RADIOGRAPHIC, COMPUTED TOMOGRAPHIC, AND HISTOLOGIC STUDY
OF CENTRAL TARSAL BONE FRACTURES IN RACING GREYHOUNDS

A THESIS
Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science
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Fracture of the right central tarsal bone (CTB) is a common injury in racing greyhounds. The aim of this study was to use standard radiography, computed tomography (CT), and histology to evaluate changes in CTB of racing greyhounds to determine an underlying cause of fracture. Paired tarsi from 12 racing greyhounds were evaluated; six dogs had sustained fractures to the right CTB. Radiographs and CT were evaluated on intact tarsi and dissected CTB. The bone mineral density gradient was calculated in the sagittal plane of each bone and on either side of fracture planes. Fractured right CTB had greater bone mineral density, in the dorsal and mid body regions, when compared to the contralateral CTB and non-fractured right CTB. Dorsal slab fractures occurred though zones of uniform density. Data from this study are the first to support the phenomenon of site specific remodeling in fractured right CTB of racing greyhounds.
To my parents, Linda and John;

For their endless love and support, and for allowing me to follow my dream.
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CHAPTER 1

INTRODUCTION

Greyhound racing is a popular international sport, and is the sixth most popular spectator sport in the USA [1]. Greyhound racing reached its peak of popularity in 1992, when 3.5 million spectators watched greyhound racing in more than 16,827 races. Successful track dogs are often raced hundreds of times in their racing career, averaging speeds around 40mph per race [1]. The intense training, high speed racing, and repetitive motions predictably cause a large number of athletic injuries [2,3]. Primarily injuries are related to fractures of the diaphysis of long bones including the tibia, fibula and metatarsal bones, as well as the cuboidal bones, namely the central tarsal bone and radial and accessory carpal bones [4-7]. Soft tissue injuries to collateral ligaments, the flexor carpi ulnaris tendon and dorsal radiocarpal ligament have been described [8,9]. Both the physiology and biomechanics of the racing greyhound are different from non-sight hound breeds, which in part explain why common injuries in racing greyhounds are rare in other breeds of dogs [10]. Many of the fractures sustained by racing greyhounds are considered
to be fatigue fractures, similar to those sustained by human athletes, dancers, and racehorses [11-13].

Sight hounds have a unique top speed gait termed the double suspension gallop. It consists of a series of leaps resulting in two phases in which the dog is completely airborne in each gait cycle. In short bursts, the greyhound can achieve speeds of 60 miles per hour. Greyhounds always race counterclockwise on a circular or oval racetrack. Sprinting around a bend increases effective body weight, as body mass is affected by both gravity and centripetal acceleration (Figure 1.1). A recent study, which evaluated both human track racers and greyhounds on oval tracks, was reported in the journal Nature [14]. The authors found that the maximum racing speed is limited by the speed at which the limbs can be swung forwards and backwards, and by the force the subject could withstand while in contact with the ground. Human subjects sprinting around banked bends were observed to change the duration of foot contact with the ground in order to spread the time over which the load is applied. This, in effect, kept the force on their legs constant. Greyhounds, on the other hand, did not change their foot contact timings, which resulted in an increase in limb forces by 65%. Centripetal acceleration resulted in an increase in effective body weight of 71%. They concluded that this supported the idea that greyhounds power their locomotion by torque about the hips, so the muscles which provide the power (back, hind limbs) are mechanically separated from those which sustain the majority of the impact (forelimbs). Thus the hind limbs and back are robust in musculature while the forelimbs are dominated by bone, tendon and pinnate muscles, which act similar to passive springs, and are capable of opposing considerable weight-induced forces.
Figure 1.1: Mechanics of greyhounds turning bends[14]. a.) Mean acceleration vectors (drawn to scale) opposed by limb forces for greyhounds sprinting around a bend; $g$ is the acceleration due to gravity, $V^2/r$ is the centripetal acceleration, and $a$ is the resultant acceleration. b.) Stance period (duration of foot contact with the ground) and swing period (the remainder of the stride) for individual limbs. Bars: green, first straight; orange, bend; red, second straight. c.) Proportion of each stride spent by foot on the ground (duty factor) for individual limbs. d.) Derived peak force on limbs estimated for greyhounds sprinting on the first straight and around a bend of radius 22.4 m. $F_{\text{max}}$ is the maximum reaction force on each limb and $m$ is body mass. Greyhounds experience substantially higher peak limb forces when running around the bend.
Sicard and colleagues evaluated racing injuries incurred over a two year period at five greyhound tracks in Wisconsin, USA [4]. One track had a significantly greater injury rate, and this track had a shorter initial straightway, a decreased turning radius, and had an increased turn bank. While temperature, body weight, race number, and type of trauma had no significant effect on injury rate, the authors did identify an effect of race length and grade (speed) on increased injury rate. The same study documented that racing injuries are most likely to occur at the first turn of the race, which may be related to increased speed at the first turn, and therefore increased load on the limbs.

