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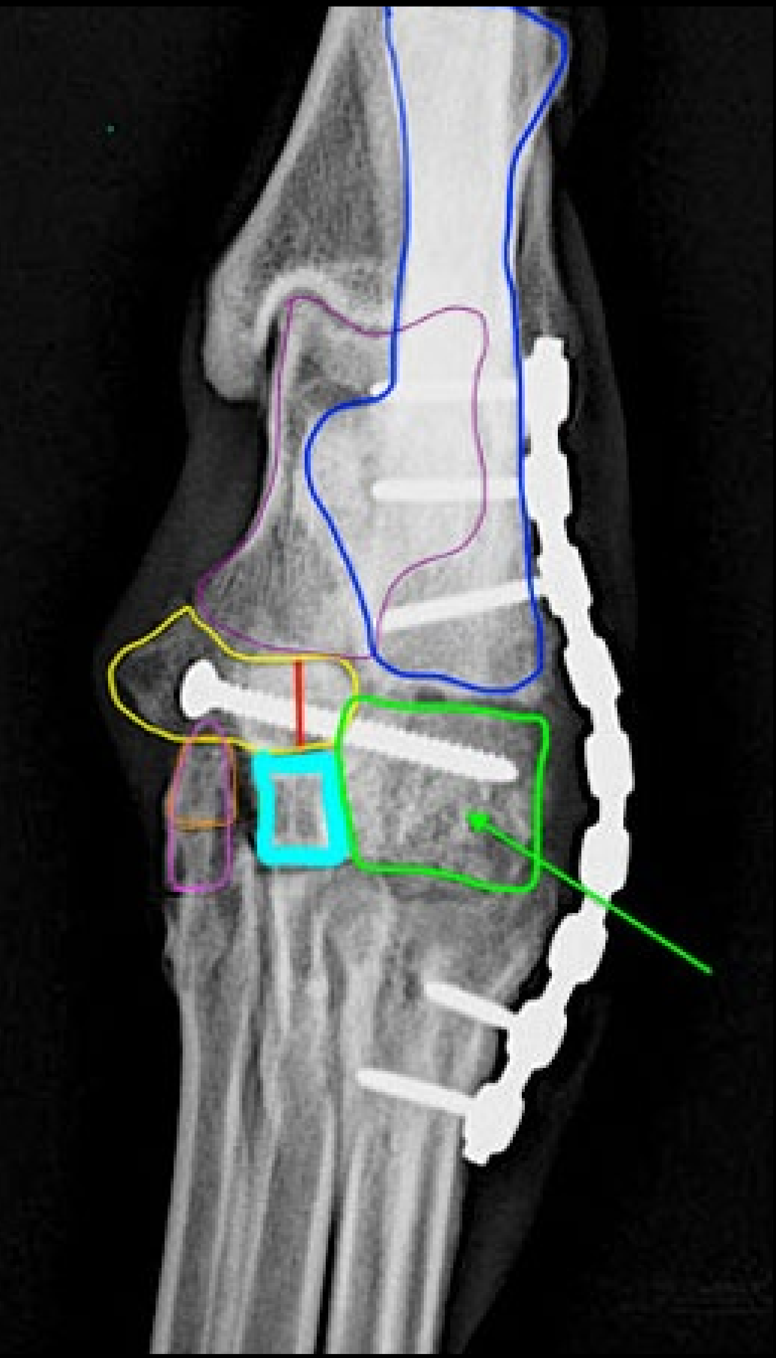

The Brutal Reality of Hock Fractures in Racing Greyhounds

Introducing Radiographic Guidelines for the Early Warning of Impending Fracture

Dr David H Larratt BVSc., IVAS

This digital article is an expanded version of C&T No. 5965 which appeared in the printed March 2023 issue and was the major winner.

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Dr David H Larratt BVSc IVAS
Singleton Vet Hospital
103 George St, Singleton NSW 2330 t. 02 65722077
The Lake Veterinary Hospitals
18 Maude St, Belmont, NSW 2280. t. 02 49 459 677

e. greyhoundtarsalscreening@gmail.com

TABLE OF CONTENTS

THE BRUTAL REALITY OF HOCK FRACTURES IN RACING GREYHOUNDS

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David with rescued greyhound, Star

INTRODUCTION

The commercial greyhound racing industry in Australia is one of the biggest in the world, with 55 active racing tracks (Coalition for the Protection of Greyhounds, 2022), it generates millions of dollars in tax revenue on the $9.4 billion wagered on results in the 2020 to 2021 financial year (Dobbin, 2021). This economic impact comes at a significant risk to all greyhounds participating in racing.

A persistent serious orthopaedic welfare issue continues to plague greyhound racing with animals suffering severe trauma in the same joint in the right rear leg, with the frequent outcome of surgical repair or euthanasia. This vulnerable joint is the Tarsus (colloquially known as the hock) and is equivalent to the ankle in humans. Injuries to the tarsus account for 25% of all greyhound racing injuries (Sicard *et al.*, 1999) and tarsal fracture is by far the most common cause of premature retirement from racing (Thompson *et al.*, 2012).

Greyhounds usually start racing at the age of 2 years. There is a 400% increased risk of serious tarsal injury after only 12 months of racing (Beer, 2014).

With the recent introduction of industry sponsored orthopaedic repair, euthanasia rates have been reduced. However, the prevalence of major injuries appears to be increasing (GWIC, *Analysis of Greyhound Racing Injuries, December 2021*).

Tarsal fractures are major injuries, causing significant trauma to the animal and should be one of the highest preventative welfare priorities for the greyhound industry (Thompson *et al.*, 2012) and (Beer, 2014).

A small cube shaped bone, within the tarsus is the most common bone to fracture (Gannon, 1972), (Prole, 1976), (Boudrieau *et al.*, 1984) and (Anderson *et al.*, 1995). This bone is the Central Tarsal Bone (CTB) and is nestled between the other 6 bones of the joint.

A commonly held view within the industry is that a tarsal fracture is spontaneous and random, occurring mainly due to racing interference. This belief can now be strongly challenged by the confirmation that the right CTB suffers a dramatic loss of bone mineral density (BMD) prior to collapse fracture (Hercock, 2010). This reduction in bone density (demineralisation) may occur without triggering an obvious pain response, remaining undetected by trainers and veterinarians.

Bone strengthens in response to athletic activity *(adaptive load)*, by depositing a dense calcium matrix into its structure (mineralisation). The inner architecture of spongey bones is organised into a flexible mesh scaffold called the Trabeculae and it is this zone within the CTB that suffers both demineralisation and fracture. Changes in mineralisation of the tarsal bones are observable with conventional radiography.

The bones in the tarsus overlap, making radiography challenging to interpret, deeming it to be of limited use to researchers (Hercock, 2010). However, the majority of greyhound research papers published have only been based on the examination of 2 radiographic views, perpendicular to each other. This restriction appears to have been entrenched since the publication of the first classification system for grading CTB fractures (Dee *et al.*, 1976).

The Radiographic Tarsal Screening Guidelines provided in this report enhance radiographic assessment beyond the traditional search for fracture lines. Three new criteria have been added to develop the guidelines and provide the foundation for a Radiographic Screening Protocol that may prevent fracture of the tarsus in racing greyhounds.

Contents

Figure 1. Right Hock collapse Photo from https://www.cagednw.co.uk/greyhoundinjuries.html

The criteria are:

1. The use of additional oblique radiographic views.
2. Close examination of the inner trabeculae of all the tarsal bones enables assessment of the state of adaptive load or overload in the entire tarsal structure.
3. The collaborative use of Computer Tomography (CT) imaging to confirm the radiographic interpretation.

This Report:

- challenges the belief that tarsal fractures occur randomly.
- challenges the belief that standard radiography is not useful as a preventative tool to detect impending fracture.
- is a synthesis of scientific literature review, personal surgical experience, application of multiple view radiography and correlation with CT imaging.
- shares the preliminary findings of the correlation of this multiple view radiographic technique with CT imaging.

CT imaging was kindly provided by Small Animal Specialist Hospital (SASH) Tuggerah (New South Wales), Dr John Katakasi from Adelaide Plains Veterinary Surgery, (South Australia) and Dr Chris Papantonio from *Colyton Veterinary Hospital*, (New South Wales).

Radiographic imaging was kindly provided by *The Lake Veterinary Hospital, Cooranbong Animal Hospital* and *Wallsend Veterinary Hospital* in the Newcastle and Lake Macquarie regions of New South Wales.

In the Australian state of Victoria, a Diagnostic Imaging Subsidy Program for racehorses was introduced by Racing Victoria in June 2021. Its goal is to achieve early detection and intervention and to minimise the risk of serious injury (Racing Victoria, 2022). Colloquially, it has been called *'Medicare for Horses'*. After a successful one-year pilot, the program will continue, making expensive diagnostic imaging for injury prevention more accessible to horse owners and trainers.

