graft were recorded.

Complications<sup>29</sup> were defined as (1) minor if the complication was resolved with conservative medical therapy or required nominal surgical intervention to resolve (i.e., pin removal under sedation); (2) major, if extended medical therapy was required or a surgical revision procedure (i.e., implant removal or replacement) was performed under general anesthesia; or (3) catastrophic, when leading to a permanent unacceptable functional impairment prompting to hindlimb amputation, euthanasia, or directly related to death. Complications were also categorized as intra- or postoperative, as well as soft tissue versus implant-related complications. Revision was defined as a surgical procedure performed involving the same anatomic site as addressed during the original surgery.<sup>30</sup>

## 2.3 | Surgery and postoperative care

MITA was performed in all cases as previously described by Pozzi et al.<sup>28</sup> Fluoroscopy was utilized during surgery to facilitate cartilage debridement, to evaluate alignment of the stabilized limb segment and confirm appropriate position of the implants.

Three separate skin incisions (proximal, central, and distal) were made during MITA (Figure 1A). When performing a pantarsal arthrodesis the proximal incision was positioned over the medial aspect of the distal tibial diaphysis. The central incision was positioned over the medial malleolus and extended to the base of the second metatarsal bone, allowing a malleolar osteotomy or a medial collateral ligament desmotomy, to be performed to expose the talocrural joint. The distal incision was positioned over the mid-to-distal diaphysis on the second metatarsal bone. When performing a partial tarsal arthrodesis, the proximal incision was positioned over the lateral aspect of the calcaneal tuber. The central incision was positioned over the lateral aspect of the tarsus to expose the calcaneo-quartal or tarso-metatarsal joints. The distal incision was positioned over the mid-to-distal diaphysis on the fifth metatarsal bone. The proximal and distal incisions were used for plate insertion and screw application at the ends of the plate.

The position of these incisions varied according to plate length. An epiperiosteal tunnel was developed between each incision to allow eventual plate placement.

Complete cartilage debridement was performed throughout the talocrural joint as well as for any articulation deemed unstable and contributing to the need to perform the arthrodesis, whereas limited cartilage debridement of the chondral areas exposed through the skin incision or no cartilage debridement was performed for stable low motion joints (i.e., intertarsal or tarsometatarsal joints). Continuous lavage was performed during debridement. Autologous cancellous bone graft or synthetic bone graft (Fortigen-p, Progenica, Duleek, Ireland) was placed in the debrided joint spaces. After cartilage debridement (Figure 1B), graft placement and alignment of the involved limb segments, the plate was inserted (Figure 1C,D). In some procedures, supplementary fixation such as interfragmentary Kirschner wires or screws were placed to facilitate reduction and alignment of the bones. In some procedures a template was inserted percutaneously, and digital pressure was applied to conform the template to osseous topography to facilitate plate contouring. In other procedures plate contouring was performed using radiographs of the contralateral limb. When performing a medial malleolar osteotomy, limited or no plate contouring was deemed necessary. The plate was

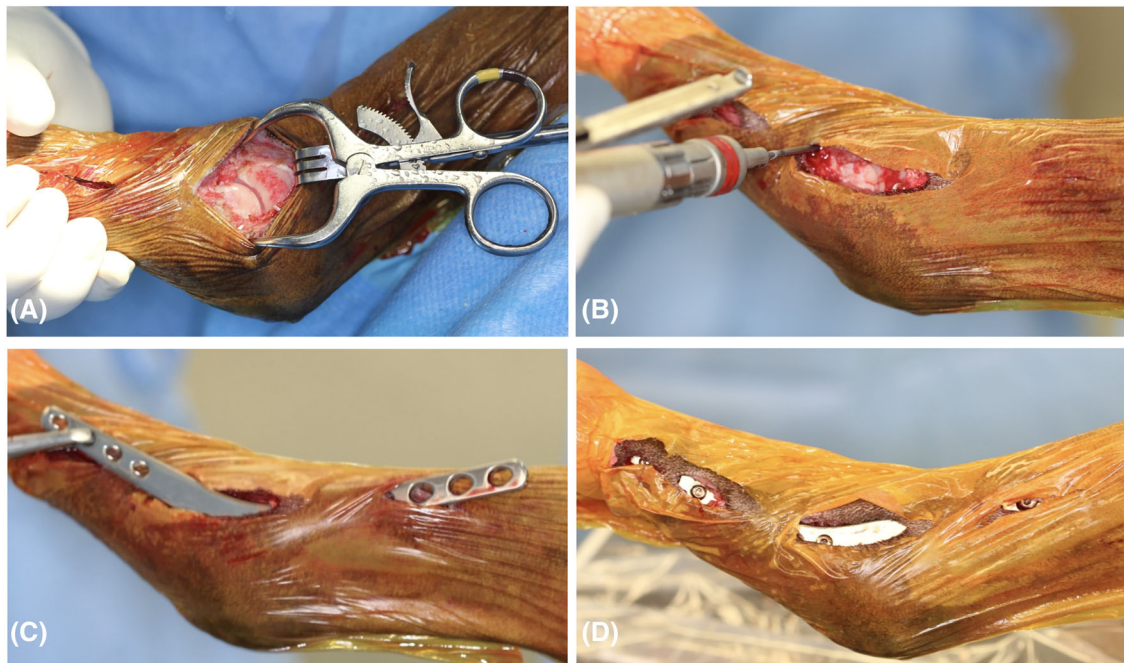


**FIGURE 1** Surgical steps during minimally invasive percutaneous arthrodesis of the tarsus (MITA). (A) Proximal, central, and distal skin portals are created for the plate positioning. (B) Self-retractors are placed in the central portal to provide adequate soft tissue exposure for the osteotomy of the medial tibial malleolus. Joints are debrided using a pneumatic burr through small skin incisions over the joints. (C and D) Show the implant positioning. (C) A precontoured pantarsal arthrodesis plate is inserted through the central portal. (D) The plate is slid along an epiperiosteal tunnel. The screws are placed directly through the skin portals. An additional second distal portal may be performed to facilitate the insertion of the distal screws.