Central tarsal bone (CTB) fractures occur in human athletes, horses, and dogs. While fatigue fractures are typically associated with long bones, cuboidal bones, especially those of the mid-foot, are also susceptible to fatigue. The structure of mid-foot cuboidal bones, with an outer shell of compact lamellar bone surrounding trabecular bone, with two or more articular surfaces differs significantly from diaphyseal long bone structure. Cuboidal bones are also subject to different loads and strains as compared to long bones. The CTB, for example, is assumed to be mainly subjected to compressive loading. Although the pathogenesis of fatigue fractures of diaphyseal bone due to cyclic loading has been investigated, much less is known about the process in cuboidal bones, which may respond differently.

The central tarsal bone is located on the medial aspect of the tarsus, residing distal to the talus, and proximal to tarsal bones 1, 2, and 3. The CTB also articulates with the calcaneus and fourth tarsal bone laterally. It is subject to considerable compressive stress, especially in counterclockwise turns, and acts as a buttress for these substantial forces.
Thus, the CTB is subject to severe cyclic loading, fatigue failure, and fracture. Fractures of the CTB often result in tarsal varus and plantar convexity.

A recent study by Colborne et al. found gross differences between greyhounds and Labrador retrievers in the kinematic patterns in the stifle, tarsal, and metatarsophalangeal joints [10]. While trotting on a treadmill, moment and power patterns were similar in shape for the stifle and tarsal joints, but amplitudes were larger for greyhounds (Figure 1.2). The metatarsophalangeal joint was a net absorber of energy in both breeds, but it was greater in the greyhound. Labrador retrievers had only one positive phase, which was across the tarsus, which was small as compared to greyhounds, which had a positive phase across all three joints at the end of stance for an active push-off. Angular and mechanical patterns of the metatarsophalangeal joint differed grossly between the two breeds (Figure 1.3). Flexion of the metatarsophalangeal joint in Labrador retrievers was not detected until almost midstance, whereas the metatarsophalangeal joint in greyhounds was an effective absorber of energy as it dorsiflexed after ground contact and through midstance. This energy was returned in a burst of positive work at the end of the stance phase, whereas the push-off burst was negligible in the retrievers. These significant variations in kinematics between breeds may play a part in the explanation why some breeds are commonly affected by cranial cruciate ligament disease or CTB fracture, whereas other breeds, are rarely affected.