Do racing greyhounds deserve similar preventative welfare initiatives as those commenced in the racehorse industry?

Background

My journey with greyhounds started soon after graduation from the veterinary faculty at The University of Sydney in 1989. My first veterinary employment was in a mixed practice in Newcastle, NSW with a high caseload of greyhound and equine cases. From my second week I also commenced the duty of On Track Veterinarian (OTV) at a local greyhound racetrack.

For 22 years, I was an OTV at various greyhound racetracks in NSW and the United Kingdom with an average attendance of 2 meetings per week. The OTV is responsible for the euthanasia of dogs suffering serious on-track injuries. I performed on-track euthanasia almost weekly and the most

Contents

common injury was by far, fracture of the right tarsus.

It was standard practice to use 4-view radiographic angles with horses to investigate lameness, so I extended this protocol to greyhounds. This radiographic sequence has revealed distinct correlations between radiographic markers and the tarsal joint stability of racing greyhounds.

In 2012, I ceased work as an OTV and, in collaboration with the charity rehoming organisation Friends of the Hound (FOTH), I undertook the surgical repair of the majority of bone fractures in greyhounds that came in for euthanasia at *Wallsend Veterinary Hospital*.

In 2018, I presented a lecture at the annual Australian Greyhound Veterinarians (now known as *Australian Greyhound, Working and Sporting Dogs Veterinarians*) conference on the surgical repair of hock fractures.

It is now my mission to share Radiographic Guidelines for the early warning of impending hock fracture with veterinarians, to be used as prevention of this common career-ending injury.

The Aims of the Report

In the racing industry, the greyhound is not yet receiving the same injury preventative measures that the racing horse receives. Unlike the equine industry, prepurchase radiography for greyhounds is not a standard protocol.

For a horse, it is standard to take 4 radiographic views when investigating the joints of the legs. In contrast, the standard greyhound radiographic procedure is restricted to the examination of 2 views, perpendicular to each other with the focus on the detection of fracture lines.

The major welfare aim of this Report is to reduce the high incidence of tarsal fractures in the greyhound racing industry by:

A. Creating an awareness of the extent of tarsal fracture statistics.

B. Highlighting the role of demineralisation in the pathogenesis of tarsal fracture and that this weakening process may occur without an obvious pain response.

C. Presenting a series of radiographic images of the right tarsus in 6 greyhounds that reveal diagnostic markers, highlighting the progression of mineralisation changes predisposing to fracture. Corresponding CT images are also presented to assess correlation with radiography.

D. Introducing 4-view radiographic guidelines to detect the diagnostic markers that are distinct to the racing greyhound and to establish the foundation for routine radiography to prevent fracture of the tarsus.

The Current Injury Situation

There is a 400% increased risk of serious tarsal injury after only 12 months of racing (Beer, 2014).

This startling statistic was uncovered by Beer (2014) in *A Study of Injuries in Victorian Racing Greyhounds 2006-2011*. The five-year analysis was conducted in collaboration with Greyhound Racing Victoria (GRV) and covered a total of 444,046 eligible starts at all racing tracks state-wide.

For the year ending 30 June 2022, the greyhound racing jurisdiction of NSW reported a weekly average of 14 dogs suffering major injuries, possibly requiring orthopaedic repair, with 1-2 resulting in euthanasia (GWIC Analysis of Greyhound Racing Injuries, 2022)

In 2018 the Greyhound Welfare and Integrity Commission (GWIC), the regulator for the greyhound industry in NSW, was established after the reversal of the racing ban initiated by premier Mike Baird in 2015. GWIC has been publishing a quarterly Analysis of Greyhound Racing Injuries since July 2018 (https://www.gwic.nsw.gov.au/news-and-updates/reports-and-statistics/injury-report.).

Injuries to the tarsus account for 25% of all greyhound racing injuries (Sicard *et al*., 1999). Despite this historical high prevalence, the GWIC quarterly *Analysis of Greyhound Racing Injuries* does not actually identify the specific number of tarsal injuries. Rather, GWIC classifies tarsal injuries into 3 different broad range injury categories (Major I, Major II or Catastrophic). From the start of 2022, Major I and Major II injuries were clumped into a single 'Category D' which may further obscure the specific number of tarsal injuries.

Industry sponsored orthopaedic repair, the *NSW Injury Rebate Scheme*, was introduced in NSW in May 2020 by GWIC. In the first year, this scheme referred 37 fractures to the author at *Wallsend Veterinary Hospital* (WVH) for radiography and repair. The right hock was the injury site in 67% of cases. Fracture of the CTB was involved in all the tarsal bone repairs.

Contents

The introduction of the *NSW Injury Rebate Scheme* reduced the euthanasia rate from 2.3 dogs per week to 1.5 dogs per week by July 1 2022. However, there has still been a 25% increase in injuries classified as *Major* from only 18% additional race starts. (Extrapolated from quarterly *Analysis of Greyhound Racing Injuries* July 2018 -June 2022).

The 2 Standard Radiographic Views and a Common Collapse Fracture

The 2 standard radiographic views of the greyhound tarsus are illustrated in the following Figures. *(Refer to Figures 2. and 3., below)*. They are perpendicular views and referred to as Plantar-dorsal and Medio-lateral respectively. This standard was established with the first classification system for grading *Central Tarsal Bone* (CTB) fractures (Dee *et al*., 1976). *(Refer to Figure 5., Pg. 8)*. The 2 views are useful for detecting many tarsal fractures and are usually adequate for preoperative planning for surgical repair.

The radiographs below highlight the position of the Central Tarsal Bone (CTB) within the tarsal structure. The bones are outlined in different colours to assist identification.

Figure 2. Plantar-Dorsal (AP) Radiographic Sequence of Right Tarsus: Intact, Collapse and Repair.

A. Intact

Radiograph kindly provided by:
The Lake Veterinary Hospital

Outline of tarsal bones in *Dog #1.

Yellow – CTB

Green – T 4

Light blue – T3

Orange – T2

Pink- T1

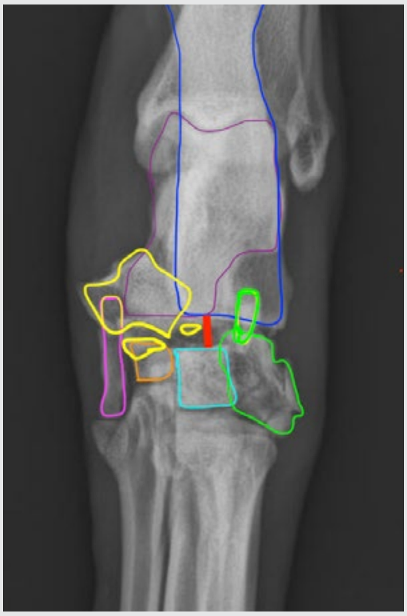
Purple- Talus

Dark blue - Calcaneus

Red dotted line shows position of transverse CT image.

White arrows point to a vertical white line of increased mineralisation. (A response to increased vertical load).

B. Collapse Fracture



Radiograph kindly provided by:
Wallsend Veterinary Hospital

Outline of tarsal bones in *Dog #5

This is a Type V comminuted fracture of CTB

Yellow – fragments of CTB

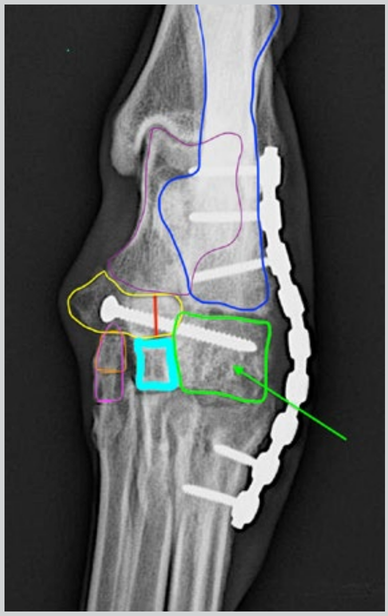
Green – collapsed sections of T4

Light blue – T3

Red bar indicates the space normally occupied by the CTB. The height is reduced as the T4 has collapsed.

T3 remains intact.

C. Repair



Radiograph kindly provided by:
Wallsend Veterinary Hospital

Outline of tarsal bones in *Dog #5

Surgical repair of the collapsed fracture of CTB and T4 with a single 2.7mm mediolateral screw in the CTB and 2mm lateral locking plate.

Green arrow points to the irregular trabeculae within the crushed T4.