inserted through one of the plate insertional incisions and advanced through the epi-periosteal tunnel bridging the incisions. The screws were placed through the incisions or percutaneously under fluoroscopic imaging. Subcutaneous tissue and skin were closed routinely and postoperative radiographs were obtained.

A protective soft padded bandage with a plantar (partial tarsal arthrodesis) or plantar-lateral (pantarsal arthrodesis) splint was applied to the operated limb for 4 weeks after surgery. The splint was replaced every other day during the initial week following surgery, and weekly thereafter. After the 4-week recheck evaluation, splinting was discontinued. Owners were advised to confine their dogs to a kennel when unattended until the arthrodesis had obtained radiographic union.

## 2.4 | Clinical outcomes review

The follow-up interval was categorized as perioperative (0–3 months), short- (3–6 months), medium- (6–12), and long-term (> 12 months).<sup>29</sup> Each dog was assessed in the immediate postoperative period, and then at 4-week intervals until radiographic union was obtained. Visual inspection and physical palpation were performed at each re-evaluation to assess the pes and distal pelvic limb for skin inflammation, soft tissue swelling, incisional discharge, superficial and deep sensation, stability and crepitus, pain elicited on manipulation of the arthrodesis site or when direct pressure was applied to the implants and muscle atrophy of the ipsilateral pelvic limb. Orthopedic recheck examinations were performed by a board-certified surgeon to evaluate the pelvic limb function.

Lameness evaluations were performed while the dog was standing, walking, and trotting. A five-point scale was used to grade lameness.<sup>30</sup>

The lameness score at the final clinical evaluation was also used to assess limb function. Functional weightbearing was defined when the postoperative lameness score was either 0/5 or 1/5. Final clinical outcomes were defined as full, acceptable, or unacceptable limb function.<sup>29</sup>

## 2.5 | Radiographic assessment

Orthogonal radiographs of the distal pes were obtained in all cases pre- and postoperatively (Figure 2). The pelvic limb alignment was evaluated using a commercially available DICOM software (Osirix Version, Pixmeo, Geneva, Switzerland). Immediate postoperative radiographs were reviewed to assess implant placement, the alignment and the angle of the arthrodesed limb segments (Figure 3). Follow-up radiographs were obtained at scheduled monthly rechecks to monitor the progress towards radiographic osseous union. Owners were solicited to return to the referral facilities for mid- to long-term radiographic evaluation (>6 months).

To assess frontal limb segment alignment,<sup>31,32</sup> the tibial mechanical axis was defined as a line connecting the mid-point of the tibial intercondylar eminences to the most distal point of the distal tibial intermediate ridge. The distal tibial orientation line was defined as a line connecting the most proximal points of the two arciform grooves of the cochlea tibiae (Figure 3A). Assessment of the tibio-tarso-metatarsal frontal and sagittal alignment was based on a modification from the previously reported measurement