The phenomenon of bone fatigue has been investigated in human and animal athletes. The principle is that cyclic compressive loading of bone leads to microdamage (cracks) and that the accumulation of microdamage results in bone remodeling/modeling.
Figure 1.2: Joint angles, net joint movement, net joint power of tarsal joints in greyhounds and Labrador retrievers in the stance phase [10]. Mean (solid line) and standard deviation (dashed lines) for joint angle (A and B), net joint moment (C and D), and net joint power (E and F) for the tarsal joints of six Labrador retrievers (A, C, and E) and six greyhounds (B, D, and F) during the stance phase.
**Figure 1.3:** Joint angles, net joint movement, net joint power of metatarsophalangeal joints in greyhounds and Labrador retrievers in the stance phase [10]. Mean (solid line) and standard deviation (dashed lines) for joint angle (A and B), net joint moment (C and D), and net joint power (E and F) for the metatarsophalangeal joints of six Labrador retrievers (A, C, and E) and six greyhounds (B, D, and F) during the stance phase.
Matrix microdamage has been documented in CTB from racing greyhounds [15]. In this study, microcracks were longer in the right CTB, and there was a greater density of microcracks in right CTB, suggesting a possible role of microcrack formation in the ultimate development of fracture. Johnson et al. found asymmetric adaptive modeling in greyhound CTB, as evidenced by thickening of cortical bone and coalescence of trabeculi in right CTB as compared to left CTB [19]. This response may be reparative to the formation of microcracks and may represent site specific bone adaptation. Upon CT imaging of tarsi, they found that bone mineral density was greater in racing greyhound CTB as compared to non-racing greyhounds, and that the dorsal region of right CTB has thicker and has more compact trabeculae. Interestingly, there was a partial reversal of changes present in retired racing greyhounds.

Fractures of the CTB occur when the adaptive response is inadequate or does not respond fast enough to cyclic loading stress. Fractures are classified into types I-V based on the configuration of the fracture. Type I consists of a dorsal slab fracture of the CTB without displacement of the fracture. Type II is a dorsal slab fracture with displacement present. A type III CTB fracture is uncommon and consists solely of a medial slab fracture. Boudrieau reported that many suspected type III fractures may actually have a non-displaced dorsal slab as well, therefore care should be taken in making a correct identification of fracture type in order to plan a successful fracture repair [20]. A type IV CTB fracture is the most commonly identified configuration and consists of a dorsal and medial slab fracture. A type V fracture is highly comminuted and frequently is non-reconstructable.

Due to the anatomic location and multiple articulations of the CTB, fractures of the CTB are frequently associated with other secondary fractures. Overall, 64% of tarsi with a CTB fracture have at least one secondary fracture [21]. In a study of 114 dogs, 45% of CTB fractures also had a fracture of the fourth tarsal bone, 28% had a transverse
fracture of the calcaneus, and 28% had an avulsion fracture of proximal MT5. Boudrieau reported that the prevalence of secondary fractures increases with the severity of the CTB fracture [21].

Management of CTB fractures greatly depends on the fracture type, the presence of secondary fractures or ligamentous injury. External coaptation in the form of a lateral splint could be utilized in any fracture type, however may have a poorer outcome, as fewer dogs treated with external copatation return to racing (58% vs. 88% treated surgically) [20]. Fracture types I and II are frequently repaired with a single dorsoplantar screw to provide interfragmentary compression across the fracture plane. The approach is made on the dorsomedial aspect of the tarsus with the cranial tibial tendon medially, and the long digital extensor laterally. Typically, a 2.0 or 2.7 mm cortical screw is placed in lag fashion into the plantar process, and the head is countersunk in order to distribute load. Frequently, external coaptation will be utilized for 3-6 weeks post-operatively. A two-screw fixation is often used for type III and IV fractures. A dorsoplantar screw is placed proximal to a 4.0 mm cancellous screw which is placed from the CTB into the fourth tarsal bone. The point of insertion of this screw is just proximal to the origin of the oblique intertarsal ligament (which attaches the CTB to T2). The head of this screw is also countersunk. Several prosthetic implants or spacers have been described for type IV and V fractures, but their use is rarely reported in the literature. The first implant was made of acrylic [22], later came the polyethylene implant which was found to be insufficiently durable enough to withstand cyclic loading. The titanium alloy implant was described in the late 1980’s and was reported to be both durable and biocompatible. It is secured with a mediolateral screw into the fourth tarsal bone. In a case report of one bitch
who returned to successful racing after implantation, there was no evidence of osteoarthritis or implant loosening 9.5 months post-operatively [23,24].