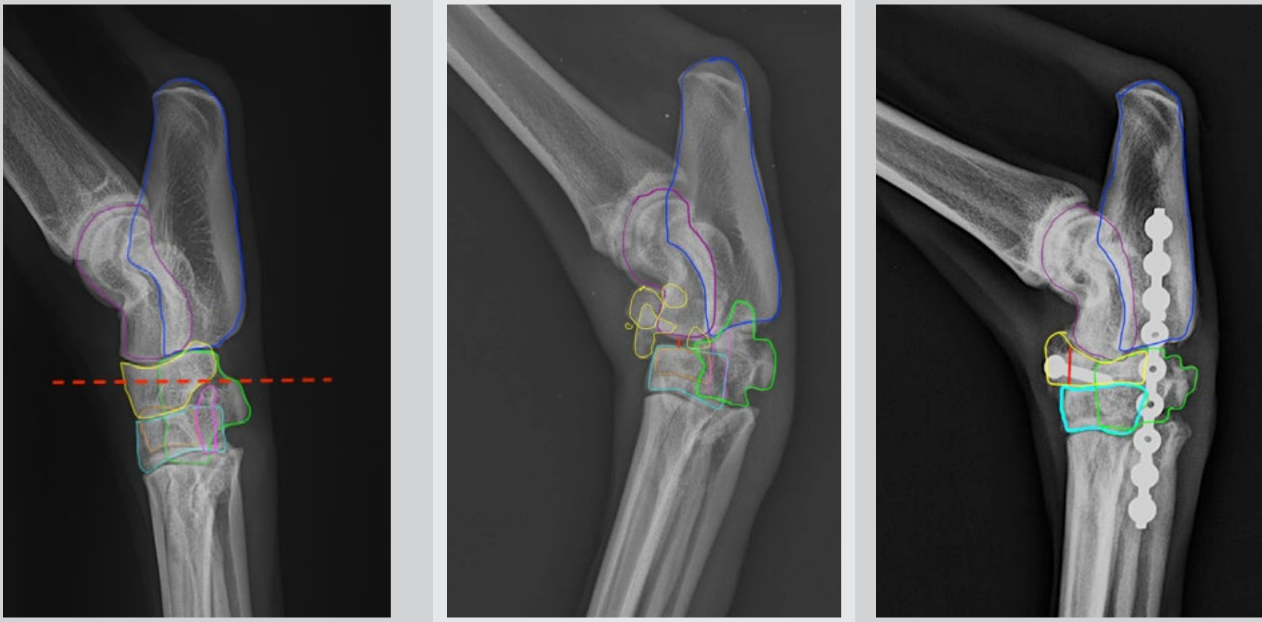
Red bar is now taller, indicating partial restoration of the height of T4.

**This dog returned to racing after a 9 month recovery period.*

* *(Refer to page 11 for description for 6 dogs in the study)*

Figure 3. Medio - Lateral (Lateral). Radiographic Sequence of Right Tarsus: Intact, Collapse and Repair

A. Intact. **B.** Collapse Fracture **C.** Repair.



A. Intact.

Radiograph kindly provided by

The Lake Veterinary Hospital

Outline of tarsal bones in *Dog #1.

Yellow - CTB, **Green –** T 4

Light blue – T3, **Orange –** T2,

Pink - T1, **Purple -** Talus.

Dark blue - Calcaneus.

Red dotted line shows position of transverse CT image.

B. Collapse Fracture

Radiograph kindly provided by

Wallsend Veterinary Hospital

Outline of tarsal bones in *Dog #5

This is a Type V comminuted fracture of CTB

Yellow – fragments of CTB

Green – collapsed T4

Light blue – T3

Red bar indicates the space normally occupied by the CTB. The height is reduced. T3 remains intact.

Note: The top of the tarsus (calcaneus and talus) is collapsing forward. Before 2020 the majority of dogs with this injury were euthanised in NSW.

C. Repair.

Radiograph kindly provided by

Wallsend Veterinary Hospital

Outline of tarsal bones in *Dog #5

Surgical correction with restoration of height of T4.

Yellow – CTB has been restructured. Good vertical alignment.

Red bar is now taller, indicating partial restoration of the height of T4.

Note: This dog returned to racing after 8 months. However, this is an exception as such a long recovery time would prevent a successful return to racing.

** (Refer to page 11 for description for 6 dogs in the study)*

The severe collapse fracture of the CTB occurs concurrently with T4 fracture in 62% of cases. (Boudrieu *et al*., 1984). This is shown in the 'B' images *(Refer to Figures 2 and 3, above)*. Before the introduction of industry sponsored repair, most dogs with this severe fracture were euthanised.

The Right Tarsus is the Fracture Site in 96% of Cases (Boudrieau, *et al*., 1984)

The vast majority of greyhound racing is on circular tracks and all circular tracks in the world race in the counterclockwise direction. *The impact of circle racing as the major contributor to tarsal fracture* is supported by the finding in the Victorian study by Beer (2014) which states that circle tracks have a 5 to 12 times increase in incidence of tarsal fracture in comparison to straight track racing.

Like a ridden motorbike, the greyhound leans left into the corner, which shifts the vertical weight axis onto the bones closest to the inner circle of the track. This inner circle is called the railing. Railing-side bones in each leg experience increased loading resulting in adaptive bone thickening compared to the contralateral side of each leg (Hercock, 2010).

The hind legs power the acceleration of running (Hercock, 2010), while the right hind leg counters the centrifugal force of the curve of the track. Within the right tarsus, the CTB.positioned on the railing side, experiences increased loading and becomes the primary site of fracture (Bateman, 1960), (Gannon, 1972), (Hickman, 1975), (Boudrieau. *et al*., 1984) and (Guilliard, 2000).

Fracture of the right CTB has been referred to as a fatigue or stress fracture resulting from the asymmetrical loading of unidirectional circle running (Johnson *et al*., 2000) and (Tomlin *et al*., 2000).

The Vulnerable Anatomy of the Central Tarsal Bone

The 7 tarsal bones are stacked tightly forming a structural shock absorber that dissipates the force of the descending weight load in the rear leg. The bones are organised into 3 rows with the CTB positioned on the medial side in the middle row (Refer to *A images on Figures 2. and 3., Pg. 5 and Pg. 6).

The *talus* bears most of the weight load at the highly mobile tibio-tarsal joint which accounts for 90% of the total movement in all the tarsal bones (Evans and de Lahunta, 2012). Lateral support for the talus is provided by the tall *calcaneus* which anchors the common calcaneal (*Achilles*) tendon and the plantar ligaments.

The CTB *(with its concave ceiling)* is positioned below the talus so it bears the brunt of the descending load. This relationship is analogous to the CTB being the *mortar* to the *pestle* shaped talus.

The CTB is teacup shaped when observed on the Lateral radiographic view *(Refer to *A image on Figure 3., Pg.6)* with a rear protruding handle called the plantar process. In the greyhound, the CTB is approximately 10 mm high, 15mm wide and 15mm deep.

The CTB has lateral support provided by the large T4 and distal pedestal support provided by T1, T2 and T3.

The stability of the entire tarsal structure is critical to maintain performance function and prevent damage to underlying bones. The supporting soft tissues for the tarsal bones include synovial joints, collateral and interosseous ligaments, longitudinal tendons and the fibrous *capsular sleeve* (Evans and de Lahunta,2012). The capsular sleeve forms the outer joint collagen layer of the underlying synovial joints, surrounds all the 7 bones and provides compressive support to the entire structure.

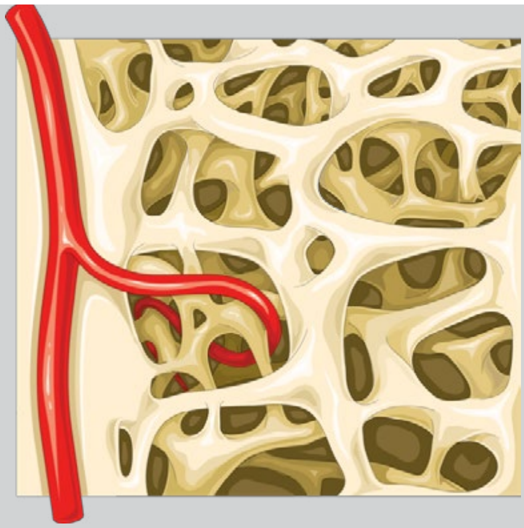
The flexibility of the tarsus is provided by the inner structure of each bone in conjunction with the supporting soft tissues. The CTB is composed primarily of inner spongey *(trabecular)* bone surrounded by a thin layer of outer cortical bone. The outer cortical layer of bone is usually thin, hard and compact with little flexibility. The inner trabecular bone is porous with struts *(trabeculae)* organised in a honeycomb-like scaffold.

The pores (spaces) allow the flow of blood and cell migration. The struts (trabeculae) consist of collagen strands organised into a triple helix configuration which only become mineralised when load is applied. This collagen configuration provides elasticity to enable compression and recoil (similar to a spring) and is also present in the supporting soft tissues.

