Calcaneal Fractures in Non-Racing Dogs and Cats: Complications, Outcome, and Associated Risk Factors

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Abstract

Objective: To estimate the prevalence of complications and describe the outcome associated with calcaneal fractures in non-racing dogs and in cats.

Study Design: Retrospective multicenter clinical cohort study.

Animals: Medical records of client-owned dogs and cats (2004–2013).

Methods: Medical records were searched and 50 animals with calcaneal fractures were included for analysis. Complications were recorded and an outcome score applied to each fracture. Associations between putative risk factors and both major complications, and final outcome scores were explored.

Results: Complications occurred in 27/50 fractures (61%) including 23 major and 4 minor complications. At final follow-up, 4 animals (10%) were sound, 27 (64%) had either intermittent or consistent mild weight-bearing lameness, 7 (17%) had moderate weight-bearing lameness, and 1 (2%) had severe weight-bearing lameness. Fractures managed using plates and screws had a lower risk of complications than fractures managed using pin and tension band wire, lag or positional screws or a combination of these techniques (Relative risk 0.16, 95% CI 0.02–1.02, P = .052). Non-sighthounds had reduced odds of a poorer outcome score than sighthounds (Odds ratio 0.11, 95% CI 0.02–0.50, P = .005) and fractures with major complications had 13 times the odds of a poorer outcome score (Odds ratio 13.4, 95% CI 3.6–59.5, P < .001).

Conclusion: This study reports a high occurrence of complications associated with calcaneal fracture stabilization in non-racing dogs and in cats, and a poorer outcome score was more likely in animals with complications. A more guarded prognosis should be given to owners of non-racing dogs or cats with calcaneal fractures than previously applied to racing Greyhounds with calcaneal fractures.

INTRODUCTION

Tarsal fractures are seen in racing dogs, often involving the calcaneus, the central tarsal bone, the numbered tarsal bones, and the talus. Despite this, there is minimal peer-reviewed veterinary literature on calcaneal fractures in non-racing dogs or in cats. Case series of calcaneal fractures in racing Greyhounds have been reported, but these are considered fatigue or stress-fractures which are rarely seen in other dog breeds. While suspected stress fractures have been reported in 2 cats, other literature proposes that tarsal injuries in cats, including calcaneal fractures, are usually the result of trauma. The pathogenesis, fracture patterns, treatment options, and prognoses may differ between stress fractures seen in racing dog breeds and traumatic fractures seen in non-racing dogs and in cats.

Different causes of calcaneal fractures in dogs create different fracture configurations. Racing Greyhounds run either clockwise (United Kingdom) or counterclockwise (United States, Australasia). Counterclockwise racing is theorized to create excessive load on the medial aspect of the right hind limb, causing compression fractures of the central tarsal
in 2 cats with suspected stress fractures, but there are no reports of outcomes of traumatic calcaneal fracture in cats.

The objectives of this retrospective study were to estimate the prevalence of complications and assess the outcome after treatment of calcaneal fractures in non-racing dogs and in cats. Putative risk factors associated with major complications and final outcome were also explored.

2 MATERIALS AND METHODS

The databases of 3 referral hospitals were searched for dogs or cats treated for a fracture of the calcaneus from January 2004 to December 2013. Racing Greyhounds were excluded but pet sighthounds with no history of racing were included. The data retrieved from the medical records included species, breed, sex, age, weight, and cause of fracture. Fractures were categorized based on the fracture types which have been recognized previously (Table 1). Fractures were also categorized as comminuted (yes/no), open or closed, articular or non-articular and whether there was involvement of other tarsal bones (yes/no). The anesthesia and surgery duration, perioperative and postoperative antibiotic administration, surgical approach, treatment method, and use of additional external coaptation postoperatively (yes/no) were recorded (Table 2).

Immediate postoperative radiographs were reviewed by one board-certified surgeon for accuracy of immediate fracture reduction, categorized as anatomic, minimal malreduction (<1 mm), moderate malreduction (1–3 mm), or severe malreduction (>3 mm). Implant placement was categorized as satisfactory or non-satisfactory.

The occurrence and nature of post-treatment complications was recorded. Complications were defined as any undesirable outcome associated with the treatment and were categorized as major (surgical intervention performed) or minor (managed non-surgically). Details of any revision surgery were recorded.

The time of first and subsequent post-treatment assessments, and the physical examination and radiographic findings at these assessments was recorded. Radiographs were reviewed by one board certified surgeon. The progression of osseous union and development of articular pathology for articular fractures was noted and categorized as previously described. Progression of osseous union was categorized as complete osseous union, progressing appropriately toward osseous union for follow-up time, progressing inappropriately toward osseous union for follow-up time or failure of stabilization. Evidence of articular pathology was categorized as no radiographic evidence of articular pathology, joint effusion or soft tissue changes without evidence of osteoarthritis, early or minimal osteoarthritis, severe osteoarthritis or unable to assess due to arthrodesis having been performed.

### TABLE 1 Categorization of calcaneal fracture configuration

| Category | Calcaneal fracture configuration |
|----------|---------------------------------|
| 1        | Mid-body                        |
| 2        | Slab Fracture                   |
| 3        | Salter-Harris fracture          |
| 4        | Avulsion fracture of calcaneal tuberosity in skeletally mature animal |
| 5        | Fracture of the base            |
| 6        | Combination of any of the above |

Bone while clockwise racing creates similar forces on the left hind limb. The asymmetric loading results in an accumulation of forces on the lateral and plantar aspects of the tarsus, causing calcaneal fracture. Calcaneal fractures not associated with central tarsal bone fractures result from extreme tension on the plantar aspect of the calcaneus and create a transverse fracture or a plantarodistal chip fracture of the base of the calcaneus. Iatrogenic and pathologic calcaneal fractures have also been reported. In people, fractures of the calcaneus are typically produced by an axial force, which creates a highly variable fracture pattern affected by the magnitude and direction of the impacting force, the foot position, and the muscular tone.