A summary of the outcomes of racing greyhounds that sustained CTB fractures is shown in figure 1.4. Most dogs had radiographic evidence of intertarsal ankylosis, but this did not appear to adversely affect clinical outcome post-operatively. Remodeling of the fractured bones occurred over a 4-6 month time period. Additionally, there was a decreased degree of osteoarthritis in dogs what had surgical treatment as compared to those that had external coaptation. Factors which may affect the overall outcome following CTB fractures include the inaccurate identification of fracture type and presence of secondary fractures, the surgeon’s lack of experience with the specific repair, failure of the dog to return to racing post-operatively for reasons unrelated to the tarsal injury, and finally, a skewed population of dogs receiving treatment, as surgery may not have been pursued in average racers, older dogs, or because of the cost, lay-up period, or a perceived poor prognosis. Additionally, and perhaps most importantly, equipment and imaging advances may positively affect the outcome following CTB fracture in dogs. Ultimately, the overall prognosis following CTB fracture is good to excellent, and the outcome may be improved if more cases are managed surgically versus with external coaptation.

Central tarsal bone fractures have been infrequently described in other breeds of dogs. Two Dalmatians sustained type III CTB fractures of the left tarsus during normal pet (non-racing) activity. These dogs received a standard one-screw repair and had an excellent recovery [25]. A basset hound and a series of border collies have also been reported to have CTB fractures, but these have been often accompanied by secondary
fractures and CTB luxation [26,27]. The outcome of CTB fracture in breeds other that the greyhound appears to be equally good.

Future areas for study of CTB fractures are several. A more accurate clinically useful methodology for evaluating the type of CTB fractures and secondary fractures should be validated and used to routinely grade all fractures. Proper follow-up should be instituted and post-operative outcomes updated from the Boudrieau papers. Further, better correlation of CT imaging, standard radiography, and histomorphometric evaluations should be made.
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<th>Euthanized</th>
<th># racing</th>
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<td>7</td>
<td>2</td>
<td>14</td>
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**Figure 1.4:** Summary of the racing outcome of greyhounds that sustained CTB fractures [20].
2.1 Introduction and hypotheses:

Fracture of the right central tarsal bone (CTB) is a common injury in racing greyhounds. These fractures have been classified into five types; all of which usually contain a dorsal slab component. The cause of these fractures has not been rigorously investigated, but it is suspected that racing in a counter clockwise direction on oval tracks produces cyclic overload of the medial compartment of the right tarsus. Previously, it has been shown that the right CTB of healthy racing greyhounds have evidence of matrix microdamage and secondary remodeling which in turn leads to increase in bone size and density, especially in the dorsal region of the right CTB. However, fractured CTB from racing greyhounds have not been previously studied, except by standard radiography. The aim of this study was to use standard radiography, computed tomography (CT), and histology to evaluate changes in the CTB of racing greyhounds which sustained a fracture to determine an underlying cause of CTB fracture. We hypothesized that there would be increased bone density in the right CTB of all dogs when compared to the left CTB, and
that the bone density of fractured right CTB would be greater than non-fractured right CTB. Further, we hypothesized that the dorsal slab density would be significantly greater in fractured CTB when compared to non-fractured CTB and that the dorsal slab would fracture through a transition zone of more dense and less dense bone.

2.2 Materials and Methods:

Paired tarsi from 12 racing greyhounds were collected after euthanasia due to reasons unrelated to this study. Six dogs had sustained fractures to the right central tarsal bone; the remaining six dogs did not sustain any tarsal injury prior to euthanasia. The tarsi were harvested post-mortem and stored at -80°C until use in the study. Radiographic and CT imaging of each intact tarsus was performed and the tarsi were replaced into the -80°C freezer. This freezer sustained an electrical malfunction and lost power to sustain appropriate cooling of its contents. At the time of the discovery of the malfunction, the tarsi were in various stages of decomposition, and the CTB were dissected from the tarsi for imaging of the individual CTB.