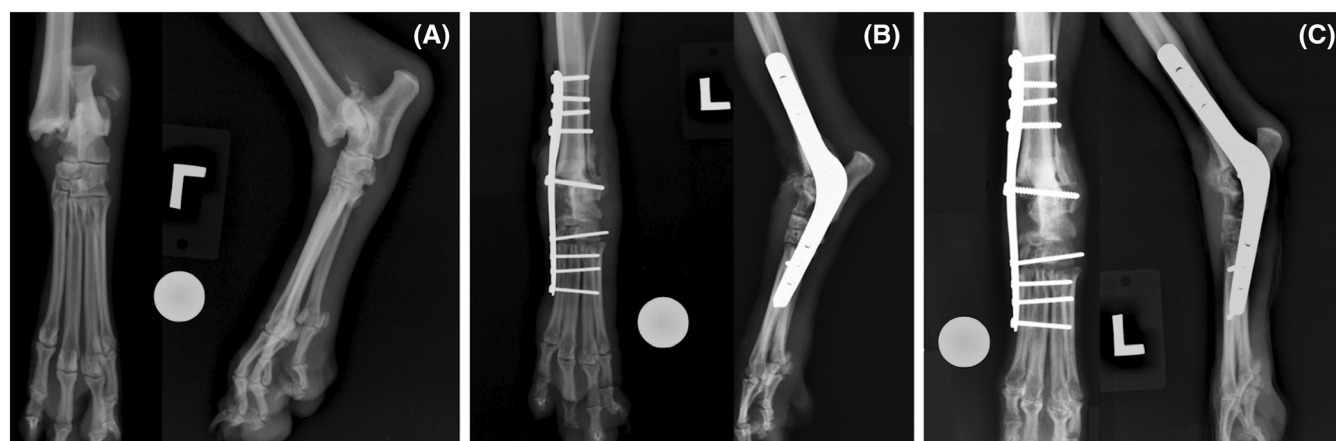


**FIGURE 2** Tarsal minimally invasive percutaneous arthrodesis (MITA) of a 2-year-old, 9 kg, Miniature Schnauzer. (A) Preoperative radiographs show a left tibio-tarsal luxation and a mildly comminuted talar fracture. (B) Orthogonal postoperative radiographs show the implant positioning after a pantarsal MITA. In this case, only the talocrural joint was debrided and packed with bone graft. (C) Follow-up orthogonal radiographs taken 2 years after surgery display a complete osseous fusion (complete obliteration of the joints spaces), appropriate implant positioning without loosening. A metatarsal synostosis between metatarsal bone I/II and III/IV was noticed.

of the radio-carpal-metacarpal alignment in dogs.<sup>33</sup> The mechanical axis of the metatarsus in the frontal plane was defined as a line passing through the midpoint of the distal tibial orientation line and the midpoint between the center of the distal epiphyses of the third and fourth metatarsal bones (Figure 3A). The angle resulting from the intersection of the metatarsal mechanical axis and distal tibial joint orientation line was defined as the mechanical lateral proximal tarsal-metatarsal angle (mLPTMA, Figure 3A). Whenever it was possible, the mLPTMA was compared to the unaffected contralateral limb. If not, based on

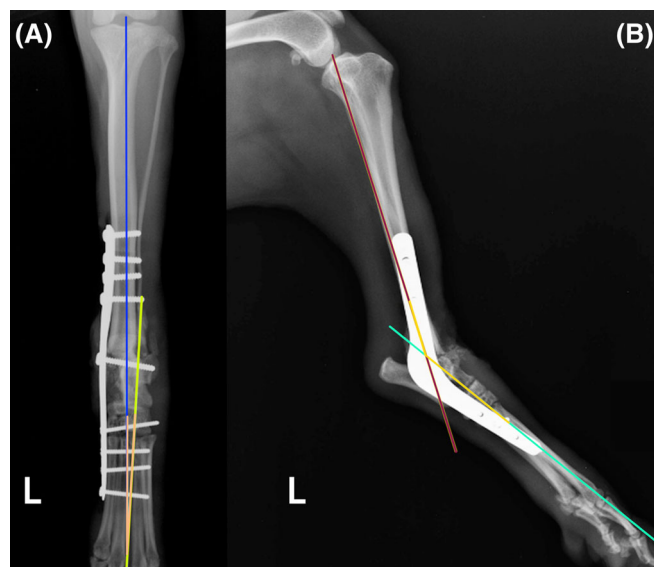


**FIGURE 3** Postoperative radiographic measurements to evaluate the alignment of the minimally invasive tarsal arthrodesis (MITA). (A) On the frontal plane, the mechanical tibial axis extending from the proximal midpoint between the tibial intercondylar eminences is drawn (blue line). The metatarsal axis is drawn between the third and fourth metatarsal bones (light green line). The resulting angle is defined as the mechanical lateral proximal tarsal-metatarsal angle (mLPTMA, orange). (B) On the sagittal plane, the mechanical tibial axis is drawn from the proximal tibial intercondylar eminences to the distal center of the talus (dark red line). The metatarsal axis is defined as a line bisecting either the second or the fifth metatarsal bones and ending to the center of the talus (green line). The resulting angle is the defined as MITA angle (yellow).

preliminary radiographic measurements obtained from the pes of several healthy dogs, the mLPTMA was deemed as normal if ranging from 80°–90°. The sagittal plane metatarsal axis was defined as a line bisecting either the second (pantarsal MITA) or fifth (partial tarsal MITA) metatarsal bone (Figure 3B). A second axis bisecting the distal tibia was drawn and the resulting angle was defined as the MITA angle (Figure 3B).

Osseous union was defined as a loss of definition of the debrided joints and an increase of mineral opacity and bridging of the debrided joint surfaces.<sup>34</sup> The orthogonal view radiographs obtained at the time of the final recheck examination were scored on a scale ranging from 0% to 100% to describe the extent of osseous bridging (Table 1). Referring to a previously reported scoring systems for bone healing,<sup>18</sup> but here adapted to arthrodesis, radiographic osseous union was defined as 100% bone bridging with obliterated or barely discernible joint spaces. A clinical union was defined as the presence of bone bridging equal or greater than 50% on both orthogonal radiographs along with the presence of functional weightbearing and no palpable instability.

### 3 | RESULTS

#### 3.1 | Demographic data

A total of 15 dogs were included in the study. Signalment, type of injury, and description of MITA received are summarized in Table 2. The study population included six neutered males, one intact male, and eight spayed females. Mixed-breed dogs ( $n = 5$ ) were the most represented breed. The mean age at the time of surgery was  $7 \pm 3.3$  years (range: 2.5–12 years). Mean bodyweight was  $26.6 \pm 15.3$  kg (range: 11–69 kg).