Four types of calcaneal fracture are described: (1) Salter Harris type 1 or 2 fractures involving the proximal calcaneal physis, (2) mid-body fractures, (3) slab fractures of the distolateral or dorsomedial calcaneus, and (4) fractures of the base of the calcaneus. The stress fractures reported in 2 cats were complete transverse fractures at the base or body of the calcaneus.

Treatment for stabilizing calcaneal fractures in dogs include external coaptation, tension band wiring, lag screw application, plate application, arthrodesis of the calcaneoquartal joint, and biodegradable rods and osteosutures. The method of stabilization chosen depends on fracture configuration, presence of proximal intertarsal subluxation, and presence of concurrent tarsal injuries. Healing time and prognosis are not associated with type of fracture or treatment method.

The outcome of treatment of calcaneal fractures in people remains poor. Various classification systems have been developed to direct treatment and prognosis. Fractures of the calcaneal body have a better prognosis than intra-articular fractures, and a better prognosis has been reported for certain classifications of fracture when treated surgically. Conversely in the limited reports for dogs with calcaneal fractures, 95% of 22 dogs undergoing surgery were sound at follow-up with radiographic union documented and only 2/22 dogs had complications. Surgery was successful.
The overall outcome for lameness was determined for the latest follow-up and assigned a score according to a modified categorization scheme with 0 — no observable lameness, 1 — intermittent weight-bearing lameness with little if any change in gait, 2 — consistent, mild weight-bearing lameness with little change in gait, 3 — moderate weight-bearing lameness — obvious lameness and change in gait, 4 — severe weight-bearing lameness — toe-touching only, and 5 — non weight-bearing lameness.

### 2.1 Statistical analysis

Continuous data were summarized as median and range. Categorical data were summarized as proportions (95% CI). The association between putative risk factors (explanatory variables) and major complications (outcome) was assessed using univariate Poisson regression analysis with robust standard errors. In addition, each variable was assessed for a univariate association with final outcome score using a proportional odds regression model. Age and weight were examined as continuous, categorical, and as multiple fractional polynomials to determine any evidence of nonlinearity in the association with major complication. Explanatory variables with association at $P < .25$ and any a priori potential confounding factors identified using causal diagrams were included in a multivariate Poisson model for association with complications and a multivariate proportional odds model for association with final outcome score. The selected variables were then subjected to bivariate analysis to identify any collinearity between explanatory variables. Variables associated with the highest $P$ values were eliminated sequentially by backward selection to identify the most parsimonious model, only including variables with $P < .05$, or any confounding variables that caused a change $> 20\%$ in the risk ratio (RR) or odds ratio (OR). Two way interactions were examined between explanatory variables and retained if $P < .05$. The goodness of fit for the Poisson regression model was assessed using the deviance test. The goodness of fit and the proportional odds assumption were assessed using the Lipsitz test and graphical assessment methods. Weight was not included in the multivariate models because cats typically weigh less than most dog breeds and thus this is not a biologically meaningful variable when dogs and cats are combined in the same model. To assess explanatory variables for major complications and final outcome scores specific to dogs, the multivariate Poisson regression model with robust standard errors and the multivariate proportional odds regression model were also analyzed with data for dogs only. Statistical analyses were conducted in R 3.2.1 using the packages “mfp,” “Modern Applied Statistics with S,” “Vector Generalized Additive Model,” and “sandwich.”

### 3 RESULTS

A total of 36 dogs (one bilateral simultaneously) and 10 cats (3 bilateral—2 simultaneously, one 25 months apart) for a total of 50 calcaneal fractures were identified. Dog breeds included Lurcher (n=6), cross breed (5), Greyhound (4), Labrador (3), Border Collie (2), Dalmatian (2), Newfoundland (1), West Highland White Terrier (1), Patterdale Terrier (1), Staffordshire Bull Terrier (1), Beagle (1), Siberian Husky (1), Rhodesian Ridgeback (1), Yorkshire Terrier (1), Boxer (1), Rough Collie (1), Papillon (1), Doberman (1; bilaterally affected), Borzoi (1), and Weimaraner (1). Breeds were categorized as 11 sighthounds and 26 non-sighthounds. There

### TABLE 2 Categorization of treatment methods for calcaneal fractures

| Category | Stabilization/treatment | Total N | Postoperative external coaptation (n) |
|----------|-------------------------|---------|---------------------------------------|
| 1        | Pin and tension band wire | 16      | 13                                    |
| 2        | Lateral plate           | 7       | 6                                     |
| 3        | Biaxial plate           | 2       | 2                                     |
| 4        | Lag/positional screws only | 4      | 4                                     |
| 5        | Lag/positional screws and tension-band wire | 2 | 2                                     |
| 6        | Partial tarsal arthrodesis | 5      | 5                                     |
| 7        | Pantarsal arthrodesis   | 2       | 2                                     |
| 8        | Transarticular external skeletal fixator | 3 | 0                                     |
| 9        | Nonsurgical             | 7       | 3                                     |
| 10       | Euthanasia              | 1       | –                                     |
were 5 neutered male dogs, 11 entire male, 8 neutered female, and 12 entire female. Dogs ranged in body weight from 3.1 to 48.0 kg (median 21.2; n = 22).

