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Running head: Calcaneal fractures in non-racing dogs and cats

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Abstract

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

Study Design: Retrospective multicenter clinical cohort study

Animals or Sample Population: Medical records from 2004 to 2013

Methods: Medical records were searched and 50 calcaneal fractures included for analysis. Complications were recorded and an outcome score applied to each case. Associations between potential risk factors and both major complications and final outcome scores were investigated.

Results: Twenty-seven (61.4%) cases developed complications (23 major and 4 minor). At final follow-up 4 cases (10%) were sound, 27 cases (64%) had either an intermittent or consistent mild weight-bearing lameness, 7 cases (17%) a moderate weight-bearing lameness and one case (2%) a severe weight-bearing lameness. Cases managed using plates and screws had a lower risk of complications than cases managed using pin and tension band wire, lag or positional screws or a combination of these two techniques (RR=0.16, [95% CI: 0.02; 1.02] p=0.052). Non-sighthounds had reduced odds of poorer outcome than sighthounds (OR = 0.11 [95% CI: 0.02; 0.50], p=0.005) and cases suffering major complications had more than 13 times greater odds of a poorer outcome (OR 13.4 [95% CI: 3.60; 59.5], $p<0.001$).

Conclusions: This study demonstrates a high complication rate associated with calcaneal fracture stabilization in companion animals and that a poorer outcome can be expected in cases that suffer complications. Accordingly, a more guarded prognosis may be given to owners than that applicable to racing greyhounds with calcaneal fractures.

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

Introduction

Tarsal fractures are seen commonly in working breeds,[1] often involving the calcaneus, the central tarsal bone (CTB), the numbered tarsal bones and the talus.[1] Despite this, there is a distinct paucity of information in the peer-reviewed veterinary literature regarding calcaneal fractures in non-working dogs and cats. Case series of calcaneal fractures in racing greyhounds have been reported,[1-6] but these are often considered to be fatigue or stress fractures [7,8] which are uncommon in other breeds of dog.[9] While suspected stress fractures have been reported in 2 cats [10] other literature proposes that tarsal injuries in cats, including calcaneal fractures, are largely traumatic in origin.[11] The pathogenesis, fracture patterns, treatment options and prognoses may differ between these stress fractures commonly seen in working breeds and the likely largely traumatic fractures seen in the general non-working companion animal population.

The pathogenesis of calcaneal fractures in dogs varies depending on their configuration and whether they involve other tarsal bones. Depending on which country the race is in, Greyhounds may race either clockwise (as in the United Kingdom) or counterclockwise (as in the United States). Counterclockwise racing is theorized to create excessive load on the medial aspect of the right pelvic limb causing compression fractures of the CTB[6]; clockwise racing wound create similar forces on the left. This results in an accumulation of forces on the lateral and plantar aspects of the tarsus which are relieved by calcaneal fracture.[6] Calcaneal fractures not associated with CTB fractures result from extreme tension on the plantar aspect of the calcaneus resulting in a transverse fracture or a plantarodistal chip fracture of the base of the calcaneus.[6] Iatrogenic [12,13] and pathologic [14] calcaneal fractures have also been reported. This pattern of pathogenesis is in contrast to that reported in the human literature where fractures of the calcaneus are typically produced by axial force [15] with a highly variable fracture pattern affected by the magnitude and direction of the impacting force, the foot position and the muscular tone.[15] Given the lack of information regarding non-working dogs and cats, whether the pathogenesis is more similar to that in working breeds or humans is unknown.

Four types of calcaneal fracture are generally recognized [1,16]; Salter Harris type 1 or 2 fractures involving the proximal calcaneal physis, mid-body fractures, slab fractures of the distolateral or dorsomedial calcaneus and fractures of the base of the calcaneus. The two reported stress fractures in cats were reported as complete transverse fractures at the base or body of the calcaneus.[10]

Various methods have been recommended for treatment of calcaneal fractures in dogs including external coapation,[1] tension band wiring,[1,6,17] lag screw application,[1,6] plate application,[1,6] arthrodesis of the calcaneoquartal joint [6] and biodegradable roads and osteosutures.[18] Which stabilization method is elected depends on the configuration of the fracture, presence of proximal intertarsal subluxation and presence of concurrent tarsal injuries.[1,6] Healing time and prognosis have not been shown to correlate with type of fracture or method of repair.[6]

In humans, despite extensive clinical experience treating calcaneal fractures, the final outcomes are reported to remain poor.[19] Various classification systems have been developed to improve management with some being helpful in determining treatment [20] as well as prognosis.[21,22] Calcaneal body fractures are known to have a better prognosis than intra-articular fractures [23] and a better outcome is achieved in some groups of surgically-treated patients.[24] Conversely in the limited reports available regarding calcaneal fractures in dogs, the prognosis is reported to be very positive with 95% (n=22) of surgically treated dogs with follow-up being sound at the time of radiographic union with only 2 complications encountered.[6] In the feline cases of suspected stress fracture a similarly positive prognosis has been reported [10] but results following significant numbers of traumatic calcaneal fracture in cats remain essentially unreported. In the authors' experience, the outcome following treatment of calcaneal fractures in the general companion animal population is more akin to what is described in the human literature and extrapolation of prognoses from these previous reports in working breeds may be misleading. The objectives of this retrospective study were therefore to estimate the prevalence of post-treatment complications, assess the expected outcome associated with calcaneal fractures in non-working dogs and cats and to investigate potential risk factors associated with major complications and final outcome.