#### 3.2 | Surgery outcomes

A total of 10 dogs had a lateral partial tarsal arthrodesis performed, while five dogs underwent a medial pantarsal

**TABLE 1** Score for the evaluation of the radiographic healing of the minimally invasive tarsus arthrodesis.

| Radiographic healing score |                                                                                                                                                         |                                                                                                                                                       |                                                                                                                        |                                                                                                                                     |                                                                                                                                          |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
|                            | 0%                                                                                                                                                      | 25%                                                                                                                                                   | 50%                                                                                                                    | 75%                                                                                                                                 | 100%                                                                                                                                     |
| Bone bridging              | <ul style="list-style-type: none"> <li>Debrided bone margins clearly defined</li> <li>Little mineral opacity within the debrided joint space</li> </ul> | <ul style="list-style-type: none"> <li>Debrided bone margins poorly defined</li> <li>Increased mineral opacity in the debrided joint space</li> </ul> | <ul style="list-style-type: none"> <li>Advanced bone bridging</li> <li>Confluent bone bridging obliteration</li> </ul> | <ul style="list-style-type: none"> <li>Advanced bone bridging</li> <li>Obliteration with barely discernible joint spaces</li> </ul> | <ul style="list-style-type: none"> <li>Homogeneous and extensive bone bridging</li> <li>Complete obliteration of joint spaces</li> </ul> |

TABLE 2 Descriptive data for tarsal minimally invasive plate arthrodesis patients.

| Patient | Age (years) | Breed               | Bodweight (kg) | Injury                                                           | Arthrodesis          | Implants                                                                                 | Bone graft                             | Additional injuries                          |
|---------|-------------|---------------------|----------------|------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------|----------------------------------------|----------------------------------------------|
| 1       | 12          | Bull Terrier        | 26             | Traumatic tarsometatarsal instability                            | Left partial tarsal  | 12 holes, 2.7 LCP-DCP, 9 screws                                                          | Autogenous cancellous + bone allograft | Left tibial and ulnar fx                     |
| 2       | 10.2        | Shetland Sheepdog   | 17             | Non-erosive polyarthritis Intertarsal hyperextension-            | Left partial tarsal  | 9 holes, 2.7/2.0 LC-DCP, 7 screws                                                        | Autogenous cancellous + allograft      |                                              |
| 3       | 2.8         | Miniature Schnauzer | 8.2            | Traumatic tibiotarsal luxation                                   | Left pantarsal       | 9 holes, 2.7/2.0 pantarsal arthrodesis plate, 9 screws                                   | Autogenous cancellous + bone synthetic | Left degloving injury                        |
| 4       | 3.8         | Mixed breed         | 5.2            | Erosive polyarthritis                                            | Left pantarsal       | 9 holes, 2.7/2.0 pantarsal arthrodesis plate, 9 screws                                   | Autogenous cancellous                  |                                              |
| 5       | 2.5         | Mixed breed         | 24.5           | Traumatic tarsometatarsal subluxation-hyperextension             | Left partial tarsal  | 10 holes, 2.7 LC-DCP, 8 screws                                                           | Autogenous cancellous                  | Left hip dysplasia, first phalanx 4 digit fx |
| 6       | 9.1         | Shetland Sheepdog   | 17.5           | Chronic traumatic intertarsal plantar instability                | Right partial tarsal | 8 holes, 2.7 LC-DCP, 5 screws                                                            | Autogenous cancellous                  |                                              |
| 7       | 11.9        | Labrador Retriever  | 33             | Tarsus DJD                                                       | Right pantarsal      | 9 holes, 2.7/2.0 carpal arthrodesis plate, 7 screws                                      | Autogenous cancellous + bone allograft |                                              |
| 8       | 8.5         | Shetland sheepdog   | 11             | Proximal intertarsal luxation of the left hind limb              | Left partial tarsal  | 12 holes, 2.7/2.0 pantarsal arthrodesis plate, 9 screws                                  | Autogenous cancellous                  |                                              |
| 9       | 3.0         | Mixed breed         | 26             | Traumatic tarsometatarsal luxation, Metatarsal fx                | Left partial tarsal  | 12 holes, 2.4 DCP, 12 screws                                                             | Autogenous cancellous                  | Pneumothorax                                 |
| 10      | 8.1         | Mixed breed         | 39             | Proximal intertarsal joint luxation                              | Right partial tarsal | 10 holes 2.7 LC-DCP, 10 screws; 1 trans. K wire                                          | N.a                                    |                                              |
| 11      | 3.3         | Labrador Retriever  | 26             | Traumatic tibiocrucluxation                                      | Right pantarsal      | 10 holes 3.5/2.7 pantarsal arthrodesis plate 10 screws; 2 trans. K wires, 1 trans. screw | Autogenous cancellous                  |                                              |
| 12      | 10.1        | Mixed breed         | 25             | Tarsometatarsal subluxation                                      | Right partial tarsal | 12 holes, 2.7 LCP-DCP, 12 screws                                                         | Autogenous cancellous                  |                                              |
| 13      | 8.0         | Labrador Retriever  | 30             | Traumatic tibiocrucluxation                                      | Right pantarsal      | 10 holes 3.5/2.7 pantarsal arthrodesis plate 10 screws; 1 trans. screw                   | Autogenous cancellous                  | Left coxofemoral luxation                    |
| 14      | 5.6         | Great Dane          | 69             | Tarsometatarsal subluxation                                      | Left partial tarsal  | 13 holes, 3.5 broad LCP, 12 screws                                                       | Autogenous cancellous                  |                                              |
| 15      | 6.6         | Greyhound           | 36             | Distal intertarsal subluxation with central tarsal bone fracture | Left partial tarsal  | 12 holes 2.7 LCP 10 screws                                                               | Autogenous cancellous                  |                                              |