Cat breeds included Domestic Short-Haired (n = 7; 1 bilaterally affected), Domestic Long-Haired (1 bilaterally affected), Exotic Short Hair (1 bilaterally affected), and British Short Hair (1). There were 4 neutered male cats, one entire male, 4 neutered female, and 1 entire female. The cats ranged in body weight from 1.5 to 5.8 kg (median 4.0, n = 11).

For many cases, the cause of the fracture was unknown (n = 21), which included the bilaterally affected dog and all 3 bilaterally affected cats. For those cases where the etiology was known causes included a fall or trauma whilst running (n = 6 fractures), iatrogenic (5), a jump or a fall from a height (4), running without trauma (3), hit by car (3), animal being trodden on (2), cat bite (1), foot stuck and struggling to get free (1), and nutritional secondary hyperparathyroidism (1). Iatrogenic fractures occurred secondary to osteomyelitis around an external skeletal fixator (ESF) pin (1), placement of a calcaneotibial screw to support an Achilles tendonorrhaphy (1), lateral plate removal after a calcaneoquartal arthrodesis (1), placement of a lateral plate for calcaneoquartal arthrodesis (1) and radiation therapy (1).

There were 48/50 calcaneal fractures classified (Table 3, Fig 1). The fractures not classified included 1 pathologic fracture due to metabolic bone disease which had started to heal on presentation preventing an accurate diagnosis from being discerned. The initial radiographs of the other unclassified fracture were not available for review. There were 20 comminuted fractures and 29 not comminuted with 1 unknown. There were 15 open fractures and 35 closed.

There were 20 articular fractures (the calcaneal fracture or concurrent fracture of another tarsal bone) and 30 non-articular. There were 36 fractures of the calcaneus only and 14 that also involved other tarsal bones; concomitant fractures of the central tarsal bone (10), fractures of the talus (2), fracture of the lateral malleolus (1), and fractures of both the fourth tarsal bone and the central tarsal bone (1).

A lateral approach was used for 38 fractures and a dorsal approach for 2 (pantarsal arthrodesis using a dorsally applied plate). The approach was unknown for 1 fracture that received a circular ESF. Surgical intervention was applied in 41 fractures, not used in 7 fractures, and 1 dog with bilateral fractures was euthanatized (Table 2). For 41 fractures managed surgically, no support bandage or frame was applied postoperatively (n = 7), a soft support dressing applied for 2 weeks only (8), a splinted dressing placed for 6–8 weeks (9),

TABLE 3  Frequency of calcaneal fracture configurations

| Fracture configuration                   | N (%) |
|-----------------------------------------|-------|
| Mid-body                                | 27 (68) |
| Slab fracture                            | 6 (15) |
| Dorsolateral                             | 1 (2.5) |
| Cranial                                 | 2 (5) |
| Distolateral                             | 3 (7.5) |
| Salter-Harris fracture                    | 4 (10) |
| Avulsion of calcaneal tuberosity         | 3 (7.5) |
| Fracture of base of calcaneus            | 4 (10) |
| Combination                              | 4 (10) |
| Mid-body and slab                        | 1 (2.5) |
| Mid-body and base                        | 2 (5) |
| Base and slab                            | 1 (5) |

were 5 neutered male dogs, 11 entire male, 8 neutered female, and 12 entire female. Dogs ranged in body weight from 3.1 to 48.0 kg (median 21.2; n = 22).

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For many cases, the cause of the fracture was unknown (n = 21), which included the bilaterally affected dog and all 3 bilaterally affected cats. For those cases where the etiology was known causes included a fall or trauma whilst running (n = 6 fractures), iatrogenic (5), a jump or a fall from a height (4), running without trauma (3), hit by car (3), animal being trodden on (2), cat bite (1), foot stuck and struggling to get free (1), and nutritional secondary hyperparathyroidism (1). Iatrogenic fractures occurred secondary to osteomyelitis around an external skeletal fixator (ESF) pin (1), placement of a calcaneotibial screw to support an Achilles tendonorrhaphy (1), lateral plate removal after a calcaneoquartal arthrodesis (1), placement of a lateral plate for calcaneoquartal arthrodesis (1) and radiation therapy (1).

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There were 20 articular fractures (the calcaneal fracture or concurrent fracture of another tarsal bone) and 30 non-articular. There were 36 fractures of the calcaneus only and 14 that also involved other tarsal bones; concomitant fractures of the central tarsal bone (10), fractures of the talus (2), fracture of the lateral malleolus (1), and fractures of both the fourth tarsal bone and the central tarsal bone (1).