Materials and Methods

The databases of 3 referral hospitals were searched for dogs or cats treated for a fracture of the calcaneus between January 2004 and December 2013. Racing greyhounds were excluded from analysis 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 classified as shown in Table 1 – while a specific classification scheme for calcaneal fractures in animals has not been reported this was based on the common fracture types which have been recognized previously. [1,16].

Fractures were also classified as comminuted or non-comminuted, open or closed, articular or non-articular and involving other tarsal bones or not. The treatment used was reported in addition to the surgical approach, if appropriate, and the use of external coaptation postoperatively. The fixation methods were classified as noted in Table 2.

Additional data retrieved included anesthesia time, surgical time and perioperative and postoperative antibiotic usage.

For cases where immediate postoperative radiographs were available, these were assessed by one of two board-certified surgeons for accuracy of reduction achieved postoperatively. As has been reported previously, reduction was classified as anatomic, minimal malreduction (<1mm), moderate malreduction (1-3mm), or severe malreduction (>3mm).[25] In addition, implant placement was classified as satisfactory or non-satisfactory.

The presence of post-treatment complications was recorded and the specific details of any complication also noted. Complications were defined as any undesirable outcome associated with the treatment and were classified as major (surgical intervention performed) or minor (managed non-surgically). Where revision surgery was performed, the details of the surgical technique used were recorded.

Postoperative data were also recorded including the time at which the first and subsequent post-treatment assessments were performed, physical examination findings at these assessments and radiographic findings at these assessments. For all cases where follow-up films were available, the radiographs were reviewed by one of 2 board-certified surgeons. The data from this review included progression of osseous union and development of articular pathology following articular fracture. These categories were based upon those used in a previous study. [25] Progression of osseous union was classified 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 classified as no radiographic evidence of articular pathology, joint effusion / soft tissue changes without evidence of osteoarthritis, early or minimal osteoarthritis, severe osteoarthritis or unable to assess due to arthrodesis having been performed.

Finally, based on the most recent data available, the cases were rated regarding their overall outcome in terms of lameness; 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; 5 - non weight-bearing lameness. This classification was adapted from a previous study.[25]

Statistical analysis

Continuous data were expressed as median values and ranges; categorical data were expressed as proportions with 95% confidence intervals (95% CI). The association between potential risk factors and major complications was assessed using univariable Poisson regression analysis with robust standard errors. To investigate risk factors for poor outcome each variable was assessed using a proportional odds regression model for final outcome score. Two continuous variables, age and weight, were examined as continuous, categorical and as multiple fractional polynomials to determine if there was any evidence of non-linearity in the association with major complication.[26] Factors with a p-value of <0.25 and any *a priori* potential confounding factors identified using causal diagrams were included in the multivariable Poisson model and proportional odds model.[27] The selected variables were then subjected to bivariate analysis with the objective to identify any collinearity between explanatory variables. Variables with the highest p-values were eliminated sequentially through backward selection to identify the most parsimonious model until only variables with p-values <0.05 and any confounding variables, determined by any change in the risk ratio (RR) or odds ratio (OR) for any risk factors >20% remained. Two way interactions were examined between explanatory variables and retained if $p<0.05$. 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 model 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 study. To assess risk factors for major complications and final outcome specific to dogs, the Poisson regression model with robust standard errors and the proportional odds regression model were also analyzed using dogs only.

Statistical analyses were conducted in R 3.2.1 [28] using the packages 'mfp',[29] 'MASS',[30] 'VGAM' [31] and 'sandwich'.[32]

Results

Signalment Data

A total of 50 calcaneal fractures affecting 36 dogs (one bilaterally simultaneously) and 10 cats (3 bilaterally; 2 simultaneously, one 25 months apart) were identified. Fifteen came from Center 1, 25 from Center 2 and 10 from Center 3.

Dogs – A variety of breeds were represented; 6 Lurchers, 4 Greyhounds, 5 cross breeds, 3 Labradors, 2 Border Collies, 2 Dalmatians and one each of Newfoundland, West Highland White Terrier, Patterdale Terrier, Staffordshire Bull Terrier, Beagle, Siberian Husky, Rhodesian Ridgeback, Yorkshire Terrier, Boxer, Rough Collie, Papillon, Doberman (bilaterally affected), Borzoi and Weimaraner. To examine the association between breed and management outcome, these were classified as 11 sighthounds and 26 non-sighthounds. Five dogs were male neutered (MN), 11 were male entire (ME), 8 were female neutered (FN) and 12 were female entire (FE). The weight was available for 22 cases and ranged from 3.06 to 48kg with a median of 21.2kg.

Cats – Breeds affected included 7 Domestic Short Hairs (DSH) (1 bilaterally affected), one Domestic Long Hair (DLH) (bilaterally affected), one Exotic Short Hair (ESH) (bilaterally affected) and one British Short Hair (BSH). Of the cats 4 were MN, one was ME, 4 were FN and one FE. The weight was available for 11 cat fracture cases and ranged from 1.48 – 5.8kg with a median of 4.01kg.

Causes

For many cases (21) the cause of the fracture was unknown. This included the bilaterally affected dog and all 3 bilaterally affected cats (which had all been missing for a number of days to weeks and returned with a plantigrade stance).