(Refer to Figure 4, below)

Figure 4. Trabecular bone.

Reference: Grey's Anatomy of the Human Body, 20th Edition,



The flexible internal struts of the trabecular bone appear **white** on radiographs, representing bone deposition onto the underlying collagen strands.

A **red blood vessel** is seen coursing through the pores (the spaces between the struts).

The struts orientate themselves according to stress lines, thickening (by adding new bone matrix) in response to mechanical load.

Excess thickening reduces flexibility of the structure while pore size is reduced and blood flow compromised. Both these factors predispose to fracture. Once broken, some struts cannot be rebuilt - leading to cascading de-mineralisation and fragility of the entire CTB structure.

Classification of CTB fractures.

Fracture of the CTB was first classified into 5 grades of severity (Dee *et al*., 1976), determined by using 2 radiographic angles, perpendicular to each other. *(Refer to Figures 2 and 3, Pg. 5 and 6)*. This classification system is still the current reference used in clinical practice.

This first classification system was used to grade 114 fractures (Boudrieu *et al*.,1984) and reinforced the protocol of the 2 radiographic views. Boudrieu *et al*. (1984) published a chart illustrating the 5 fracture types based on a transverse cross-section through the CTB. *(Refer to Figure 5. below)*

The introduction of Computer Tomography (CT) imaging has improved the ability to visualise fractures and challenges the Dee *et al*., (1976) classification system, which may have underestimated the severity of CTB fractures (Hercock, 2010). Consequently, Hercock (2010) concluded that there may be a smaller range of CTB fracture types and a higher incidence of more severe injuries than previously estimated.

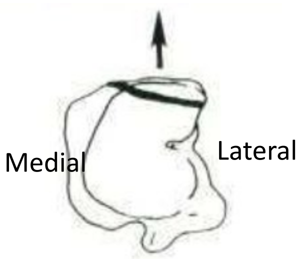
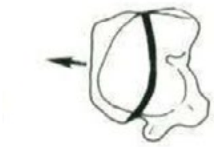
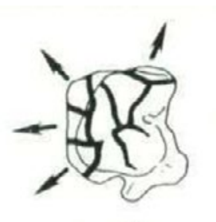
To assist orientation, the Classification Chart below, corresponds to the same transverse cross section indicated as a red horizontal dashed line on the 2 standard radiographs displayed earlier. *(Refer to *A images in Figures 2 and 3, Pg. 5 and 6).*

The fracture line on the dorsal (forward facing) surface of the CTB is classified as Type I (non-displaced) or Type II (displaced). This is called the *Dorsal Fracture Line* and represents less than 25% of CTB fractures (Boudrieu *et al*.,1984). This fracture line is commonly detected with the standard Medio-lateral radiographic view.

The additional longitudinal fracture that runs from dorsal to plantar is along the *Midbody* or *Sagittal Line* and is classified as Type III and IV. Type IV has both Dorsal and Sagittal fractures. The Sagittal fracture is difficult to detect when non-displaced but may be seen on the Plantar-dorsal radiograph. *(Refer to Image B. Figure 6., Pg.9)*

Type V is an exploded fragmentation or comminuted fracture of the CTB. *(Refer to Figures 2 and 3, Pg.5 and Pg.6)*

Figure 5. Classification Chart of CTB Fracture Types, published by Boudrieau et al., 1984. Transverse cross section of right CTB

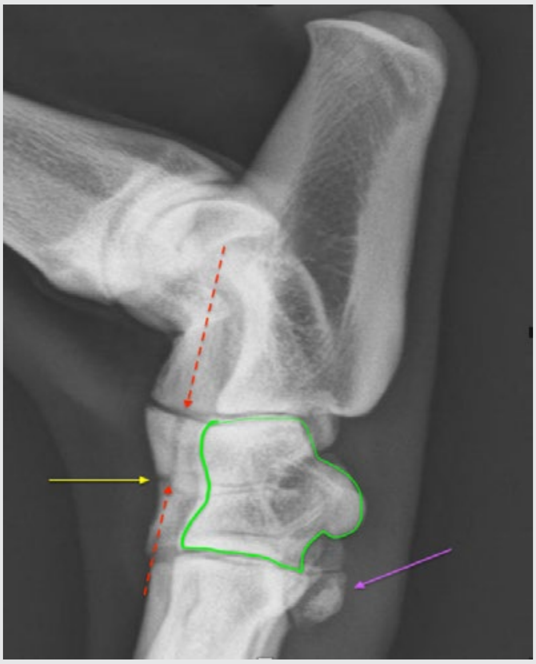
Type I & II	**Type III**	**Type IV**	**Type V**
Dorsal  *Plantar*	*Dorsal*  *Plantar*	*Dorsal*  *Plantar*	*Dorsal*  *Plantar*
Seen in 25% of CTB fractures *(based on 1984 statistics)* Heavy lines indicate fracture sites and types. Arrows denote displacement.	**Rarely seen** *(based on 1984 statistics)*	**Seen in 70% of CTB fractures** *(based on 1984 statistics)*	**Seen in 5% of CTB fractures using radiography.** *(based on 1984 statistics)* ***This percentage is dramatically higher when fractures are assessed with CT.***

Type IV and V represents 75% of all CTB fractures and have the highest rate of euthanasia or failure to return to racing (Boudrieu *et al*,1984). These severe grades of fracture are not only the most frequent (Boudrieu *et al*., 1984), but may occur concurrently with fracture of neighbouring tarsal bones (Ost *et al*., 1987) and (Guilliard, 2000). This co-fracture rate has been recorded as high as 86% (Boudrieau *et al*., 1984).

The most prevalent co-fracture involves the T4 62% of the time (Boudrieu *et al*., 1984) and this correlates well with the author's surgical experience. The other common co-fracture is the calcaneus (Boudrieu *et al*.,1984).

Figure 6. Examples of Fracture lines

A



Dorsal fracture line seen on Medio-dorsal radiograph

Red arrows point to the non-displaced Type I dorsal fracture line of the CTB.

Yellow arrow points to a black zone at the base of the fracture line which may indicate pre-existing demineralisation. This area can be difficult to assess due to the overlay of the CTB with T3 and T2.

Note: the complete white contrast in the dorsal (front facing) aspect of the CTB indicates that the inner trabecular pores have been compacted with bone matrix (mineralised) leading to reduced flexibility and blood flow. These factors precede fracture.

Green outline of the T4.

Purple arrow points to increased mineralisation in the plantar soft tissue which indicates potential chronic instability of the tarsal structure.

B

Sagittal fracture line seen on Plantar-dorsal radiograph

Red arrows point to the non-displaced Type IV Sagittal fracture line of the CTB.

Note: this dog also had a dorsal fracture line seen on Medio-lateral view).

Yellow dashed line on the increased white contrast in the vertically aligned Talus, CTB, T3 and Metatarsal III. This highlights the vertical stress line and the adaption to load by increasing mineralisation in the inner trabeculae of all 4 bones. This is common and highlights why fractures may occur in the CTB, T3 and the underlying Metatarsal III.

Note: the complete white contrast in the bone either side of the fracture line indicates that the inner trabecular bone is compacted leading to reduced flexibility and blood flow. These factors precede fracture.

Pathogenesis of CTB Fracture

As reviewed on page 6, the universal counterclockwise direction of greyhound racing is the reason why the right tarsus is the fracture site in 96% of cases (Boudrieau, *et al*., 1984) and this would be acknowledged by the majority of veterinarians and trainers involved in the industry.

The question of "why do only some greyhounds break their hocks?" has the standard answer of "racing interference, bad track or just bad luck". This belief, that tarsal fractures are random and spontaneous, can be strongly challenged once we gain an awareness of the mineralisation changes occurring with load and subsequent overload of the tarsal structure. The contributing role of laxity (loosening) of the supporting soft tissue structures will be reviewed in the Discussion section of this Report *(Refer to Pg. 22)*.

Normal Bone Adaption to racing load (vertical weight plus torsion of cornering) involves strengthening of bone via the deposition of calcium matrix and a balance in the bone remodelling processes of building (by *osteoblasts*) and removal (by *osteoclasts*). As a result, new bone is deposited on the outer cortical surface in sheets called Lamellae, and onto the collagen scaffold of the inner trabecular bone.

The impact of counterclockwise running results in a higher load on the right CTB compared to the left CTB and correlates with the higher BMD measured in the right CTB (Johnson *et al*., 2000).