A lateral approach was used for 38 fractures and a dorsal approach for 2 (pantarsal arthrodesis using a dorsally applied plate). The approach was unknown for 1 fracture that received a circular ESF. Surgical intervention was applied in 41 fractures, not used in 7 fractures, and 1 dog with bilateral fractures was euthanatized (Table 2). For 41 fractures managed surgically, no support bandage or frame was applied postoperatively (n = 7), a soft support dressing applied for 2 weeks only (8), a splinted dressing placed for 6–8 weeks (9),

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| Mid-body and slab                        | 1 (2.5) |
| Mid-body and base                        | 2 (5) |
| Base and slab                            | 1 (5) |

FIGURE 1  Calcaneal fracture configurations based on radiographic and computed tomographic (CT) images. (A) Mediolateral and (B) caudocranial radiographic views of a mildly comminuted mid-body fracture. (C) Sagittal CT image demonstrating a cranial slab fracture. (D) Mediolateral and (E) caudocranial radiographic views of a distolateral slab fracture. (F) Mediolateral and (G) caudocranial views of an avulsion fracture of the calcaneal tuberosity. (H) Sagittal CT image demonstrating a fracture of the base of the calcaneus
Robert Jones dressing applied for 6–8 weeks (4), cast applied for 6–8 weeks (9), and a transarticular ESF applied for 6–8 weeks (4). Only 3 fractures were categorized as treated with primary transarticular ESF, the remaining fracture received a minimal transarticular ESF to provide additional support.

The anesthesia duration ranged from 115 to 510 minutes (median 260) and the surgery duration ranged from 60 to 305 minutes (median 140). Perioperative antibiotics were administered in all animals undergoing surgery. Postoperative antibiotics were administered in 28 animals (68%).

The accuracy of reduction immediately postoperative was anatomic (n=12 fractures), minimal malreduction (15), moderate malreduction (8), and unknown (6). Implant placement was satisfactory (35 fractures), unavailable (5), and the K-wire was too long in 1. First radiographic follow-up was available for 41 fractures at a median of 6 weeks postoperative (range 1–20 weeks, n=36). The time of first radiographs was unknown for 4 fractures. Complete radiographic healing was recorded at first radiographic follow-up (n=12 fractures), progressing appropriately towards radiographic union for this stage (22), progressing inappropriately slowly towards union (2) and failure (4). Failure was due to infection necessitating implant removal (n=2 fractures) and nonunion (2).

Second radiographic follow-up was available for 18 fractures at a median of 12 weeks postoperative (range 2–80 weeks). Two fractures had complete radiographic healing at first follow-up, which was verified at the second follow-up. The remaining 16 fractures at second follow-up had complete radiographic healing (n=11 fractures), progressing appropriately toward radiographic union (4) and failure (1). Failure was due to infection and bone necrosis necessitating implant removal and pantarsal arthrodesis.

Evaluation of final follow-up for the 20 fractures with articular involvement reported no radiographic evidence of articular pathology (n=5 fractures), evidence of joint effusion or soft tissue changes without evidence of osteoarthritis (4), evidence of early or minimal osteoarthritis (3), and severe osteoarthritis changes (1). Assessment was unavailable in 7 articular fractures since arthrodesis had been performed (n=3 fractures), lost follow-up (2), no radiographs taken (1), and radiographs unavailable (1).

Assessment of complications was available for 44/50 fractures with 6 lost to follow-up. There were complications in 27/44 fractures (61%) with major complications in 23/44 (52%) and minor complications in 4/44 (9%). One dog with bilateral fractures was euthanized. One dog developed osteosarcoma of the proximal tibia 2 months after fracture repair and underwent hindlimb amputation; this was not considered a complication of fracture repair. There were 35 complications overall with 23 major and 12 minor complications. Both major and minor complications occurred in 5 fractures and 3 minor complications in 1 fracture (Table 4).

The final post-treatment assessment for surgical and nonsurgical treatment was available for 42 fractures at a median of 12 weeks post-treatment (range 2–204 weeks). The outcome (l lameness) scores at final follow-up were grade 0 (n=4 fractures), grade 1 (14), grade 2 (13), grade 3 (7), and grade 4 (1). The lameness score was grade 6 (unclassified) for 3 fractures in animals undergoing amputation.

Univariate analysis showed the risk of major complications at Center 2 was twice that of Center 1 (RR 1.83, 95% CI 0.79–4.24, P=.16) but there was no difference in risk for Centers 1 and 3 (P=.75, Table 5). The risk for major complications for fractures stabilized using a plate was less than those stabilized with pins/wire or screws (RR 0.17, 95% CI 0.03–1.06, P=.06) but not different between pins/wires or screws and arthrodesis (P=.56) or pins/wires or screws and

| Complication                                                                 | Category | N   |
|------------------------------------------------------------------------------|----------|-----|
| Severe dressing injuries or infection leading to amputation                  | Major    | 2   |
| Implant irritation or protrusion through skin necessitating removal          | Major    | 10  |
| Infection and failure of fixation necessitating implant removal and alternative fixation | Major | 5  |
| Nonunion leading to persistent instability necessitating alternative stabilisation | Major | 3  |
| Implant breakage necessitating replacement                                    | Major    | 2   |
| Multiresistant infection necessitating placement of antibiotic impregnated beads | Major | 1  |
| Gastrocnemius tendon rupture postoperatively managed with orthotic support externally rather than repeat surgery due to multi-resistant infection present from initial surgery | Minor | 1  |
| Dressing sores managed conservatively                                         | Minor    | 5   |
| Reduced range of motion of hock                                              | Minor    | 2   |
| Delayed union                                                                | Minor    | 1   |
| Severe digital swelling following pantarsal arthrodesis                      | Minor    | 1   |
| Intermittent swelling over implants associated with increased exercise levels | Minor | 1  |
| Surgical site infection controlled with 6 week course of appropriate antibiotics | Minor | 1  |