For those cases where the cause was known, 6 were caused by a fall or trauma whilst running, 3 occurred whilst running but with no trauma noted, 3 were secondary to road traffic accident, 4 occurred following a jump or a fall from a height, 5 were iatrogenic, 2 were due to the animal being trodden on, one was due to a cat bite, one due to getting a foot stuck and struggling to get free and one was pathological secondary to nutritional secondary hyperparathyroidisim. Iatrogenic fractures occurred secondary to osteomyelitis around an 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).

Calcaneal fracture classifications

Out of the 50 calcaneal fractures identified, 48 were classified into fracture configuration categories as shown in Table 3. Representative images of these fracture configurations are shown in Figure 1. Two fractures were not classified; one was a pathological fracture due to metabolic bone disease, which had already started to heal on presentation and for which an accurate configuration could not be discerned; for the other fracture the initial radiographs could not be found and therefore an accurate configuration could not be confirmed.

Twenty fractures were comminuted, 29 cases were not comminuted. One case was unknown. Fifteen fractures were open whilst 35 were closed.

Twenty injuries involved an articular surface (either directly due to the calcaneal fracture, or due to fracture of another tarsal bone concomitantly). Thirty cases were non-articular.

Thirty-six fractures did not involve any other tarsal bone whilst 14 did involve other bones within the tarsus. Ten of these involved concomitant fractures of the CTB, 2 involved fractures of the talus, one involved a fracture of the lateral malleolus and one involved fractures of both the fourth tarsal bone and the CTB.

Treatment

Thirty-eight cases were approached using a lateral approach and 2 using a dorsal approach (for pantarsal arthrodesis using a dorsally applied plate). The approach was minimal but unknown in one case where a circular external skeletal fixator (ESF) was placed. Seven fractures were managed without surgical intervention and owners elected euthanasia in the one bilaterally affected canine case. The treatment methods used are detailed in Table 2.

Out of the 41 cases managed surgically, 7 had no support bandage or frame applied postoperatively, 8 had a soft support dressing applied for 2 weeks only, 9 had a splinted dressing placed for 6-8 weeks, 4 had a Robert Jones dressing applied for 6-8 weeks, 9 had a cast applied for 6-8 weeks and 4 had a transarticular ESF applied for 6-8 weeks. (The additional case which has a transarticular ESF in place here over the 3 cases which were classified as being treated using a transarticular ESF as their primary fixation is a case where a minimal transarticular ESF was placed to provide additional support in a case considered unlikely to tolerate external coaptation).

The median surgical time was 140 minutes (range 60-305 minutes). The median anesthesia time was 260 minutes (range 115-510 minutes). Perioperative antibiosis was used for all surgically managed cases. Postoperative antibiosis was used for 28 cases (68.3%).

The accuracy of reduction was assessed immediately postoperatively and found to be anatomic in 12 cases. Minimal malreduction was reported in 15 cases, moderate malreduction in 8 cases and accuracy of reduction was unknown in 6 cases. No case was reported to have severe malreduction immediately postoperatively Implant placement was considered satisfactory for 35 cases. For one case, one K-wire was considered to be too long and for 5 cases radiographs were not available to review.

Forty cases returned for a first radiographic follow-up. For 4 cases, the exact timing of this visit relative to the surgery was not known but for the other 36, the median time postoperatively for this visit was 6 weeks (range 1-20 weeks). At this first follow-up appointment 12 cases were considered completely radiographically healed, 22 were considered to be progressing appropriately towards radiographic union for this stage, 2 were considered to be progressing inappropriately slowly towards union and 4 cases were considered to have failed. Two of the failures were due to infection necessitating implant removal and 2 were due to development of non-union.

Eighteen cases returned for a second radiographic follow-up at a median of 12 weeks (range 2-80 weeks) postoperatively. Two of these had been completely radiographically healed at the first revisit and remained so at this visit. Of the 16 cases which returned for a second follow-up which had not been completely healed at the first visit, 11 were now graded as completely radiographically healed, 4 were graded as progressing appropriately toward radiographic union while one further case had failed due to infection and necrotic bone necessitating implant removal followed by pantarsal arthrodesis.

Of the 20 fractures which were considered to affect an articular surface, at final follow-up, 5 were not considered to show any radiographic evidence of articular pathology, 4 showed joint effusion / soft tissue changes without evidence of osteoarthritis, 3 cases showed evidence of early / minimal osteoarthritis, and one case showed evidence of severe osteoarthritic changes. Arthrodesis had been performed in 3 cases and therefore the joints could not be assessed for this pathology, 2 cases were lost to follow-up, one case had no radiographs taken and for one case the radiographs could not be located.

Complications

Out of the total of 50 cases, 6 were lost to follow-up and were excluded from any further analysis, leaving 44 cases. Twenty-seven cases (61.4%) developed complications; 23 (52.3%) cases developed major complications that required surgery, and 4 (9.1%) developed minor complications. One dog with bilateral fractures was euthanased. One dog developed an osteosarcoma of the proximal tibia necessitating amputation 2 months postoperatively. As this was considered unlikely to be a complication arising directly from the fracture of the calcaneus, this complication was not included in the statistical analysis.

The total number of complications was 35 with 5 cases developing both major and minor complications and one case developing 3 minor complications. Twenty three of these complications were major and 12 minor. The types and number of each complication that occurred are shown in Table 4.

Outcome

The final post-treatment check was performed in 42 cases to assess the outcome following surgery or conservative management (euthanasia had been performed in 2). Final follow-up was performed at a median of 12 weeks post-treatment (range 2-204 weeks).