The dorsal and mid-body zones of the CTB are reported to have high *Bone Mineral Density* (BMD) (Johnson *et al.*, 2000) and (Bergh *et al.*, 2012). These zones are in the inner trabecular bone where a high BMD indicates the thickening of trabecular struts responding (adapting) to the increase in load. The thicker struts are now less flexible and the spaces (pores) between the struts gradually shrink, compromising blood flow within the bone. This loss of flexibility and blood flow increases susceptibility to cracking (Thompson *et al.*, 2012) and (Muir *et al.*, 1999.

When this tipping point is reached the load is considered excessive and is called *Overload*. These two zones of high BMD are the recognised sites of the dorsal and sagittal fracture lines in the CTB in the racing greyhound (Bergh *et al.*, 2012).

Overload stimulates a rapid removal of damaged bone (by osteoclasts) primarily in the compromised inner trabecular structure. The time frame for this rapid evacuation of damaged bone has not been measured in canines but in humans occurs 3-5 days after injury (Martin, 1995).

Demineralisation results when there is a significant delay in the replacement (by osteoblasts) of the evacuated damaged bone. Thus, leading to a net loss in mineral density, structural weakness and increasing vulnerability to fracture. In the horse, bone replacement takes 60-120 days (Stewart and Kawcak, 2018) and at the time of writing, there was no published canine reference.

In the right CTB, demineralisation can progress to a net loss of 32% (compared to the left CTB) before resulting in the dramatic Type V collapse fracture (Hercock, 2010). *(Refer to Figures 2 and 3, Pg. 5 and 6).*

This weakening process of demineralisation is a significant welfare concern as it may occur without an obvious pain response. As a result, dogs may have tarsal fractures detected on CT imaging without any history of injury (Thompson et al., 2012) or lameness may be mild and veterinary examination is not obtained (Guilliard, 2010).

Within the right CTB, fractures occur in compacted trabecular bone (with high BMD) yet the BMD of the entire bone is low when it collapses. Therefore, the inevitable conclusion is that there must be a zone within the CTB where this dramatic demineralisation is occurring!

PROCEDURE

Selection Criteria for the Greyhounds in this Report

The greyhounds in this Report, with the exception of Dog #6 (who never raced), were in their first year of racing and aged between 2-3 years.

The greyhounds were selected to represent different scenarios to illustrate the adaptive changes in tarsal bones occurring with load and overload and to highlight the potential progression with these changes. Case selection was also dependent on a limited availability of CT images.

Diagnostic Radiographic Markers

The bone strengthening response of increasing mineralisation can be observed with radiography. The intensity of whiteness in the image correlates with the density of calcium, the main mineral in bone (Feng, 2009). Therefore, the terms mineralisation and calcification are interchangeable.

Demineralisation occurs with a net loss of bone, which is a response to overload when bone removal exceeds bone replacement. This can be observed in radiography as a reduced intensity of whiteness.

The analysis of greyhound tarsal radiographs can extend well beyond the search for fracture lines. With this in mind, the following radiographic markers can be observed:

1. *Areas of increased mineralisation* presenting as contrasting shades of white intensity. This can be seen when there are changes in adaptive load represented as thickening of trabecular struts, or widening of cortical bone when lamellar sheeting is evident. Mineralisation within supportive soft tissue can also occur when collagen fibres are overloaded and may indicate soft tissue laxity and structural instability.

2. *Areas of demineralisation* presenting as shades of black contrast or loss of white contrast. Trabecular struts may become damaged and resorbed by osteoclasts. This is represented as irregular dark areas in the trabecular structure. Demineralisation of outer cortical bone is observed as blurring of the bone's outline. These changes are usually associated with overload.

3. *Changes in trabecular texture* in different parts of the same bone may indicate either adaptive load or overload. Both unloaded trabeculae and overloaded broken trabeculae will appear as shades of black contrast.

Once the images were obtained, they were analysed and significant radiographic markers were identified and marked with colour-coded outlines and arrows. Explanations were then provided beside the images.

Dogs participating in the Report

Radiographic images were chosen for the following 6 dogs:

- **Dog #1 *(Normal Adaptive Load)***
- Currently racing and cornering well. This is an example of normal adaptive load as the dominant radiographic marker is increased mineralisation.
- **Dog #2 *(Overload – Early)***
- Currently racing but running wide on corners. Radiographs are presented which show early signs of overload in the tarsal bones.
- **Dog #3 *(Overload – Moderate, Type I fracture).***
- Not racing due to lameness. Type I CTB fracture on radiography however, Type IV fracture is detected on CT imaging.
- **Dog #4 *(Overload – Moderate, Type IV fracture)***
- Not racing due to lameness. Type IV CTB fracture on radiography however, Type V fracture is detected on CT imaging.
- **Dog #5 *(Overload – Severe, Type V collapse fracture)***
  Not racing due to lameness from severe tarsal fracture collapse. Radiographs are presented, revealing Type V CTB fracture and T4 collapse. .
- **Dog #6 *(Never Raced)***
  6 years old and was never in training. Radiographs and CT are presented to allow a comparison with changes related to racing. . .

Radiography procedure

The four Radiographic views were as follows:

1. Plantar-dors*al (AP)*
2. *Medio-lateral (Lateral)*
3. *Plantarolateral-dorsomedial oblique (Medio-oblique)*
4. *Plantaromedial-dorsolateral oblique (Lateral-oblique*).

Computer Tomography (CT) images were obtained for 3 of the greyhounds to allow comparison between a dog that had never raced (Dog #6) and the 2 dogs with non-displaced fractures (Dog #3 and Dog #4). The comparison of tarsal CT images with 4 view radiography is continuing in collaboration with Dr John Katakasi from Adelaide Plains Veterinary Surgery (South Australia).

The introduction of CT imaging into the veterinary industry has been fantastic for the diagnosis of subtle musculo-skeletal injuries due to enhanced accuracy for examining inner bone structure and detecting subtle fractures. CT utilises up to 180 radiographic angles to produce detailed cross-sectional images free from superimposed overlay, and reconstruction of the anatomical detail in multiple viewing planes (Fitch *et al*., 1996) and (Gielen *et al*., 2001).

The disadvantages of CT which prevented its use for all dogs in this report were:

- the high cost (between $1000 and $2500 AUD),
- requirement for general anaesthesia
- restricted access (the majority of veterinary hospitals are not equipped with CT).

However, standard radiography with high resolution digital processing is readily available in all veterinary hospitals at a significantly lower cost and it was not necessary to sedate the greyhounds to obtain the 4 views.

RESULTS

Two sequences of images are presented. The first sequence examines the correlation of Computer Tomography (CT) imaging with 4- view radiography. The second sequence consists of 4 separate charts for each of the 4 radiographic views. Each of the 4 charts displays an image for each of the 6 dogs, comparing the differences in mineralisation between the dogs from the perspective of that one view.

1. Comparative CT correlation with 4 view Radiography for 3 dogs

The 3 Charts on pages 13-15, display the Transverse CT image of the CTB and T4 with accompanying images of 4-view tarsal radiography. There is a chart for each of the 3 dogs for which CT imaging was obtainable (Dog#6, Dog#3 and Dog#4 respectively).

The case sequence is based on increasing pathology and will start with Dog #6 (never raced).to establish a baseline. This is followed by Dog #3 (Type I CTB fracture) then Dog #4 (Type IV CTB fracture). The horizontal alignment for the transverse CT image through the Right CTB and T4 is highlighted with a red dashed line as seen on the images on pages 5 and 6 *(Refer to *A images in Figures 2 and 3).*

The CT images are placed in the centre, surrounded by the 4 radiographic images. They are defined according to the horizontal plane within the CTB as either mid-body or distal-body. The CTB is located to the left of the T4 in the images and the dorsal (forward facing) side of the bones are orientated to the top of the images.

Fractures are highlighted with *coloured arrows* (yellow, pink or light blue). The same colour coding is consistent for CT and radiography.

Demineralisation within the CTB and T4 - Red arrows point to areas of black contrast to highlight these markers.

Note: for Dog #6 (Never raced) the red arrow pointing to the T4 area shows relatively normal mineralisation (compared to the other 2 dogs, Dog #3 and Dog #4).

Increased mineralisation in soft tissue – indicated by White arrows in images for the older Dog #6.
Further detail and coloured identification of each tarsal bone is provided in sequence 2.

2. Overload Sequence Progression for all 6 dogs

The chart for each of the 4 radiographic views allows a comparative analysis between all 6 dogs. The observation of variable mineralisation may indicate a progression in changes that occur with adaptive load and subsequent overload of the tarsal structure. The same radiographic features marked in the Comparative CT Correlation Sequence are also used in the Overload Sequence Progression using the same colour coding.

Continued...

1 A. COMPARATIVE CT CORRELATION WITH 4 VIEW RADIOGRAPHY

Figure 7. #6.(Never-raced) Radiography + CT images

Dog #6.

AP

Red arrow points to relative normal mineral-isation

White arrow points to increased mineralised soft tissue, obvious on lateral view.