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Second radiographic follow-up was available for 18 fractures at a median of 12 weeks postoperative (range 2–80 weeks). Two fractures had complete radiographic healing at first follow-up, which was verified at the second follow-up. The remaining 16 fractures at second follow-up had complete radiographic healing (n=11 fractures), progressing appropriately toward radiographic union (4) and failure (1). Failure was due to infection and bone necrosis necessitating implant removal and pantarsal arthrodesis.
TABLE 5  Univariate estimation of relative risk (RR) for major complications of calcaneal fracture management

| Variable               | Levels                          | Total animals (N) | n (%) with complications | Unadjusted RR* | 95% CI       | P value |
|-----------------------|---------------------------------|-------------------|---------------------------|----------------|-------------|---------|
| Center                | Center1                         | 11                | 4 (36%)                   | Reference      |             |         |
|                       | Center 2                        | 23                | 16 (70%)                  | 1.83           | 0.79–4.24   | .16     |
|                       | Center 3                        | 10                | 3 (30%)                   | 0.82           | 0.24–2.82   | .76     |
| Species               | Dog                             | 33                | 19 (58%)                  | Reference      |             |         |
|                       | Cat                             | 11                | 4 (36%)                   | 0.66           | 0.28–1.54   | .34     |
| Dog breed             | Sighthound                      | 10                | 6 (60%)                   | Reference      |             |         |
|                       | Non-sighthound                  | 23                | 13 (56%)                  | 0.87           | 0.46–1.67   | .68     |
| Cat breed             | Domestic short/long-haired       | 8                 | 2 (25%)                   | Reference      |             |         |
|                       | Pedigree                        | 3                 | 2 (67%)                   | 2.67           | 0.63–11.28  | .18     |
| Sex                   | Male                            | 21                | 11 (52%)                  | Reference      |             |         |
|                       | Female                          | 23                | 12 (52%)                  | 1.1            | 0.60–2.04   | .76     |
| Age                   | Unit—month                      | 43                |                           | 1.01           | 1.00–1.01   | .03     |
| Weight                | Unit—kg                         | 29                |                           | 1.02           | 1.00–1.05   | .09     |
| Comminution           | No                              | 23                | 14 (61%)                  | Reference      |             |         |
|                       | Yes                             | 20                | 9 (45%)                   | 0.78           | 0.43–1.45   | .44     |
| Open fracture         | No                              | 31                | 16 (52%)                  | Reference      |             |         |
|                       | Yes                             | 13                | 7 (54%)                   | 1.12           | 0.59–2.09   | .73     |
| Articular involvement | No                              | 26                | 15 (58%)                  | Reference      |             |         |
|                       | Yes                             | 18                | 8 (44%)                   | 0.82           | 0.44–1.55   | .54     |
| Other tarsal fracture | No                              | 32                | 16 (50%)                  | Reference      |             |         |
| Surgical approach     | Lateral                         | 33                | 19 (58%)                  | Reference      |             |         |
|                       | Dorsal                          | 2                 | 1 (50%)                   | 0.87           | 0.21–3.58   | .85     |
| Treatment method      | Pins or screws and wire         | 20                | 15 (75%)                  | Reference      |             |         |
|                       | Plate                           | 8                 | 1 (12%)                   | 0.17           | 0.03–1.06   | .06     |
|                       | Arthrodesis                     | 5                 | 3 (60%)                   | 0.8            | 0.37–1.71   | .56     |
|                       | ESF                             | 3                 | 2 (67%)                   | 0.89           | 0.38–2.06   | .78     |
|                       | Nonsurgical                     | 6                 | 0 (0%)                    | –              | –           | –       |
| Postoperative         | no postoperative coaptation      | 7                 | 2 (0.3%)                  | Reference      |             |         |
|                       | Yes                             | 29                | 19 (66%)                  | 2.29           | 0.69–7.62   | .18     |

(continues)
TABLE 5 (continued)

| Variable                  | Levels                  | Total animals (N) | Total n (%) with complications | Unadjusted RR*a | 95% CI          | P value |
|---------------------------|-------------------------|-------------------|--------------------------------|----------------|----------------|---------|
| Surgical duration         | Unit—minute             | 20                | 1                              | 0.99–1.01       | .47            |         |
| Anesthesia duration       | Unit—minute             | 21                | 1                              | 1.00–1.00       | .8             |         |
| Postoperative antibiotics | No                      | 13                | 4 (31%)                        | Reference       |                |         |
|                           | Yes                     | 24                | 17 (71%)                       | 2.3             | 0.98–5.41      | .06     |
| Reduction achieved        | Anatomic reduction      | 11                | 4 (36%)                        | Reference       |                |         |
|                           | Minimal malreduction    | 12                | 8 (67%)                        | 1.38            | 0.93–2.06      | .11     |
|                           | Moderate malreduction   | 7                 | 5 (71%)                        |                |                |         |
| Implant placement         | Satisfactory            | 29                | 16 (55%)                       | Reference       |                |         |
|                           | Unsatisfactory          | 1                 | 1 (100%)                       | 1.81            | 1.30–2.50      | <.001   |

*aPoisson regression model with robust standard errors.

ESFs (P=.78). No major complications occurred in the 7 fractures treated non-surgically. The risk for major complications was approximately twice as high when postoperative antibiotics were administered (RR 2.3, 95% CI 0.98–5.41, P=.06) or when there was unsatisfactory postoperative implant placement (RR 1.81, 95% CI 1.30–2.50, P<.001).