Lameness scores at final follow up documented 4 cases as grade 0, 14 as grade 1, 13 as grade 2, 7 as grade 3, and one as grade 4. Three cases were given a grade 6 (unclassified) on this scale as amputation had been performed.

Risk Factors Associated With Major Complication

Univariable analysis was used to examine the association between potential risk factors and major complications (Table 5). The risk of having a major complication at Center 2 was twice that of Center 1 (RR= 1.83 [95% CI: 0.79; 4.24], p=0.16) however there was no evidence of a difference between Centers 1 and 3 (RR= 0.82, p=0.75). Fractures stabilized using a plate were less likely to have major complications than those stabilized using pins and wire or screws (RR 0.17 [95%CI 0.03; 1.06], p=0.06), however there was no evidence to suggest a difference in complications between pins and wires or screws, and arthrodesis (p=0.56) or pins and wires or screws, and ESF (p=0.78). No major complications occurred in the 7 fractures treated conservatively. Cases given postoperative antibiotics had more than double the risk of major complications (RR 2.3 [95%CI 0.98; 5.41], p=0.06). Unsatisfactory implant placement postoperatively was associated with a 1.8 times higher risk of major complication (RR 1.81 [95% CI: 1.30; 2.50] p<0.001).

Nine potential risk factors met the criteria for inclusion in the multiple Poisson regression model with robust standard errors: referral center, breed of cat, age (as a linear variable), weight (as a linear variable), management strategy, use of postoperative support, use of postoperative antibiotics, level of anatomical reduction achieved, and implant placement. Center 2 was strongly associated with the use of postoperative antibiotics (p=0.003) and use of postoperative support and was left out of the multiple Poisson regression model. Only one implant was placed unsatisfactorily which failed, thus this variable was not included in the multiple regression model. Following a manual backward elimination process, 2 of the 7 candidate variables were included in the final model, age and management strategy. For every one-month increase in age, there was a 0.4% (RR = 1.004 [95% CI: 1.001; 1.01], p=0.049) increased risk of major complication when adjusted for the effect of management strategy. None of the cases managed conservatively had major complications; hence the risk of major complication was infinitely smaller than cases managed using pins and screws (RR= $6.7x10^{-9}$ [95% CI: $2.5x10^{-9}$; $1.8x10^{-8}$] p<0.001). Cases managed using a plate had a lower risk than cases managed using pins and wires or screws (RR = 0.16, [95% CI: 0.02; 1.02] p=0.052), however there was no evidence of a difference in risk of major complications between cases managed by arthrodesis (RR = 0.77, p=0.48) or ESF (RR=0.92, p=0.84) when compared to pins and wires or screws. The results of the model to assess risk factors specific to dogs, identified the same risk factors as the model which included both dogs and cats (Table 6).

Risk Factors Associated With Final Outcome

The final outcome was assessed using a standard lameness score as described above. The results of the univariate proportional odds model are presented in Table 7. For a one unit decrease in surgical reduction achieved, i.e. going from ‘anatomic reduction’ to ‘minimal malreduction’, cases demonstrated an almost 3 times greater odds of a poorer outcome score (OR = 2.94 [95% CI: 1.17; 7.95] p=0.03). For example the odds of ‘amputation’ versus lameness score of 4 or less was 2.94 times greater in cases with minimal malreduction compared to anatomic reduction. Likewise the odds of having a lameness score of 4 or amputation versus lameness score of 3 or less was 2.94 times greater in cases with minimal reduction compared to anatomical reduction. Cases that had any complications had more than 7 times greater odds of a poorer outcome than cases with no complications (OR 7.57 [95% CI: 2.21; 29.5] p=0.002) and cases with major complications had more than 9 times greater odds of a poorer outcome (OR = 9.25 [95% CI: 2.66; 37.30] p<0.001).

Twelve variables met the inclusion criteria for selection for the multivariable proportional odds logistic regression model, breed of dog (categorized as sighthound or non-sighthound), comminution, open fracture, articular fracture, use of postoperative support, surgical time, postoperative antibiotic use, level of anatomic reduction postoperatively, type of implant, any complications and major complications. For variables between which a strong association existed, only the variable with the lowest p-value for association with final outcome was kept. This resulted in comminution, articular fracture and any complication being removed in preference of open fracture and major complication.

Results of the final proportional odds model revealed that non-sighthounds had reduced odds of poorer outcome than sighthounds (OR = 0.11 [95% CI: 0.02; 0.50], p=0.005); open fractures had lower odds of a poorer outcome than closed fractures (OR = 0.18 [95% CI: 0.04; 0.70], p=0.02); cases that had major complications had more than 13 times greater odds of a poorer outcome (OR 13.4 [95% CI: 3.60; 59.5], p<0.001). The risk factors for poorer outcome specific to dogs, were identified as the same as those for dogs and cats together (Table 8).

The proportional odds model was compared to a multinomial logistic regression model using deviance goodness of fit test (p=0.75) and graphical methods employed to assess the proportional odds assumption. There was no evidence to suggest the proportional odds assumption did not hold.

Discussion

Results of this study demonstrated significant differences with respect to both outcome and fracture configuration frequencies, between this case population and previous reports of calcaneal fractures. In the study by Ost et al, the majority of fractures seen were small slab fractures (63%).[6] This is in stark contrast to the results in our study where only 16% were classified as slab fractures. Fractures of the base of the calcaneus were also less frequent in our study only occurring in 10% of cases, whereas in racing greyhounds these were seen in 20% of cases. The majority of fracture configurations seen in our study population were mid-body fractures (68%), which were reported in only 37% of cases previously. Another contrast is that a greater percentage of fractures in our study were comminuted (40%) in comparison to the previously reported 14%.[6] Similarly, in the study by Ost et al [6] 80% of calcaneal fractures were associated with CTB fractures whereas in our study this was only true in 20% of cases. The differing fracture configurations likely indicate differing pathogeneses between racing Greyhounds and companion dogs and cats.