2.2.1 Radiographic study

Mediolateral, plantarodorsal, plantarolateral-dorsomedial oblique, and plantaromedial-dorsolateral oblique radiographic views were obtained for each tarsus. (Figure 2.1) The radiographs were evaluated for CTB fracture and if a fracture was identified, it was classified as type I-V. Additionally, the number of fracture fragments was estimated and the presence and type of concurrent tarsal bone injuries was determined.
Figure 2.1: Plantarodorsal (A), mediolateral (B), plantarolateral-dorsomedial oblique (C), and plantaromedial-dorsolateral oblique (D) radiographic views were obtained for each tarsus. Fracture types were classified and the number of CTB fracture fragments was estimated. Additionally, the presence and type of concurrent tarsal bone injuries was determined.
2.22 Computed tomographic study

Each intact tarsus was imaged with a Picker PQS helical CT machine using a joint algorithm. A series of 1 x 1-mm contiguous transverse and sagittal plane images with a 140 mm FOV and 512 x 512 matrix (voxel element = 0.075 mm$^3$) were acquired. A calibrated dipotassium phosphate CT phantom, containing a range of known density values ranging from cortical bone to fat, was scanned with each tarsus to enable internal calibration for quantification of bone mineral densities. CT attenuation data were converted from Hounsfield units to dipotassium phosphate equivalent density (PPED) for universal comparisons.

The CT images were evaluated for the presence of CTB fracture. If a fracture was identified, it was classified as type I-V. Additionally, the number of fracture fragments was estimated and the presence and type of concurrent tarsal bone injuries was determined. (Figure 2.2)

2.23 CTB reconstruction

CTB were dissected from each tarsus. (Figure 2.3) The number of fragments greater than 1mm$^3$ in size from each fractured CTB was counted and each bone was reconstructed anatomically with the aid of cyanoacrylate. CTB were then embedded in polymethylmethacrylate (PMMA).

2.24 Imaging of individual CTB

Transverse and sagittal CT images were obtained of each PMMA-embedded CTB, in the same protocol as the entire tarsi. (Figure 2.4) A representative transverse and
Figure 2.2: Sagittal (A) and transverse (B) images were obtained of each intact tarsus by computed tomography.
sagittal slice was chosen from the images in each series to calculate bone mineral density. Density plots were created for visual assessment of each slice (Figure 2.5). The selected transverse and sagittal slices were approximately equidistant in the proximo-distal and mediolateral planes, respectively. The bone mineral density gradient was calculated in six 1mm regions of interest from each bone in the sagittal plane; region 1-6, dorsal to plantar (Figure 2.6). Bone mineral density in fractured CTB was measured on either side of fracture planes and was expressed as a ratio, and then this ratio was compared to density ratios in the same regions in the non-fractured right CTB. (Figure 2.7) CT data were converted from Hounsfield units to dipotassium phosphate equivalent density (PPED) to allow for universal comparisons.

2.25 Histologic preparation and evaluation

Non-decalcified CTB were infiltrated and embedded in polymethylmethacrylate (PMMA) under vacuum and these embedded samples were sectioned in the mid-transverse and mid-sagittal planes and ground to 100um on a surface grinder (EXAKT systems, Inc.). Each slide was then surface stained with Masson’s Trichrome. Each slide was evaluated qualitatively to assess bone type and to confirm the absence of a reparative response or other pathologic process including osteomyelitis and neoplasia. Contact radiographs were taken of each 100um section and then each section was qualitatively evaluated for variations in bone density (Figure 2.8).
2.26 Statistical analysis

Data analysis with linear mixed effects models was performed using Statistical Analysis Systems, SAS, version 9.1.3 (SAS Institute Inc., Cary, NC). Differences were considered significant if P<0.05.
Figure 2.3: Dissection of fractured CTB. After each tarsus had been thawed to room temperature, each CTB was dissected from the soft tissues. The number of fracture fragments $>1\text{mm}^3$ was calculated, and then the fractured CTB were reconstructed with the aid of cyanoacrylate.
Figure 2.4: After reconstruction of the fractured CTB, all dissected CTB were embedded in polymethylmethacrylate and computed tomography imaging was repeated. Image A depicts a transverse image of a fractured CTB in situ, and image B shows CT imaging of the same CTB after dissection and reconstruction.
Figure 2.5: Color bone mineral density plots in the transverse plane of a fractured right CTB (A) and a non-fractured left CTB (B). Fractured right CTB had greater bone mineral density within the dorsal and mid-dorsal regions. Data are reported as PPED.