Nine variables were entered into the multivariate Poisson regression model with robust standard errors; referral center, cat breed, age (in months), weight (in kg), treatment method, use of postoperative external coaptation, postoperative antibiotic administration, anatomical reduction achieved and implant placement. Center 2 was positively associated with the administration of postoperative antibiotics (P=.003) and the use of postoperative external coaptation and was excluded from the multiple Poisson regression model. Only 1 implant had unsatisfactory placement which precluded inclusion of implant placement in the multiple regression model. Manual backward elimination resulted in 2 variables remaining in the final model; age and treatment method. For every 1 month increase in age, there was a 0.4% increased risk of major complications, adjusted for treatment method (RR=1.004, 95% CI 1.001–1.01, P=.049). No fractures managed non-surgically had major complications, hence the risk of major complication was infinitely smaller than fractures managed using pins and screws (RR 6.7 × 10^{-9}, 95% CI 2.5 × 10^{-9}–1.8 × 10^{-8}, P<.001). Fractures managed using a plate had a lower risk for major complications than fractures managed using pins/wires or screws (RR 0.16, 95% CI 0.02–1.02, P=.052) but there was no difference for fractures managed by arthrodesis (P=.48) or external skeletal fixation (P=.84) compared to pins/wires or screws. Model analysis for dogs alone identified the same risk factors as for model analysis of dogs and cats combined (Table 6).

Univariate proportional odds model analysis of final outcome (lameness) score showed a 1 unit decrease in surgical reduction score was associated with 3 times the odds of a poorer outcome (OR 2.94, 95% CI 1.17–7.95, P=.03, Table 7). Fractures with any complications had 7 times the odds of a poorer outcome than fractures with no complications (OR 7.57, 95% CI 2.21–29.5, P=.002). Fractures with major complications had 9 times the odds of a poorer outcome than fractures with no complications (OR 9.25, 95% CI 2.66–37.30, P<.001). Twelve variables were included for multivariate proportional odds logistic regression; breed of dog (sighthound/non-sighthound), comminution, open fracture, articular fracture, use of postoperative external coaptation, surgery duration, postoperative antibiotic administration (yes/no), anatomic reduction achieved, treatment method, any complication (yes/no) and major complication (yes/no). When explanatory variables were likely collinear, only the explanatory variable with the lowest P value for association with the final outcome remained in the model. Thus, comminution, articular fracture and any complication were removed with open fracture and major complication included.

The final proportional odds logistic regression model showed non-sighthounds had lower odds of a poorer outcome score than sighthounds (OR 0.11, 95% CI 0.02–0.50, P=.005), open fractures had lower odds of a poorer outcome score than closed fractures (OR 0.18, 95% CI 0.04–0.70, P=.02) and fractures with major complications had 13 times the odds of a poorer outcome score (OR 13.4, 95% CI 3.6–59.5, P<.001). The model for dogs alone identified the same risk factors for a poorer outcome score as for dogs and cats combined (Table 8).
The proportional odds logistic regression model was compared to a multinomial logistic regression model using deviance goodness of fit test ($P = .75$) and graphical methods to assess the proportional odds assumption. There was no evidence to suggest the proportional odds assumption did not hold.

4 | DISCUSSION

The results of this study were disparate from previous reports of calcaneal fractures, in both outcome and fracture configuration. Ost et al.\(^6\) examined fractures in racing Greyhounds which had mostly small slab fractures (63%) and fractures at the base of the calcaneus (20%) compared to only 16% slab fractures and 10% calcaneal base fractures in our study. Most fractures in our study were mid-body fractures (68%) compared to 37% in the paper by Ost et al. Further contrast is the proportion of comminuted fractures in our study (40%) and central tarsal fractures (20%) compared to 14% and 80%, respectively, reported by Ost et al.\(^6\) The different fracture configurations likely indicate different pathogeneses of fractures in racing Greyhounds and non-racing dogs or cats.

Fractures sustained during racing are considered fatigue or stress fractures.\(^7,8,33\) Fatigue fractures result from accumulation of microdamage in bone due to excessive cyclic loading beyond the threshold for repair.\(^34–38\) These fractures are uncommon in non-racing dogs\(^9\) but have been suspected in cats.\(^10\) Counterclockwise racing creates excessive load on the medial aspect of the right hind limb which can cause compression fracture of the central tarsal bone.\(^6\) When the central tarsal bone is fractured, the talus travels distally and acts as a fulcrum over which the calcaneus fractures. In this situation, tarsal ligament avulsion fractures are frequent, including dorsomedial and lateral sagittal slab fractures.\(^1\) The non-racing dogs in our study would not be subject to the same excessive loads or cyclic loading as racing Greyhounds which may explain why central tarsal bone fractures were infrequent and why there were few slab fractures.

Only 2 cats with suspected stress fractures of the calcaneus have been reported\(^10\) and therefore a pattern for this injury does not exist. Both previously reported cats sustained bilateral, simple complete transverse fractures, one at the base of the calcaneus and the other at the mid-body. Neither cat had a history of trauma but this could not be excluded. In our study, 10 cats had 13 calcaneal fractures. Three cats had a known history of trauma and 3 fractures were comminuted, so unlikely to be stress fractures. Furthermore, 1 fracture was pathologic and 1 was iatrogenic. However, the remaining 5 fractures in 3 cats were simple transverse fractures of unknown cause and stress fractures cannot be ruled out. To avoid confusing the results of our study with inclusion of possible stress fractures and with combining cats and dogs as a non-racing cohort, the statistical analysis was also performed for dogs alone. Interestingly, the risk factors associated with both complications and final outcome were the same for dogs alone as that for cats and dogs combined, and therefore further discussion is directed at both species.