Many of the fractures sustained during racing are thought to be fatigue or stress fractures.[7,8,33] Fatigue fractures result because of accumulation of microdamage in bone from excessive cyclic loading beyond the threshold for repair.[34,35] These types of fracture are rare in other types of dogs [9] but have been suspected in cats.[10] Counterclockwise racing creates excessive load on the medial aspect of the right pelvic limb which can lead to compression fracture of the CTB.[6] When the CTB is fractured, the talus travels distally and acts as a fulcrum over which the calcaneus fractures. In this situation, tarsal ligament avulsion fractures are common including dorsomedial and lateral saggital slab fractures.[1]

The non-working population in this study, would not have been subject to the same excessive loads or cyclic loading experienced by racing greyhounds and CTB fractures were infrequent. This subsequently may contribute to the low number of slab fractures and the differing fracture configurations noted.

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 suffered bilateral, simple complete transverse fractures, one at the base of the calcaneus and the other at the mid-body. Neither cat had a known history of trauma but this could not be excluded. In this case series, out of 13 calcaneal fractures in 10 cats, 3 had a known history of trauma and 3 were comminuted rendering stress fracture unlikely. One fracture was pathologic and one iatrogenic. However in the remaining 5 cases (in 3 cats) with simple transverse fractures of unknown cause, stress fractures cannot be ruled out. In order to avoid any potential impact on the results of this study by including potential stress fractures and grouping cats and dogs together as non-racing companion animals, the statistical tests were repeated including only the dogs. The risk factors identified associated with both complications and final outcome were the same as when cats and dogs were analyzed together and therefore the authors have discussed both species together for the remainder of the manuscript.

The fracture patterns noted in this study appear to have more in common with the patterns seen in calcaneal fractures in humans rather than those in racing Greyhounds with higher portions of mid-body and intra-articular fractures.[39,40] The authors postulate that this may be due to a higher incidence of traumatic injuries associated with axial force in this population in comparison to the fatigue fractures seen in Greyhounds. However, the pattern of fractures most commonly noted in people has also been associated with the trabecular pattern within the cancellous bone.[41] Common fracture patterns initiate 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 along trabecular weaknesses.[41] Three major factors are hypothesized to contribute to the fracture pattern in the calcaneus in people; the shape of the calcaneus, the mechanism of loading and the pattern of the trabeculae.[41] It is likely that all of these factors also play a role in dogs and cats, however, to the authors' knowledge, in-depth analysis of the internal architecture of the calcaneus in dogs and cats has not been carried out and extrapolation from the human studies is likely inappropriate due to the differing stance adopted by dogs and cats.

A major difference between this study and previous ones in this area is the high complication rate. In this study, 61% of cases developed complications, with 52% of cases developing major complications which required remedial surgery. In the study by Ost et al, a 9% complication rate was reported in 22 cases which were treated surgically. A higher number of cases were managed surgically in this study (82%) in comparison to the previous study (55%).[6] If only the cases managed surgically in our study are included then complications occurred in 65% of these. Similar stabilization methods were used in both studies and all surgeries were performed in specialized referral facilities so surgical decision-making and technique are considered unlikely to be the cause of the increased complication rate. More fractures were stabilized using plates in this study but this was associated with a lower complication rate in comparison to the other techniques and is considered unlikely to explain the differences in complication rates reported. While the breeds and species are significantly different between the 2 studies, this is also considered unlikely to be the reason for the increased complication rate. In our study, non-sighthounds actually had a reduced odds of suffering a poor outcome when compared to sighthounds. The authors consider it likely that the differing fracture configurations in this study, with a higher frequencies of comminuted and intra-articular fractures, may play a role in the increased complication rates noted. Further study would be needed to confirm this.

The differing complication rates in this study are important to consider as this study showed that cases that suffered major complications were also thirteen times more likely to suffer a poorer outcome. Many of the major complications reported here related to implant irritation or protrusion through the skin necessitating implant removal and 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-long term. At final follow-up in this study, out of 39 cases which were given a lameness score only 10% of cases were assessed as being sound. Whilst the majority of cases (69%) suffered only either a consistent or intermittent mild weight-bearing lameness, 18% had a moderate weight-bearing lameness and 3% a severe weight-bearing lameness. These results are important to be aware of as this represents a dramatic difference in prognosis for the owner considering calcaneal fracture stabilization when compared to the positive prognosis reported in the current veterinary literature.[1,6,16] The outcomes achieved in this study appear similar to the more guarded prognoses which are generally associated with calcaneal fractures in people where despite extensive clinical experience the final outcomes remain poor.[19]

This study demonstrated a lower complication rate associated 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. The limited literature which exists regarding calcaneal fracture stabilization indicates that plates are infrequently used,[1,6] and when they are used it is normally for complex comminuted calcaneal fractures.[1] In this study 40% of cases were comminuted and 9 cases were stabilized using plates. Out of the 9 cases where plates were used, 4 of these were comminuted fractures and 5 were non-comminuted. To the authors' knowledge, no robust evidence-based recommendations exist detailing the ideal surgical treatment of differing calcaneal fracture types. Computed tomographic classification of calcaneal fractures has been influential in improving understanding and standardizing management of calcaneal fractures in people [23] with the Sanders system being useful in determining treatment options as well as prognosis.[20] To date, no such classification is available for companion animals however, based on the results of this study, the use of plates and screws to stabilize calcaneal fractures may be recommended more frequently in this group of patients in an attempt to reduce the considerable complication rate.