Abbreviation: fx, fracture; DCP, dynamic compression plate; LC-DCP, limited contact dynamic compression plate; LCP, locking compression plate.

arthrodesis. Partial tarsal MIPA was performed for traumatic tarsometatarsal instability (5/10), traumatic intertarsal instability (4/10), and nonerosive polyarthritis (1/10). Pantarsal MITA was performed due to traumatic tibiotarsal luxation/subluxation (3/5), degenerative joint disease (1/5), and erosive polyarthritis (1/5) (Table 2). A laterally positioned, 2.7/2.0 mm limited contact dynamic compression plate (LC-DCP) partial tarsal arthrodesis plate was the implant used most often to stabilize the partial tarsal arthrodeses, while a 2.7/2.0 mm pantarsal arthrodesis plate was medially applied in 3/5 pantarsal arthrodeses. Bone grafting was performed in all but one partial tarsal arthrodesis (Table 2).

### 3.3 | Clinical outcomes

The duration of follow-up was categorized as perioperative in two dogs, short-term in seven dogs, medium-term in two dogs, and long-term in four dogs. Six of the dogs had a full functional outcome. Eight dogs had an acceptable functional outcome, with substantial improvement in pelvic limb weightbearing (Table 3), while one dog had an unacceptable functional outcome with persistent lameness. Six dogs had no visible lameness (0/5°), seven dogs had a mild lameness (1/5°), while two dogs had a persistent lameness (3/5°).

A total of 14 dogs had palpably stable arthrodesis sites, but one of the dogs with an unacceptable functional outcome had residual instability at the level of the right talocrural joint and a 3/5° lameness 9 months after a pantarsal arthrodesis (Table 3). The owner did not elect for surgical revision and the dog was managed with orthotics. The other dog with an unacceptable functional outcome 2 years after a partial tarsal arthrodesis, had an ipsilateral hip luxation and progressive degenerative joint disease of the affected coxofemoral joint which was perceived to be the cause of the dog's persistent lameness.

### 3.4 | Radiographic outcomes

The mean radiographic follow-up was  $11.4 \pm 13.1$  months (range: 2 to 38 months, Table 4). A total of 12 dogs had physiological postoperative distal limb alignment on the immediate postoperative radiographs. One partial MITA had a varus deviation, while two partial tarsal MITA were affected by valgus deviation (Table 4).

The mean time to radiographic osseous union was  $1.8 \pm 0.5$  months (range: 1.5 to 3 months, Table 4). Complete radiographic osseous union (100% gap bridging) was documented in 46% of the cases (7/15 MITA, Table 4). In the remaining 54% cases (8/15 MITA), the osseous union was equal to or greater than 50%. In detail,

**TABLE 3** Intra- and postoperative complications and revisional strategies after minimally invasive plate arthrodesis of the tarsus.

| Patient | Intraoperative complications | Postoperative complications |                           | Revision                       | Implant removal     |
|---------|------------------------------|-----------------------------|---------------------------|--------------------------------|---------------------|
|         |                              | Soft tissue                 | Implant                   |                                |                     |
| 1       |                              |                             |                           |                                |                     |
| 2       |                              |                             | Plate loosening           |                                |                     |
| 3       |                              |                             |                           |                                |                     |
| 4       | Mtb #2 fracture              |                             | Screw loosening           |                                | Screw removal       |
| 5       |                              | Incisional swelling         |                           |                                |                     |
| 6       |                              |                             | Screws loosening          | Plate and screw reposition     |                     |
| 7       | Broken drill bit             |                             |                           |                                |                     |
| 8       |                              |                             |                           |                                |                     |
| 9       |                              | Medial tarsal sore          |                           |                                |                     |
| 10      |                              |                             | Pin migration             |                                | Pin removal         |
| 11      | Broken drill bit             | Incisional discharge        | Infection, pin migration. | Comm. calcaneal tendon release | Plate + pin removal |
| 12      |                              | Lick lesion                 |                           |                                |                     |
| 13      |                              |                             |                           |                                |                     |
| 14      | Broken drill bit             |                             | Infection                 |                                |                     |
| 15      |                              |                             |                           |                                |                     |

Abbreviations: Mtb, metatarsal bone; TESF, transarticular external skeletal fixator.