The fracture patterns noted in our study have more similarities with the patterns of calcaneal fractures in people than in racing Greyhounds, with higher proportions of mid-body and intra-articular fractures.\(^39,40\) The authors speculate this is due to a higher number of traumatic injuries associated with axial force in our cohort compared to the fatigue fractures seen in racing Greyhounds. However, the fracture patterns most frequently noted in people are associated with the trabecular pattern in the cancellous bone.\(^41\) Fracture patterns begin in the so-called neutral triangle, a consistent area of sparse or absent trabeculae in the anterior portion of the calcaneus with fracture patterns then coursing along one of the paths of least resistance corresponding to trabecular weaknesses.\(^41\) Factors hypothesized to contribute to the fracture pattern in the calcaneus in people are the shape of the

| Variable                  | Levels                  | RR\(^a\)  | 95% CI          | $P$ value |
|---------------------------|-------------------------|-----------|-----------------|-----------|
| Age                       | Unit—month              | 1.01      | 1.001–1.01      | .049      |
| Treatment method          | Pins or screws          | Reference |                 |           |
|                           | Plate                   | 0.33      | 0.06–1.76       | .19       |
|                           | Arthrodesis             | 0.75      | 0.36–1.56       | .45       |
|                           | External skeletal fixator| 0.7       | 0.19–2.65       | .6        |
|                           | Nonsurgical             | $6.9 \times 10^{-9}$ | $2.3 \times 10^{-9}$–$2.0 \times 10^{-8}$ | <.001     |

\(^{a}\)Poisson regression model with robust standard errors.
| Variable                  | Levels                        | OR  | 95% CI         | P value |
|--------------------------|-------------------------------|-----|----------------|---------|
| Center                   | Center1 Reference             |     |                |         |
|                          | Center 2                      | 1.04| 0.29–3.84      | .94     |
|                          | Center 3                      | 0.36| 0.08–1.60      | .18     |
| Species                  | Dog Reference                 |     |                |         |
|                          | Cat                           | 0.76| 0.23–2.45      | .65     |
| Dog breed                | Sighthound Reference          |     |                |         |
|                          | Non-sighthound                | 0.35| 0.09–1.34      | .13     |
| Cat breed                | Domestic short/long-haired    |     |                |         |
|                          | Pedigree 1                    | 0.11| 0.11–8.86      | .99     |
| Sex                      | Male Reference                |     |                |         |
|                          | Female                        | 0.69| 0.23–1.99      | .49     |
| Age                      | Unit—month                    | 1   | 0.99–1.02      | .4      |
| Weight                   | Unit—kg                       | 1.04| 0.98–1.09      | .14     |
| Comminution              | No Reference                  |     |                |         |
|                          | Yes                           | 0.52| 0.17–1.55      | .24     |
| Open fracture            | No Reference                  |     |                |         |
|                          | Yes                           | 0.32| 0.08–1.10      | .08     |
| Articular involvement    | No Reference                  |     |                |         |
|                          | Yes                           | 0.42| 0.13–1.27      | .13     |
| Other tarsal fracture    | No Reference                  |     |                |         |
|                          | Yes                           | 0.77| 0.22–2.56      | .67     |
| Surgical approach        | Lateral Reference             |     |                |         |
|                          | Dorsal                        | 1.46| 0.15–14.53     | .73     |
| Treatment method         | Pins or screws and wire       |     |                |         |
|                          | Plate                         | 0.47| 0.94–2.26      | .35     |
|                          | Arthrodesis                   | 1.21| 0.19–7.68      | .84     |
|                          | ESF                           | 2.06| 0.22–17.67     | .51     |
|                          | Nonsurgical                   | 0.27| 0.05–1.40      | .13     |
| Postoperative external coaptation | No Reference   |     |                |         |
|                          | Yes                           | 3.3 | 0.77–15.6      | .11     |
| Surgery duration         | Unit—minute                   | 1.01| 0.99–1.02      | .13     |
| Anesthesia duration      | Unit—minute                   | 1   | 0.99–1.01      | .35     |

(continues)
calcaneus, the mechanism of loading, and the pattern of the trabeculae. These factors also likely play a role in dogs and cats but characterization of the internal architecture of the calcaneus in dogs and cats is lacking and clearly the posture of dogs and cats vs. people prohibits extrapolation.

Our study showed a high occurrence of complications compared to previous reports with 61% of fractures associated with complications and 52% requiring reoperation. Ost et al reports 9% complications in 22 fractures treated surgically. We had 82% of fractures managed surgically compared to 55% by Ost et al, and the occurrence of complications for only fractures managed surgically increases to 65%. We expect the difference in complication occurrence is due to the different fracture configurations, with more comminuted and intra-articular fractures in our study. Although the breeds and species are different between the 2 studies, non-sighthounds in our study actually had a reduced odds of a poorer outcome score compared to sighthounds and therefore this is considered unlikely to be the cause of the altered complication rate.