Dog #6

Lateral

Red arrow points to relative normal mineralisation in plantar aspect of T4

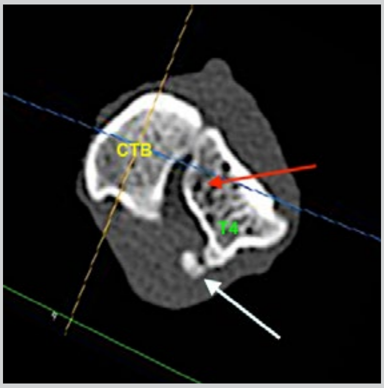
White arrow -increased mineralisation of plantar ligament insertion on T4 (*En-thesis*) which may indicate old tarsal instability.

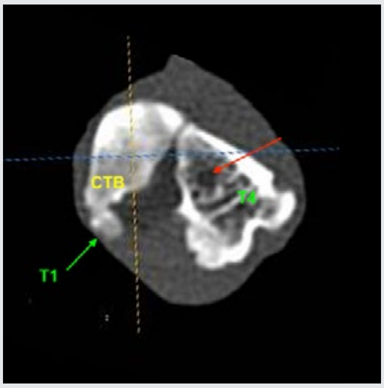
Dog #6

CT mid-body

Red arrow points to large trabecular pores which are probably normal.

White arrow points to the increased miner-alisation of soft tissue on plantar aspect of T4 (enthesis).





Dog #6

CT. R distal-body

Red arrow points to large trabecular pore in T4. May be either.uncalcified colla-gen that has not be loaded or broken overloaded trabeculae.

Green arrow points to proxi-mal aspect of T1. **.**

Dog #6. . .

Medio–oblique

Red arrow points to mild demineralisation in trabeculae observed on CT distal-body.

Dog #6.

Lateral -oblique

Red arrow points to normal mineralisation in plantar as-pect of CTB. This establishes a baseline for this area.

White arrow points to loca-tion of enthesis on plantar T4.

NOTES:

- AP radiograph shows CTB has increased mineralisation compared to T4 which correlates with CT images.
- Relative larger trabecular pore size in T4 compared to CTB seen AP, Lateral and Medio-oblique views which correlates with CT images.
- The proximal dorsal increased mineralisation in the CTB seen on Lateral and Medio-oblique correlates to cortical thickening and trabecular in-filling on CT mid-body.
- Soft tissue increased mineralisation proximal to plantar aspect of T4 seen on Lateral radiograph correlates to CT mid-body
- NOTE the red arrows indicate the areas where demineralisation commonly occurs with over-load and will be observed in the following case

1 B. COMPARATIVE CT CORRELATION WITH 4 VIEW RADIOGRAPHY

Figure 8. Dog #3. Type I fracture Radiography + CT Type IV images

Dog #3.

AP

Yellow arrows point to vertical demineralisation and suspect Sagittal fracture which was confirmed on CT. .

Red arrow points to demineralised spot in T4. This was confirmed on CT.

Dog #3

Lateral

Pink arrows point to Dorsal fracture line.

Red arrows point to demineralisation in plantar aspect of T4 which was confirmed on CT.

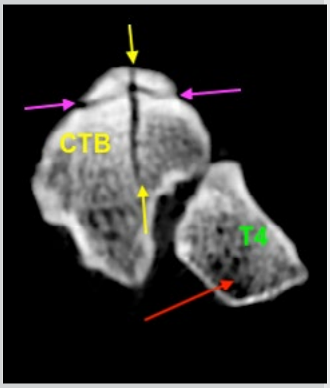
Dog #3.

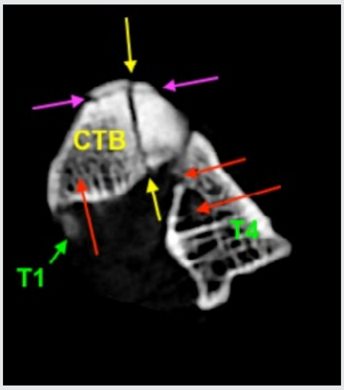
CT mid-body

Pink arrows on Dorsal fracture line.

Yellow arrows.on Sagittal fracture line.

Red arrow on demineralisation in plantar aspect of T4 correlates with AP radiograph.





Dog #3
CT distal-body
Pink arrows on Dorsal fracture line.
Yellow arrows on Sagittal fracture line.

Red arrows on demineralisation in CTB and T4. Note cortical and trabecular damage in T4.

Green arrow on T1.

Dog #3.
Medio–oblique

Red arrows point to demineralisation on medial aspect of T4 confirmed on CT.

Dog #3.
Lateral-oblique

Red arrow points to demineralisation in distal plantar aspect of the CTB which is confirmed on CT.

NOTES:

- Comparing this CT with Dog #6 (Never-raced), it is clear that the adaption to racing leads to a relative increase in the CTB compared to T4
- Both the medio-lateral and dorso-plantar axis have increased.
- The dorsal crack in compact trabecular bone (white) is seen on Lateral radiograph and correlates with CT image.
- Sagittal crack is suggested by line of demineralisation on the AP radiograph but obvious on CT. With the Sagittal fracture line, bone on both sides of the crack is only compacted in the CT distal- body. Does this suggest the crack started distally then moved proximally?
- Lateral-oblique radiograph highlights significant demineralisation in distal plantar area of CTB compared to baseline in Dog #6.
- Lateral-oblique radiographic view of the plantar area of CTB shows proximal increased mineralisation above demineralisation zone. This correlates with the CT images where there is relatively less trabecular mineralisation in CTB distal body.
- The demineralisation in T4 seen on AP radiograph correlates with CT mid-body where trabeculae is missing compared to Dog #6
- The demineralisation in T4 seen on Medio-oblique and Lateral radiographs correlates to CT distal- body where trabeculae and cortical bone is missing.

1 C. COMPARATIVE CT CORRELATION WITH 4 VIEW RADIOGRAPHY

Figure 9. Dog #4. Type IV fracture on Radiography + CT Type V fracture images

Dog #4

AP

Yellow arrows point to Sagittal fracture line in the CTB. .

Red arrows point to the black, demineralised, area in the T4 and distal edge of the CTB

Dog #4

Lateral view

Pink arrows point to Dorsal fracture line in CTB.

Red arrow points to patchy demineralisation in plantar aspect of T4.which correlates with CT image.

Dog #4

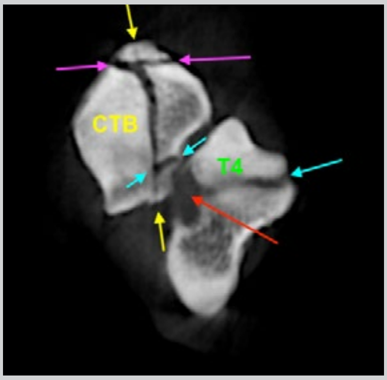
CT R mid-body

Pink arrows point to Dorsal fracture line.

Yellow arrows to Sagittal fracture line.

Light blue arrows to transverse cracks in CTB and T4.-. .

Red arrow points to demineralisation T4.



Dog #4.

CT R distal-body

Not Available.

Dog #4
Medio–oblique

Red arrow points to de-mineralised medial area of T4 observed on CT.

Dog #4.
Lateral-oblique

Light blue arrows point to the transverse cracks in CTB and T4.

Red arrow points to demin-eralised distal plantar aspect of the CTB. Unfortunately Distal- body CT was not avail-able to confirm.

NOTES:

- Comparing this CT with both previous (Dog #6 and Dog #3), the increased width of the CTB is similar with both race dogs. However, the shape of the T4 in this dog has modified compared to both other dogs.
- The dorsal crack in compact trabecular bone (white) is seen on Lateral radiograph and correlates with CT image.
- Sagittal crack is obvious on both AP radiograph and CT. Bone either side of Sagittal crack is more compact(mineralised) on the medial side.
- The cracks seen in T4 and the plantar CTB area are seen as a demineralised vague line on the Lateral- oblique radiograph.
- Lateral-oblique radiograph highlights significant demineralisation in distal plantar area of CTB compared to baseline in Dog #6.
- The large area of medial demineralisation seen on the CT of T4 correlates with the demineralisation on the radiographic views of AP, lateral and medio-oblique radiographic views.

Contents

2 A. OVERLOAD SEQUENCE PROGRESSION

Figure 10. PLANTAR-DORSAL (AP).

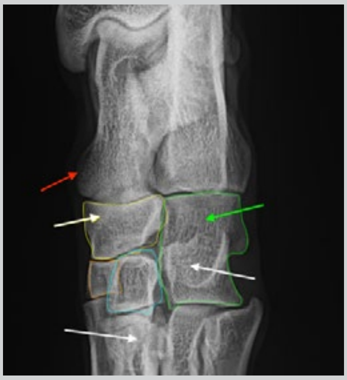
Dog #1

Normal Adaptive Load

Red arrow on cortical demineralisation Talus.