**TABLE 4** Descriptive data of radiographic and clinical outcomes after minimally invasive arthrodesis.

| Patient | Alignment  | Percentage bridging width | Radiographic healing (months) | Radiographic follow-up (months after first surgery) | Clinical union (months after first surgery) | Clinical outcome (functional weightbearing)  |
|---------|------------|---------------------------|-------------------------------|-----------------------------------------------------|---------------------------------------------|----------------------------------------------|
| 1       | 10° valgus | 75%                       | 3                             | 4.25                                                | Stable (3)                                  | Acceptable function (1/5)                    |
| 2       | Anatomic   | 75%                       | 2.75                          | 39                                                  | Stable (8)                                  | Full function (0/5)                          |
| 3       | Anatomic   | 100%                      | 1.25                          | 38.25                                               | Stable (2.25)                               | Full function (0/5)                          |
| 4       | Anatomic   | 100%                      | 1.5                           | 4                                                   | Stable (4.5)                                | Acceptable function (1/5)                    |
| 5       | Anatomic   | 75%                       | 2.5                           | 30.5                                                | Stable (2.25)                               | Unacceptable <sup>a</sup> (3/5) <sup>a</sup> |
| 6       | 6° valgus  | 75%                       | 2                             | 14.25                                               | Stable (4)                                  | Full function (0/5)                          |
| 7       | Anatomic   | 50%                       | 1.75                          | 4.75                                                | Stable (4.75)                               | Acceptable function (1/5)                    |
| 8       | Anatomic   | 100%                      | 1.75                          | 8.25                                                | Stable (2.25)                               | Full function (0/5)                          |
| 9       | Anatomic   | 100%                      | 1.25                          | 2.75                                                | Stable (2.5)                                | Acceptable function (1/5)                    |
| 10      | Anatomic   | 100%                      | 2                             | 3                                                   | Stable (2.25)                               | Acceptable function (1/5)                    |
| 11      | Anatomic   | 75%                       | 1.25                          | 9.5                                                 | Unstable (10)                               | Acceptable function (2/5)                    |
| 12      | Anatomic   | 75%                       | 2                             | 3.5                                                 | Stable (2.5)                                | Full function (0/5)                          |
| 13      | Anatomic   | 50%                       | 1.5                           | 1.75                                                | Stable (2)                                  | Acceptable function (1/5)                    |
| 14      | Anatomic   | 100%                      | 1.75                          | 4                                                   | Stable (3)                                  | Acceptable function (1/5)                    |
| 15      | 5° varus   | 100%                      | 1.5                           | 4.25                                                | Stable (2.75)                               | Full function (0/5)                          |

<sup>a</sup>Lameness attributed to omo-lateral hip joint dysplasia.

Table 4 shows that in 2/15 cases a 50% gap bridging was detected, while in 6/15 cases a 75% gap bridging was documented at the final radiographic recheck (Table 4). Although the radiographic osseous union was incomplete in 54% of the cases, the majority of those arthrodesis (7/8) had obtained a clinical union at the final follow-up. One case (case 11) did not achieve radiographic bone or clinical union (Table 4).

Mean clinical union time was  $3.7 \pm 0.8$  months (range: 2–10, Table 4). Osteopenia was radiographically visible in 46% of cases (7/15); of these, three dogs underwent implant removal. Regions affected by osteopenia were distal tibia (2/7), tarsus (5/7), and proximal metatarsal bones (4/7). Osteopenia was detected either under the plate or in the surrounding areas. No signs of osteomyelitis were observed in these cases.

### 3.5 | Complications

Intraoperative complications included drill bit breakage ( $n = 3$ ) and metatarsal fracture ( $n = 1$ ) (Table 4). Minor postoperative complications, which resolved with conservative management, occurred in six (40%) dogs (Table 3). During the initial postoperative convalescent period, mild incisional or soft tissue swelling was noted in three dogs. The swelling was subjectively described by the attending clinician as non-painful and lacking redness. None of the

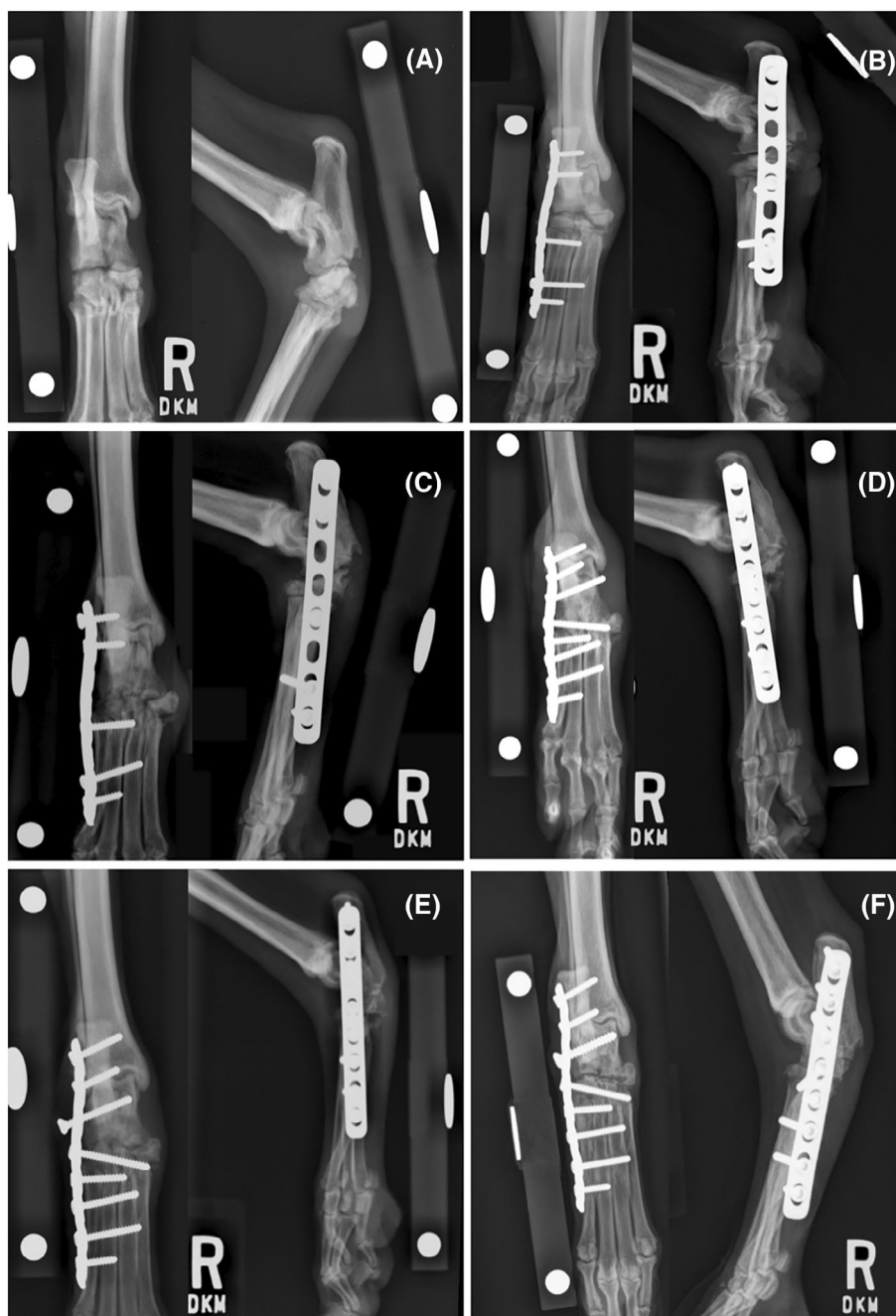
dogs developed incisional dehiscence, skin ulceration or necrosis.