Figure 2.6: A bone mineral density gradient was calculated in six 1mm regions of interest in the sagittal plane of each CTB; region 1-6, dorsal to plantar, on CT imaging.
2.3 Results:

2.3.1 Fracture classification based on standard radiography

Five dogs sustained a type IV fracture and one dog sustained a type II fracture of the right CTB based on standard radiography. The number of suspected fracture fragments ranged from 2 to 6 (median 3). Concurrent tarsal fractures were identified in 3/6 dogs and one dog had a suspected talocalcaneal subluxation based on standard radiography. Three dogs had radiographic evidence of fracture to the fourth tarsal bone. All other CTB were within normal limits.

2.3.2 Fracture classification based on CT imaging

Five dogs sustained a type IV fracture and one dog sustained a type II fracture of the right CTB based on CT image evaluation. The number of suspected fracture fragments greater than 1mm$^3$ ranged from 2 to 11 (median 6). Concurrent tarsal fractures were identified in 5/6 dogs. Four dogs had radiographic evidence of fracture to the fourth tarsal bone. All other CTB were within normal limits.

2.3.3 Fracture classification based on gross evaluation

Five dogs sustained a type IV fracture and one dog sustained a type II fracture of the right CTB based on gross evaluation. The actual number of measureable fracture fragments in each CTB ranged from two to 13 fragments (median 7 fragments).
Figure 2.7: Bone mineral density was measured on either side of fracture planes of fractured CTB (A) and was expressed as a ratio and then this ratio was compared to density ratios in the same regions in the non-fractured right CTB (B).
Figure 2.8: Contact radiographs from sagittal sections of the right CTB in racing greyhounds. There was increased bone density in fractured CTB (B), as compared to non-fractured CTB (A). Fractures occurred through compact bone in regions of uniform density.
2.34 Sensitivity of radiography versus CT scan

There was good correlation of fracture type between radiographic assessment and CT imaging. CT imaging subjectively allowed better assessment of severity of comminution and identification of subtle or non-displaced fractures. CT was more accurate at identifying concurrent tarsal bone injuries, as compared to standard radiography (3/6 vs. 5/6 concurrent tarsal fractures). CT imaging more correctly identified the number of fracture fragments of the CTB.

2.35 Density of CTB on sagittal imaging

Based on CT imaging, the right CTB had greater overall density than the left CTB regardless of the occurrence of CTB fracture (P<0.05). Dogs that sustained a CTB fracture had a significantly greater bone density in regions 2-4 in the sagittal plane when compared to all other groups (Figure 2.9) (P<0.05).

2.36 Density adjacent fracture planes

On both sagittal and transverse CT images, the ratio of bone density on either side of the fracture plane was not significantly different than ratios from similar regions of the non-fractured right CTB.

2.37 Histologic evaluation

Evaluation of the histologic sections revealed that the dense bone in the dorsal region of both the fractured and intact CTB was composed of compact bone primarily in the form of lamellar bone. Several sections had a mild degree of osteonal remodeling
Figure 2.9: Bone mineral density in six regions of the central tarsal bone (CTB) of racing greyhounds (see figure 2). Dogs that sustained a fracture of the right CTB (Fracture, R) had significantly greater (*, P<0.05) bone mineral density at regions 2, 3, and 4, as compared to the contralateral CTB (Fracture, L) and the right and left CTB of greyhounds that did not sustain a CTB fracture (Normal, R and Normal, L).
present. Periosteal modeling was present on the dorsal slab of fractured CTB which primarily consisted of woven bone. Fracture lines appeared to extend from very dense compact bone into less dense compact bone and trabecular bone. There was no evidence of reparative response, neoplasia, or osteomyelitis in any CTB.