Green arrow on normal trabeculae T4

White arrows on increased mineralisation.



Dog #6.

Never Raced

White arrow on increased mineralisati in plantar zone of T4, soft tissue

Red arrow indicating demineralisation with larger trabecular pores.

Dog #2

Overload – Early

Red arrows on demineralisation in talus and T4

White arrows indicate vertical stress line with increased mineralisation due to compacted trabeculae in talus, CTB, T3 and MT3.

Dog #3

Overload-Moderate

Type I fracture

Yellow arrows on suspect Sagittal fracture in CTB

Red arrows on demineralisation in talus, CTB and T4.

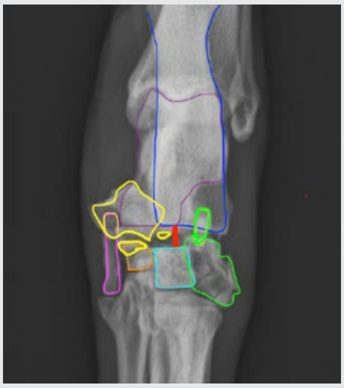
Dog #4

Overload – Moderate

Type IV fracture

Red arrows on demineralisation in talus and T4.

Yellow arrows on Sagittal fracture in CTB.



Dog #5.

Overload – Severe.

Type V fracture

Yellow – crushed CTB,. .

Green –.crushed T 4,.

Light blue – T3,. **Orange –** T2,

Pink - T1,. . . . **Purple** - Talus.

Dark blue - Calcaneus

NOTES:

- AP view is useful to assess vertical stress line through CTB and search for Sagittal fractures. Overload demineralisation can be seen in talus, CTB and T4.
- There is variation in mineralisation in the CTB with proximal increased mineralisation present in the first 3 dogs (Normal adaptive (Dog #1), Never- raced (Dog #6) and Early overload (Dog #2)) . This proximal mineralisation then becomes dispersed in the Overloaded dogs with fracture #3 and #4.

2 B. OVERLOAD SEQUENCE PROGRESSION

Figure 11. MEDIO-LATERAL. (LATERAL)

Dog #1

Normal Adaptive Load

Yellow - CTB

Green – T 4

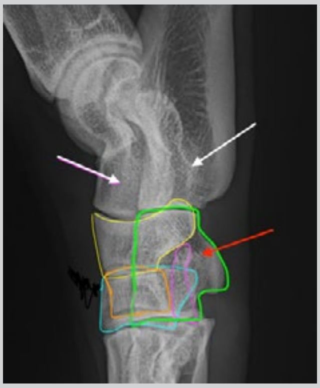
Light blue – T3

Orange – T2

Pink - T1

Red arrow on demineralisation in T4

White arrows on adaptive increased mineralisation in talus and calcaneus.



Dog #6

Never Raced

Light blue arrow on increased mineralisation.of soft tissue.

Red arrow points to area of common demineralisation in racing dogs though not present here.

Dog #2

Overload – Early

Red arrows on plantar ligament insertion. Damage on calcaneus & T4. Cortical demineralisation on dorsal aspect T3 & CTB.

White arrows on trabecular thickening in CTB, talus & calcaneus indicate adaption.

Dog #3
Overload -Moderate Type I fracture
Between Red dotted line and **Red arrows** indicate demineralisation in T4 and T3.
Pink arrows on dorsal fracture line CTB

Dog #4
Overload – Moderate Type IV fracture
Between Red dotted line and **Red arrows** indicate demineralisation in T4 and T3.
Pink arrows on dorsal fracture line CTB

Dog #5.
Overload – Severe. Type V fracture

Yellow – CTB crushed

Green – T 4 crushed

Light blue – T3

Orange – T2

Pink - T1

Purple - Talus.

Dark blue – Calcaneus collapsing forward.

NOTES:

- Lateral view useful to assess vertical adaptive increased mineralisation in talus and CTB.
- Dorsal cortical CTB demineralisation in Dog #2
- Dorsal CTB fracture and T4 demineralisation in Dog #3 and Dog #4
- Structural instability is suggested with plantar ligament mineralisation in Dog #2 and Dog #6
- White contrast (sclerosis) is observed in the dorsal face of the CTB in all dogs indicating a standard stress line.
- Demineralisation in the plantar aspect of T4 is observed in both dogs with CTB cracks (Dog #3 and Dog #4).

2 C. OVERLOAD SEQUENCE PROGRESSION

Figure 12. PLANTAROLATERAL-DORSOMEDIAL OBLIQUE. (MEDIO-OBLIQUE)

Dog #1

Normal Adaptive Load

Yellow - CTB
Green – T 4
Pink - T1
White arrows on adaptive trabeculae thickening

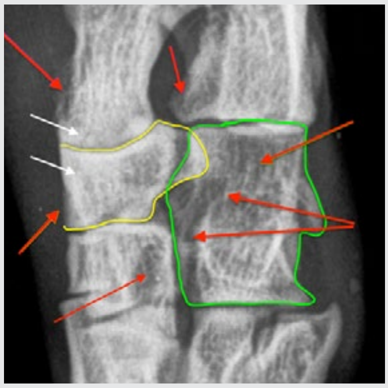
Yellow arrow on bone overlay artefact.

Red arrow on cortical demineralisation dorsal T2.
Note: normal mineralisation in T4
Green arrow on normal trabecular pattern.

Dog #6
Never Raced
Yellow - CTB
Green – T 4
Pink - T1
White arrows on increased mineralisation due to adaptive trabeculae thickening
Yellow arrow on bone overlay artefact.
Red arrows on cortical demineralisation talus and large trabecular pores in T4.

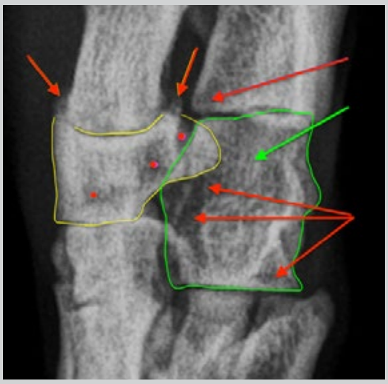
Dog #2.

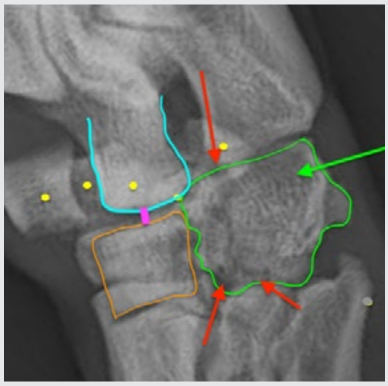
Overload – Early
Yellow - CTB
White arrows on compact trabeculae
Red arrows on demineralisation. Dorsal cortical change in CTB. Changes in T4.



Dog #3. .
Overload -Moderate
Type I fracture
Yellow - CTB
Green – T 4
White arrows on patchy whiteness suggesting trabecular breakdown.
Red arrows on multiple demineralisation sites talus, calcaneus, CTB, T4 and T3.

Dog #4.
Overload – Moderate
Type IV fracture
Yellow - CTB
Green – T 4
Red arrows on multiple demineralisation sites including overloaded ceiling of CTB
Green arrow on normal T4 zone
Red dots on demineralised CTB.





Dog #5
Overload – Severe.
Type V fracture
Green – T 4 crushed,

Orange – T3 intact

Light blue -. Talus
Red arrows on demineralised crush lines in T4
Green arrow on normal T4 area
Pink bar showing collapse.

Yellow dots on crushed pieces of CTB

NOTES:

- Medio- oblique view is useful to assess adaptive changes to talus, CTB and especially T4.
- Trabecular demineralisation in T4 of Dogs: #2, #3, #4 and #5.
- Trabecular demineralisation in CTB in Dog #4,.
- Trabecular demineralisation in Calcaneus in Dog #3.
- Cortical demineralisation in talus (Dog #3 and #6), CTB (Dog #2 and Dog #3) and Calcaneus in Dog #3.
- Medial demineralisation of T4 is observed in the dogs with CTB cracks (Dog #3 and Dog #4) and the dog with CTB collapse. Dog #5.

2 D. OVERLOAD SEQUENCE PROGRESSION

Figure 13. PLANTAROMEDIAL-DORSOLATERAL OBLIQUE (LATERAL.OBLIQUE)

Dog #1
Normal Adaptive Load
Yellow - CTB
Green – T .
Pink - T1
Red arrow points to contact area between T1 and plantar area of CTB. Small amount of demineralisation compared to *Never-raced*

Dog #6
Never Raced
Yellow - CTB
Green – T 4
Pink - T1
Red arrow points to normal trabecular mineralisation in plantar aspect of CTB

Dog #2.
Overload - Early
Yellow - CTB
Green – T 4
Pink - T1
Red arrow points to large trabeculae pores and possible demineralised trabeculae in CTB.