Major complications occurred in four (26%) dogs (Table 3) and included one soft tissue-related and three were implant-related complications. One dog, which was chronically non-weightbearing due to undiagnosed surgical site infection following pantarsal arthrodesis, developed a flexor contracture of the ipsilateral stifle that which was not addressed until 9 months following a pantarsal arthrodesis. The implants were removed and radiographic bone healing was deemed as 75%. The contracture was addressed by transecting of the gastrocnemius and accessory components of the common calcaneal tendon, while preserving the superficial digital flexor tendon, with immediate improvement of stifle extension and extension continued to improve more over time. The final clinical function was deemed acceptable, with the dog having only intermittent lameness at final recheck (Table 4). Two implant-associated infections requiring implant removal were observed. Additionally, in one case two proximal screws had loosened at the 1-month radiographic recheck after a partial tarsal MTA (Figure 4). The plate was repositioned and strengthened by adding multiple screws.

## 4 | DISCUSSION

The results of this descriptive retrospective case series substantiate that MTA is an effective technique in dogs

**FIGURE 4** (A) A right talocalcaneal subluxation with a plantarodistal calcaneal avulsion fracture was observed in a 9-year-old, 17 kg male Shetland sheep dog. (B) A partial tarsal minimally invasive percutaneous arthrodesis was performed. An iatrogenic mild valgus deviation of the tarsus and metatarsus was observed. (C) At the 1-month radiographic recheck, loosening of the two proximal screws was noticed. (D) A revision surgery was performed adding three cortical screws (2.7 mm) to the same implant. One month after revision surgery, the third screw was loose (E) and was therefore replaced with a 3.5 mm cortical screw (F).



affected with various tarsal abnormalities. Our outcomes are consistent with the results of experimental<sup>35</sup> and clinical studies in horses<sup>36,37</sup> and people,<sup>35,36</sup> which support a minimally invasive approach to arthrodesis. In our study, all dogs, except one, reached clinical union in less than 12 weeks, with almost 50% of tarsal MITA achieving a complete osseous union. We also found tarsal MITA to be a safe procedure with an incidence of major complications (26%) equal<sup>16</sup> to or lower than that previously reported in studies<sup>8,17</sup> evaluating results following open tarsal arthrodeses.<sup>8,17</sup> Neither major skin-related complications nor severe vascular damage were observed postoperatively.

In this case series, none of the dogs developed plantar necrosis, which has previously been reported as a catastrophic complication in dogs undergoing open pantarsal or partial tarsal arthrodesis.<sup>8,16</sup> The development of plantar necrosis has been ascribed mainly to the intraoperative injury of the dorsal pedal or perforating metatarsal artery that may occur during soft tissue dissection, cartilage debridement or metatarsal screw insertion, especially during lateral plating.<sup>8,16</sup> Our results are similar to the results of Anesi et al.<sup>17</sup> in which none of the dogs developed plantar necrosis after medially applied pantarsal arthrodesis. Anesi et al.<sup>17</sup> performed pantarsal arthrodesis using

an open approach; however, the authors debrided the cartilage of tarsal-intertarsal joints only from the medial side, without creating any joint subluxation. This less aggressive exposure of the joints and minimalistic debridement technique may have resulted in decreased vascular trauma and complications. Both the results from the present study and those of Anesi et al.<sup>17</sup> suggest that the cause of plantar necrosis might be a combination of extensive soft tissue trauma, excessive wound tension and postoperative swelling rather than an isolated vascular injury from drilling and screw insertion. A more conservative approach to surgical dissection and cartilage debridement may decrease the risk of soft tissue complications.