An additional finding of this study was the lack of major complications associated with conservative management of calcaneal fractures. While this is interesting this is considered likely to be due to appropriate case selection. The 7 fractures managed conservatively included 3 mid-body non- or minimally displaced fractures, one minimally displaced non-articular slab fracture, one pathologic fracture secondary to nutritional secondary hyperparathyroidism which was already healing at the time of diagnosis, one minimally displaced Salter-Harris fracture in a 7 week old puppy, and one open minimally displaced slab fracture secondary to a cat bite. In humans, the goals of treatment for calcaneal fractures are stated to be to prevent chronic pain and arthritis by restoring calcaneal shape and joint congruency.[42] Extra-articular fractures are generally treated conservatively excepting fractures through the posterior tuberosity that destabilize the common calcaneal tendon.[42] However, conservative treatment of intra-articular fractures results in a slow and generally unsatisfactory recovery due to disruption of the subtalar joint and alteration in hind foot biomechanics.[43-45] The ideal treatment for any displaced intra-articular fracture is anatomical reduction, stable fixation and early joint mobilization.[46] Given the lack of complications associated with the fractures treated conservatively in this study and the impact of complications on outcome careful case selection should be employed when treating calcaneal fractures, and conservative management for non- or minimally-displaced extra-articular fractures can be recommended based on these results.

This study also demonstrated that for every one-month increase in age, there was a 0.4% increased risk of major complication when adjusted for the effect of management strategy. Younger dogs may be expected to heal more quickly,[47] reducing the risk of failure of implants which may explain this reduction in complication rate in younger dogs. An additional factor, which was not directly investigated in this study, is that younger dogs may suffer different fracture configurations to older dogs. For example, 10% of the fractures in this study were Salter-Harris fractures in younger dogs which may be anticipated to have a lower risk of complications when compared to some of the other fracture configurations identified.

One of the statistically significant findings was that open fractures had a lower odds of having a poor outcome than closed fractures. The authors do not appreciate an obvious explanation for this. When looking at the open fracture cases, a variety of breeds are included with a wide age range between 3 months and 9 years of age. A full spectrum of surgical techniques were used in these cases including pins and tension band wires (2), a combination of lag / positional screws and tension band wires (2), lag / positional screws only (2), plates and screws (4), conservative management (3), transarticular ESF (1), partial tarsal arthrodesis (1). One aspect which could have been a contributing factor to the outcome is that in 8 out of the 10 cases where reduction postoperatively was assessed, either anatomical reduction or minimal malreduction had been achieved which may have contributed to a better outcome. This may also be a type 2 statistical error. Further investigation may be helpful here in assessing which factors may explain this unexpected result.

In the univariable analysis, cases given postoperative antibiotics had more than double the risk of major complications and the risk of having a major complication at Center 2 was twice that of Center one. There was a strong association between Center 2 and postoperative antibiotic use. Postoperative antibiotic use remained in the statistical model but referral center was not included as the factors are considered collinear; a multiple regression model would not work as well with both factors included as one would diffuse the other out. There are several possible reasons for this association. For example, postoperative antibiotics may be more likely to be given when the surgical procedure was longer or more complicated which may predispose it to complications but it was not possible to evaluate this further due to the incomplete nature of retrospective data. This may warrant further study in the future.

Following univariable analysis in this study, for every one unit decrease in surgical reduction achieved, cases demonstrated an almost 3 times greater odds of a poorer outcome score. Suboptimal reduction may be anticipated to increase the risk of implant failure, delayed union and non-union and therefore suboptimal reduction may have simply increased the complication rate and hence the risk of a poor outcome. The reduction achieved, however was not identified as a risk factor associated with major complications on statistical analysis. In the human literature, the restoration of calcaneal shape and joint congruency are considered major goals when stabilizing calcaneal fractures [42, 48-50] and improved outcomes have been reported in those subsets of patients where anatomical reduction can be achieved by operative treatment.[51,52] In some cases, anatomical reconstruction of calcaneal shape and joint surfaces may be impossible, such as in highly comminuted fractures, and some authors recommend primary subtalar arthrodesis in these cases.[22,53] The maintenance of articular congruity is considered crucial and intra-operative imaging with radiography,[22] CT,[54] fluoroscopy [55] or subtalar arthroscopy [56] is recommended to ensure that this is achieved. Given the importance of achieving accurate reduction documented in the human field, it is perhaps not surprising that suboptimal reduction was associated with poorer outcomes in this study. It should also be noted that for some cases in this study, the follow-up time to both final radiography and final follow-up was relatively short (median 12 weeks), especially when considering the development of degenerative joint disease and subsequent lameness in the long-term. The importance of anatomical reduction may have been underestimated in this study due to this and further studies with longer-term follow-up may be warranted. Every effort should be made to achieve accurate reduction when stabilizing calcaneal fractures, and intra-operative imaging should be considered in complex cases. In cases where accurate reduction cannot be achieved, primary arthrodesis may be a viable option in order to prevent suboptimal outcomes.