2.4 Discussion

Data from this study are the first to support the phenomenon of site specific remodeling in fractured right CTB of racing greyhounds. CTB which sustained a fracture had greater bone mineral density within the mid-dorsal and mid-body regions, when compared to both the contralateral CTB and non-fractured right CTB. Previously, the dorsal region of the CTB has been shown to have increased density in right CTB and the increase in density within the more plantar regions of bone which was seen in our study may suggest progressive remodeling secondary to other factors including increased microdamage, increased body weights of the patients, or increased cyclic loading [19].

Data from this study did not support our hypothesis that fractures would occur through a transition zone of more dense and less dense bone. Instead, the fractures occurred through a zone of greater uniform density. The bone in these regions became more compact through coalescence of trabeculi. This phenomenon has been documented in CTB of racing greyhounds and the bone in this region has been shown to have increased number of microcracks. In fact, evaluation of the dorsal slab in fractured right CTB has revealed large branching arrays of microcracks [28]. It has been hypothesized that the fatigue fracture occurs secondary to an imbalance between microdamage
formation and repair by remodeling, such that microcracks accumulate until catastrophic failure occurs by crack propagation or coalescence [28].

As the material properties of this dense bone are unknown, it is possible that, although the bone is more dense, it may be more brittle. Micro-hardness testing of this bone would give insight into its material properties of the combined mineral and organic matrix and may reveal additional information regarding etiology of fracture. If the bone is more brittle, it may give rise to microcracks which weaken the bone construct and may make the bone more susceptible to fracture. Bulk staining the CTB with the basic fuschin stain and evaluating histologic sections has been described as a method to evaluate for the presence and magnitude of microcrack formation. Although this staining method was not employed for this study, as its penetration through the reconstructed CTB and cyanoacrylate was questionable, such evaluation may add useful information regarding the etiology of CTB fracture. Further, more detailed imaging by way of microcomputed tomography or electron microscopy may provide objective assessment of the quality of the bone as well.

Prospective, linear studies of in vivo bone mineral density and the response to training would provide additional insight into the progression and development of bone mineral density as well as strength properties. Nuclear scintigraphy, magnetic resonance imaging, dual energy x-ray absorptiometry, and peripheral quantitative computed tomography (pQCT) have been described as non-invasive methods to evaluate lower extremity stress fracture injuries [29]. It is possible that with prospective screening, changes in the CTB can be detected prior to catastrophic failure.
Based on the results of this study, standard radiography was equally as precise and accurate as CT imaging for determination of CTB fracture type. CT was more accurate at identifying concurrent tarsal bone injuries however (3/6 vs 5/6). CT offered a better assessment of degree of comminution and identification of non-displaced fractures. Given that prognosis for CTB fracture greatly depends on accurate and complete identification of tarsal injuries, CT scanning should be performed whenever possible prior to making treatment decisions.

Limitations to this study are the low sample size and subsequently limited power to detect differences. Little was known about the details of the racing histories, age or sex of the animals in this study and this may have greatly affected the magnitude and pattern of modeling and remodeling changes seen in these dogs. Finally, although five of the six dogs sustained a type IV fracture of the CTB, they each had unique fracture patterns which also introduced variability into the analysis. Additionally, this study evaluated a 1mm slice in two planes, and it is possible that the changes seen in these slices are not representative of the bone in its entirety. Nonetheless, this is the first study to specifically evaluate in naturally occurring CTB fractures in racing greyhound and provides a basis for future investigation to identify additional factors which may play a role in the pathogenesis of CTB fracture in racing greyhounds.

Although the number of individuals in this study are limited, the data from this investigation support the phenomenon of site specific remodeling in fractured right CTB of racing greyhounds. There is increased bone mineral density within the mid-dorsal and mid-body regions of the bone and fractures occurred through a zone of greater uniform density as compared to both the contralateral CTB and non-fractured right CTB. These
changes may be due to progressive remodeling secondary to excessive microdamage, increased body weights of the patients, or increased cyclic loading. Further investigation is warranted to identify additional factors which may play a role in the pathogenesis of CTB fracture in racing greyhounds.
BIBLIOGRAPHY