During pantarsal arthrodeses in this case series, limited cartilage debridement was performed in the intermediate tarsal and tarsometatarsal joints, which are low motion joints, whereas the talocrural joint was adequately exposed and debrided through the central incision. All dogs achieved a clinical union despite the limited cartilage debridement. The extent of bridging bone ranged from a minimum 50% to a maximum 100% of the width of the joint, but no differences in clinical outcome were found among dogs. Adequate joint exposure and meticulous thorough articular cartilage debridement have been considered prerequisites for a successful arthrodeses.<sup>38,39</sup> In MITA, the cartilage of the intertarsal and tarso-metatarsal joints may not be debrided if the joints are stable. In contrast, high motion joints and unstable joints are thoroughly debrided to facilitate achievement of full osseous bridging.

Postoperative swelling was marginal in this study, with little edema or wound discharge, in contrast to standard open tarsal arthrodesis which are commonly characterized by severe soft tissue swelling postoperatively.<sup>8</sup> We speculate that preserving segments of intact skin over the plate mitigates tension during wound closure, reducing the tourniquet effect which often complicates the closure of a large incision over the plate with a traditional open approach.<sup>4,11</sup> The reduced vascular trauma caused by MITA approach could be another key factor which may have contributed to the limited amount of postoperative swelling.<sup>28,40</sup> Results of a cadaveric angiographic study demonstrated that MIPO in the radius was less disruptive to the regional periosteal circulation than an open plating technique.<sup>22</sup>

Most of the complications of this study were implant-related, necessitating implant removal either because of plate and screw loosening, pin migration, or screw breakage. The loosening complications of the implants may be attributed to the persistent motion between metatarsal bones during weightbearing and the predisposition of implant loosening which typically result when implants are applied on the compression surface.<sup>28</sup> A second reason for implant loosening could be ascribable to the

limited cartilage debridement that was performed in some cases and may have resulted in persistent motion. Non-locking implants may be at higher risk of loosening compared to locking implants.<sup>41,42</sup> Additionally, Anesi et al.<sup>17</sup> reported a high incidence of metatarsal fracture and screw breakage in arthrodeses performed without using postoperative coaptation, and attributed these complications to high forces at the metatarsal-implant interface.<sup>17</sup>

Percutaneous arthrodesis techniques in people have been mainly recommended in joints with normal preoperative alignment,<sup>25,41,42</sup> whereas limb segments that have preoperative malalignment may require a traditional open arthrodesis approach. Fusion of the limb segment in a functional position is one of the pivotal principles of arthrodesis.<sup>2,38</sup> MITA may be challenging in dogs with torsional, frontal, or sagittal plane malalignment. The limited surgical approach and joint exposure may prevent the surgeon from either detecting an iatrogenic malalignment or efficiently correcting a preoperative limb segment malalignment. Immobilization of the tarsus in malalignment may lead to gait abnormalities and abnormal forces acting on the limb.<sup>17,28</sup> In this study, only three out of 15 arthrodeses had iatrogenic postoperative malalignment. All three had mild postoperative varus or valgus limb segment deviation. At the long-term clinical recheck weightbearing was assessed as functional in all three of the dogs with mild postoperative limb segment malalignment.

The limitations of the study include its intrinsic retrospective nature. Furthermore, we acknowledge the lack of objective clinical outcome measurements. Although the majority of dogs resumed normal activity without apparent lameness by the time of the final evaluation, objective limb function was not included in the medical record. There was no force plate data or sensitive walkway data included in this study. We only obtained long-term follow-up evaluations on four dogs. Finally, the postoperative mLPTMA has not been statistically compared with contralateral values, as our medical records did not always include the radiographic views of the healthy contralateral limb for all the patients.

MITA yielded promising results, with a similar or lower complication rate than previously reported with open tarsal arthrodesis. None of the dogs developed catastrophic vascular complications. Complete radiographic union occurred in nearly 50% of MIPAs and all but one arthrodesis obtained clinical union. Our results suggest that employing a more conservative approach for joint exposure may decrease the risk of soft tissue complications. The continued high incidence of implant-associated complications suggests that further improvement should be focused on implant design and fixation strategies for stabilizing tarsal arthrodeses. The reported outcomes warrant a prospective

evaluation to assess if MIPA can reduce the soft tissue complications compared to the traditional open plating techniques.

## AUTHOR CONTRIBUTIONS

Longo F, DVM, PhD: Participated in the study design, reviewed the medical records, analyzed and interpreted the data, performed the postoperative radiographic measurements, drafted the manuscript. Castelli E, DVM, DECVS: Collected data, drafted the manuscript, participated in the design of the study, reviewed the medical record, revised and approved the final manuscript. Lewis DD, DVM, MS, ACVS: Conceived the study, interpreted and analyzed the data, performed the surgery, revised and approved the final manuscript. Hudson CC, DVM, MS, ACVS: Participated in the design of the study, performed the surgery, interpreted and analyzed the data, revised and approved the final manuscript. Kim SE, BVSc, MS, ACVS: Interpreted and analyzed the data, performed the surgery, revised the manuscript, revised and approved the final manuscript. Pozzi A, DVM, MS, ACVS, ECVS, ACVSMR: Conceived and designed the study, interpreted the data, performed the surgery, revised and approved the final manuscript.

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## CONFLICT OF INTEREST STATEMENT

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

## DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

## ORCID

Federico Longo  <https://orcid.org/0000-0002-3396-4768>

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