The major limitation to our study was its retrospective nature which introduces numerous potential sources of error, particularly with regard to the potential for reporting inaccuracies and the lack of standardization in case management across multiple centers. The aim of this study was to estimate the prevalence of major post-treatment complications and to assess the expected outcome following calcaneal fractures and the statistical model was designed with this in mind. One of the main constraints of using multiple regression models with relatively small number of cases is the loss of power of tests of significance for the regression parameters corresponding to the true values. This limited the conclusions which could be drawn regarding other variables, but highlighted potentially interesting areas for future study.

In conclusion, this study demonstrated some significant differences in the configuration of calcaneal fractures between the companion animals reported here and the previous studies which have primarily focused on racing Greyhounds. It also demonstrated a high major complication rate associated with treatment of these fractures. The results indicate that with appropriate case selection, complication rates may be minimized by adopting conservative management where appropriate or by using plates and screws to stabilize where surgical management is necessary rather than pins and tension band wires or screws in isolation. The incidence of major complications was shown to impact significantly on the outcome for these patients and the prognosis for resolution of lameness was shown to be guarded in this study. These findings will assist veterinarians in providing owners with a more accurate prognosis in the face of these injuries and may assist in surgical planning. Future studies are indicated to further investigate the impact of fixation method on complication rate and the etiopathogenesis of calcaneal fractures in companion animals.

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Disclosure Statement

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

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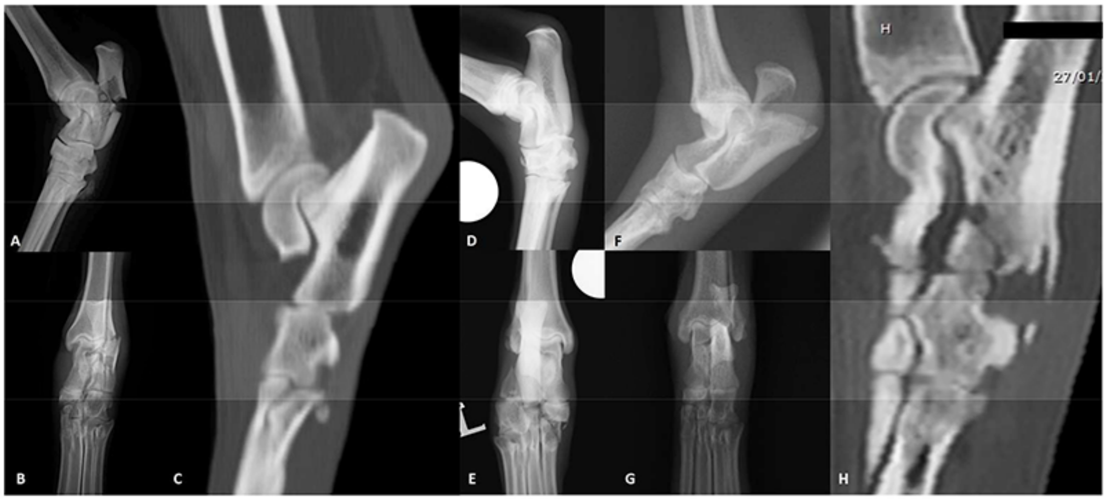
Figure 1: Representative images of selected calcaneal fracture configurations from the classification scheme



The images represent various classifications used in this study. Computed Tomographic (CT) images have been used where these more clearly delineate the fracture configuration. Mediolateral (A) and caudocranial (B) radiographic views of a mildly comminuted mid-body fracture; sagittal slice from a CT scan demonstrating a cranial slab fracture (C); mediolateral (D) and caudocranial (E) radiographic views of a distolateral slab fracture; mediolateral (F) and caudocranial (G) views of an avulsion fracture of the calcaneal tuberosity; sagittal slice from a CT scan demonstrating a fracture of the base of the calcaneus (H).

Table 1: Classification Scheme for 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

Table 2: Classification Scheme and Treatment Methods Used for Calcaneal Fractures

Category	Stabilization Technique / Treatment	Number of cases	Number which received external coaptation
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	Conservative management	7	3
10	Euthanasia	1	N/A

Table 3: Frequency of different calcaneal fracture configurations.

Fracture configuration	**Number affected (%)**
Mid-Body	27 (67.5)
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)

Table 4. Numbers and Types of Complications Occurring Following Calcaneal Fracture Treatment in Dogs and Cats

Complication	Classification	Number
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
Non-union 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 six week course of appropriate antibiosis	Minor	1

Table 5: Potential risk factors for major complications following calcaneal fracture management.