Fractures associated with major complications were 13 times more likely to have a poorer outcome score. Major complications were often related to implant irritation or protrusion through the skin, necessitating implant removal. It may be tempting to underestimate the importance of this as a complication; however, with the incidence of major complications having a significant impact on eventual outcome, it is not only the morbidity of a second surgical procedure which must be considered but also the poorer outcome in the medium-term. At final follow-up, only 10% of animals were considered sound, without lameness, and the majority of animals had consistent or intermittent mild weight-bearing.

| Variable                  | Levels               | OR*       | 95% CI    | P value |
|---------------------------|----------------------|-----------|-----------|---------|
| Postoperative antibiotics | No                   | Reference |           |         |
|                           | Yes                  | 3.33      | 0.97–12.38| .06     |
| Postoperative reduction   | Anatomic reduction   | Reference |           |         |
|                           | Minimal malreduction | 2.94      | 1.17–7.95 |         |
|                           | Moderate malreduction|           |           | .03     |
| Implant placement         | Satisfactory         | Reference |           |         |
|                           | Unsatisfactory       | 0.1       | 0.01–2.99 | .14     |
| Any complication          | No                   | Reference |           |         |
|                           | Yes                  | 7.57      | 2.21–29.50| .002    |
| Major complication        | No                   | Reference |           |         |
|                           | Yes                  | 9.25      | 2.66–37.30| <.001   |

*Proportional odds logistic regression.

**TABLE 8** Multivariate estimated odds ratio (OR) for a poorer outcome score for dogs only

| Variable                  | Levels       | OR*       | 95% CI    | P value |
|---------------------------|--------------|-----------|-----------|---------|
| Dog breed                 | Sight-hound  | Reference |           |         |
|                           | Non-sighthound| 0.11      | 0.02–0.52 | .007    |
| Open fracture             | No           | Reference |           |         |
|                           | Yes          | 0.14      | 0.02–0.66 | .02     |
| Major complication        | No           | Reference |           |         |
|                           | Yes          | 27.78     | 5.34–199.80| <.001   |

*Proportional odds logistic regression.
lameness. These results present a dramatic difference in prognosis for calcaneal fracture stabilization compared to the positive prognosis reported in the current veterinary literature.1,6,16

Our study demonstrated fewer complications with plates and screws than with the use of lag/positional screws alone, lag/positional screws with tension band wires, or pins and tension band wires alone. Literature on calcaneal fracture stabilization reports infrequent use of plates,1,6 applied mostly for complex comminuted calcaneal fractures.1 In our study, 40% of fractures were comminuted and 9 fractures (4 comminuted, 5 simple) were stabilized with plates. Classification of calcaneal fractures using CT is used to standardize management of calcaneal fractures in people23 with the Sanders system being useful in determining treatment and indicating prognosis.20 There is no similar system for dogs and cats.

Our study did not find major complications with nonsurgical management of calcaneal fractures. This is likely biased by case selection as all cases managed conservatively were extra-articular and either non- or minimally displaced. In people, the goals of treatment for calcaneal fractures are to prevent chronic pain and arthritis by restoring calcaneal shape and joint congruency.42 Extra-articular fractures are often treated non-surgically except for fractures through the posterior tuberosity that destabilize the common calcaneal tendon.42 However, nonsurgical management of intra-articular fractures results unsatisfactory recovery due to disruption of the subtalar joint and alteration in foot biomechanics43–45 and ideal treatment for any displaced intra-articular fracture is anatomical reduction, stable fixation and early joint mobilization.46 Given the results in our study, based on case selection, nonsurgical management for minimally displaced extra-articular fractures can be successful and given the high complication rates associated with surgical management, this should be considered.

We showed for every 1 month increase in age, there was a 0.4% increased risk of major complication when adjusted for management strategy. This may reflect that younger dogs are expected to heal more quickly,47 reducing the risk of implant failure. Although not investigated, younger dogs may sustain different fracture configurations to older dogs which could affect healing. For example, 10% of the fractures in this study were Salter-Harris fractures in younger dogs, which may have less risk of complications than other fracture configurations.

Although open fractures had significantly lower odds of having a poor outcome score than closed fractures, the clinical plausibility of this finding is unclear. The open fractures were in animals aged between 3 months and 9 years and various surgical techniques were used. Confounding variables may explain the lesser risk. Of note was that in 8/10 fractures where postoperative reduction was assessed, anatomical reduction or minimal malreduction was recorded which may have promoted healing and a favorable outcome.

Univariate analysis showed postoperative antibiotics was associated with twice the risk of major complications, as was Center 2 compared to Center 1. There was a strong association between Center 2 and postoperative antibiotic use. Postoperative antibiotic use remained in the statistical model but referral center was excluded as the variables were considered collinear. This result likely reflects bias in the administration of postoperative antibiotics, given when the surgical procedure was longer or more complicated, which could also be associated with complications.

Univariate analysis also showed for every 1 unit decrease in surgical reduction score, there was 3 times the odds of a poorer outcome score. Intuitively, suboptimal reduction could increase the risk of implant failure or affect fracture healing, thereby increasing the risk for complications and a poor outcome. Postoperative reduction was not, however, associated with major complications on statistical analysis but all univariate analyses are highly confounded and the results should not be considered definitive. In people, the restoration of calcaneal shape and joint congruency are important goals of stabilization of calcaneal fractures12,48–50 and anatomical reduction improves outcomes.51,52 Given the importance of accurate reduction in people, it is not surprising that suboptimal reduction was associated with poorer outcomes in our study. It should be noted that final radiographic and clinical follow-up for some fractures in our study was short (median 12 weeks) and long term development of degenerative joint disease and associated lameness may have been underestimated.

This study shows differences in the configuration of calcaneal fractures in non-racing dogs and in cats, compared to reports focused on racing Greyhounds. There was a high occurrence of major complications but based on differences in implant selection and outcomes, complications may be reduced with appropriate case selection for nonsurgical management, or by application of plates and screws (rather than pins/tension band wires or screws) when surgery is indicated. The occurrence of major complications was associated with a poorer outcome score and the prognosis for resolution of lameness was guarded for this cohort.

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