		Number of animals	Number (%) with complications	Unadjusted RR[§]	95% CI	p-val
Center	Center1	11	4 (36.4%)			
	Center 2	23	16 (69.6%)	1.83	(0.79; 4.24)	**0.**
	Center 3	10	3 (30.0%)	0.82	(0.24; 2.82)	0.
Species	Dog	33	19 (57.6%)			
	Cat	11	4 (36.4%)	0.66	(0.28; 1.54)	0.
Dog Breed	Sighthound	10	6 (60.0%)			
	Non-sighthound	23	13 (56.5%)	0.87	(0.46; 1.67)	0.
Cat Breed	DSH or DLH	8	2 (25.0%)			
	Pedigree	3	2 (66.7%)	2.67	(0.63; 11.28)	**0.**
Sex	Male	21	11 (52.3%)			
	Female	23	12 (52.1%)	1.1	(0.60; 2.04)	0.
Age	per month	43		1.01	(1.00; 1.01)	**0.**
Weight	per kg	29		1.02	(1.00; 1.05)	**0.**
Comminution	No	23	14 (60.9%)			
	Yes	20	9 (45.0%)	0.78	(0.43; 1.45)	0.
Open fracture	No	31	16 (51.6%)			
	Yes	13	7 (53.8%)	1.12	(0.59; 2.09)	0.
Articular involvement	No	26	15 (57.7%)			
	Yes	18	8 (44.4%)	0.82	(0.44; 1.55)	0.
Other tarsal fracture	No	32	16 (50.0%)			
	Yes	12	7 (58.3%)	1.25	(0.68; 2.31)	0.
Surgical approach	Lateral	33	19 (57.6%)			
	Dorsal	2	1 (50.0%)	0.87	(0.21; 3.58)	0.
Surgical technique	Pins or screws and wire	20	15 (75%)			
	Plate	8	1 (12.5%)	0.17	(0.03; 1.06)	**0.**
	Arthrodesis	5	3 (60.0%)	0.8	(0.37; 1.71)	0.
	ESF	3	2 (66.7%)	0.89	(0.38; 2.06)	0.
	Conservative	6	0 (0%)	-	-	
Postop support	No	7	2 (0.29%)			
	Yes	29	19 (65.6%)	2.29	(0.69; 7.62)	**0.**
Surgical time	per minute	20		1	(0.99; 1.01)	0.
Anesthesia time	per minute	21		1	(1.00; 1.00)	0
Postop antibiotics	No	13	4 (30.8%)			
	Yes	24	17 (70.8%)	2.3	(0.98; 5.41)	**0.**
Reduction achieved	Anatomic reduction	11	4 (36.4%)			
	Minimal malreduction	12	8 (66.7%)			

	Moderate malreduction	7	5 (71.4%)	1.38	(0.93; 2.06)	**0.**
Implant placement	Satisfactory	29	16 (55.1%)			
	Unsatisfactory	1	1 (100%)	1.81	(1.30; 2.50)	**<0.0**

§ Risk ratios were calculated using Poisson regression model with robust standard errors

Table 6: Risk factors for major complications in the final multiple Poisson regression model with robust standard errors for dogs only (excluding cats)

Risk Factor	RR	95% CI	p-value
Age	1.01	(1.001; 1.01)	**0.049**
Fixation method			
pins or screws			
plate	0.33	(0.06; 1.76)	0.19
arthrodesis	0.75	(0.36; 1.56)	0.45
ESF	0.7	(0.19; 2.65)	0.6
Conservative	6.9×10^{-9}	(2.3×10^{-9}; 2.0×10^{-8})	**<0.001**

Table 7: Potential risk factors for poorer outcome score assessed using proportional odds logistic regression.

		Odds Ratio	95% PI	p-value
Center	Center1			
	Center 2	1.04	(0.29; 3.84)	0.94
	Center 3	0.36	(0.08; 1.60)	**0.18**
Species	Dog			
	Cat	0.76	(0.23; 2.45)	0.65
Dog Breed	Sighthound			
	Non-sighthound	0.35	(0.09; 1.34)	**0.13**
Cat Breed	DSH or DLH			
	Pedigree	1	(0.11; 8.86)	0.99
Sex	Male			
	Female	0.69	(0.23; 1.99)	0.49
Age	per month	1	(0.99; 1.02)	0.4
Weight	per kg	1.04	(0.98; 1.09)	**0.14**
Comminution	No			
	Yes	0.52	(0.17; 1.55)	**0.24**
Open fracture	No			
	Yes	0.32	(0.08; 1.10)	**0.08**
Articular involvement	No			
	Yes	0.42	(0.13; 1.27)	**0.13**
Other tarsal fracture	No			
	Yes	0.77	(0.22; 2.56)	0.67
Surgical approach	Lateral			
	Dorsal	1.46	(0.15; 14.53)	0.73
Surgical technique	Pins or screws and wire			
	Plate	0.47	(0.94; 2.26)	0.35
	Arthrodesis	1.21	(0.19; 7.68)	0.84
	ESF	2.06	(0.22; 17.67)	0.51
	Conservative	0.27	(0.05; 1.40)	**0.13**
Postop support	No			
	Yes	3.3	(0.77; 15.6)	**0.11**
Surgical time	per minute	1.01	(0.99; 1.02)	**0.13**
Anaesthesia time	per minute	1	(0.99; 1.01)	0.35
Postop antibiotics	No			
	Yes	3.33	(0.97;12.38)	**0.06**
Reduction achieved	Anatomic reduction			
	Minimal malreduction			
	Moderate malreduction	2.94	(1.17; 7.95)	**0.03**

Implant placement	Satisfactory Unsatisfactory	0.1	(0.01; 2.99)	**0.14**
Any complication	No Yes	7.57	(2.21; 29.5)	**0.002**
Major complication	No Yes	9.25	(2.66; 37.30)	**<0.001**

Table 8: Risk factors associated with poorer outcome scores assessed using multiple proportional odds logistic regression for dogs only (excluding cats)

Variable	Category	OR	95% CI	p-value
Dog breed	Sight-hound			
	Non-sighthound	0.11	(0.02; 0.52)	0.007
Open fracture	No			
	Yes	0.14	(0.02; 0.66)	0.02
Major complication	No			
	Yes	27.78	(5.34; 199.8)	<0.001