Dog #3. .Overload -Moderate Type I fracture
Yellow - CTB
Green – T 4
Pink - T1
Red arrow points to distinct loss of trabeculae in distal plantar aspect of CTB. Note compacted trabeculae above this.

Dog #4 Overload – Moderate Type IV fracture
Yellow - CTB
Green – T 4
Pink - T1
Light blue arrows on transverse crack in T4/ CTB confirmed on CT
Red arrow points to distinct loss of trabeculae in distal plantar aspect of CTB

Dog #5 Overload – Severe. Type V fracture

Not Available

NOTES:

- **Lateral oblique view** is very useful to assess the distal plantar aspect of CTB which is the suggested primary site of demineralisation in the CTB prior to collapse.
- For the 2 dogs with CTB fracture (Dog #3 and Dog #4) there is obvious demineralisation in the distal plantar zone of the CTB. Note the sclerosis in the proximal area of the plantar zone indicating compacted trabeculae due to probable overload in the tarsal structure.
- A longitudinal demineralised line is observed in the CTB. (Dog #4) which was confirmed on CT as a transverse fracture of the CTB and a possible overlie of a transverse crack in the T4.
- Variation in the mineralisation of T1 is observed with higher mineralisation seen in the dogs with CTB cracks
- (Dog #3 and Dog #4)

DISCUSSION

The primary motivation for writing this Report was to correlate the pathogenesis of tarsal fracture in the racing greyhound with the radiographic detection of demineralisation within the trabecular bone. A useful statistic that supports this, is Hercock's (2010) finding that the CTB of racing greyhounds suffering a Type V collapse fracture, had a 32% reduction in BMD compared to the intact left CTB.

This report only analysed right tarsi. It would have been interesting to compare mineralisation patterns of both left and right tarsi to explore the correlation with Hercock's results. Although a comparison of BMD between left and right tarsi was out of the scope of this report, it still alerts us to the fact that significant changes in mineralisation do occur and we were able to discern some patterns which progress in the right tarsus through different stages of a greyhound's racing life.

The introduction of the two oblique radiographic planes creates viewing windows to areas of the tarsus, vulnerable to fracture, that would otherwise remain obscured. In addition, the use of 4-view radiography focusing on trabecular features, provides a more comprehensive perspective that correlates well with CT imaging and is particularly useful for monitoring the integrity of the tarsus of the racing greyhound.

It was fortuitous that the CT images supplied for this report displayed both the CTB and T4 together in the same image, as both these bones may suffer dramatic collapse fracture and the pathogenesis is likely to be the similar. Furthermore, the CT images provided for this report, substantiate the radiographic diagnostic markers seen in the oblique views. *(Refer to Results, Pg. 13 to Pg.15).*

Lateral- Oblique

The Lateral-oblique radiographs give an unobstructed view of the plantar aspect of the CTB which is the proposed zone of demineralisation of the dramatic collapse which occurred for Dog #5. Unfortunately, the Lateral-oblique radiographic view was not taken at the time before surgery as it was deemed to not be helpful in determining the surgical plan.

On this plane, both dogs with CTB fractures (Dog #3 and Dog #4) showed dramatic demineralisation in the distal plantar zone of the CTB which correlates well with the CT images (distal-body level) of Dog #3. Unfortunately, no distal-body image was available for Dog #4.

Medio-Oblique

The Medio-oblique radiograph provides an unobstructed view of the medial side of T4 and allows a comparative assessment of the relative mineralisation of the talus, CTB and T4. There was a range in mineralisation in the cases with obvious relative demineralisation in the T4 bones of all 3 dogs with the CTB fractures (Dog #3, Dog #4 and Dog #5).

Additionally, there was good correlation between the Medio-oblique radiograph and the CT imaging with confirmation of trabecular damage as the cause of the demineralisation.

The author proposes that the demineralisation occurring within the CTB before collapse, also occurs within the T4 and that this process is a progressive phenomenon.

The medio-oblique radiograph of Dog #5 with the T4 collapse (concurrent with Type V CTB fracture), highlights very obvious demineralisation at the site of the medial collapse. Furthermore, the reported 62% rate of synchronous T4 and CTB fractures (Boudrieu *et al.*, 1984) indicates that the T4 is commonly involved in the plight of the overloaded CTB.

When repositioning the displaced CTB, there is often a perceptible *softness* while drilling through the T4. This is the author's surgical observation which further supports the proposal that occult demineralisation is common in the T4.

The observation of demineralisation on the medial side of the T4 correlates with the insertion of the interosseous ligaments between T4/CTB and T4/T3. The author proposes that positional instability in the CTB creates strain on the interosseous ligament with subsequent horizontal overload on T4. The CT images of the 2 dogs with a fractured CTB (Dog #3 and Dog #4) correlate with changes in this zone of the T4.

Demineralisation – a conflicted theory

Regarding the theory of demineralisation, there are conflicting reports amongst researchers, on the Bone Mineral Density (BMD) status of the fractured right CTB. This has arisen because some researchers only sampled the dorsal and mid-section of the bone whilst others tested the entire bone.

In some cases, sampling was restricted to the dorsal and mid-section of the CTB. This resulted in a higher BMD for the fractured right CTB compared to intact CTBs according to Bergh *et al.*, (2012). When the entire CTB was tested, the BMD in the fractured right CTB was approximately 32% lower than the left (Hercock, 2010) and (Emmerson *et al.*, 2000).

Thompson *et al.* (2012) also found that the right CTB of dogs with a history of tarsal injury had a lower BMD compared to dogs without prior injury. Additional evidence of the demineralisation process, was the detection of high levels of osteoclastic enzymes in the fractured CTBs (Hercock, 2010), indicating that active bone removal was occurring in the right CTB before fracture. There is robust research evidence confirming the process of significant demineralisation within the bone, preceding Type V CTB collapse fracture.

The breaking and resorption of the trabeculae within the distal plantar zone may explain the demineralisation occurring in the CTB prior to the collapse fracture. Plantar flexibility would be compromised by the loss of the prominent elastic trabeculae leading to increased susceptibility to fracture within the whole CTB. The analogy is the collapse of the air cushion in the heel of the sports shoe.

The author proposes that the distal plantar zone of the CTB is the area vulnerable to demineralisation and that this process is a progressive phenomenon seen in the racing greyhound.

This proposal, is supported by the sagittal plane radiograph from Bergh et al. (2012), which compares an intact left CTB with a fractured Right CTB. *(Refer to Figure 14., below).* The interpretation by the author can be found to the left of the image.

The radiographic markers for increased mineralisation indicate signs of load on trabeculae whilst demineralisation provides a marker for damage due to overload. This image also highlights the important differentiation between unloaded non-calcified trabeculae and damaged demineralised trabeculae.

Figure 14. Non-screen high-detail radiographs of 2 CTBs taken from Sagittal plane sections. (Burgh *et al*., 2010)

Proximal side of the CTB is at the top of images

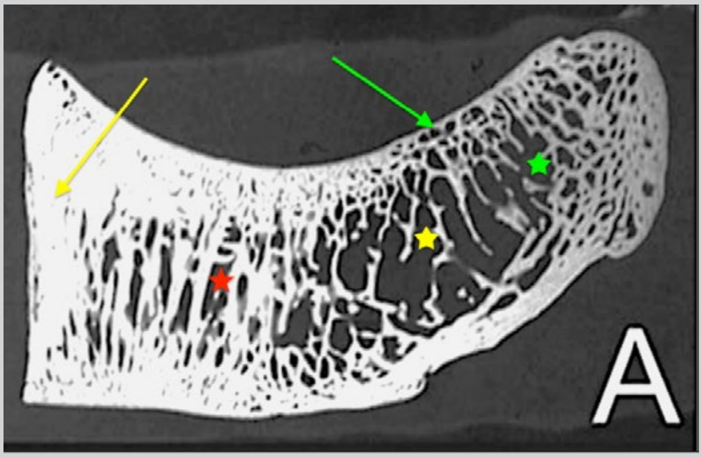
A is a normal Left CTB

Yellow arrow points to the dorsal (forward facing) surface of the Left CTB with thickened trabeculae and the filled-in pores indicate the adaptive response to load.

Between the **Yellow arrow and Red star** are the vertical white lines of calcified struts responding to the vertical load.

Green arrow points to *Plantar Process* and persisting black pores, indicating less vertical load.

Yellow and Green stars are areas where the Trabeculae have not yet calcified indicating an evolving *load* and not *overload* at this stage.



B is a fractured Right CTB

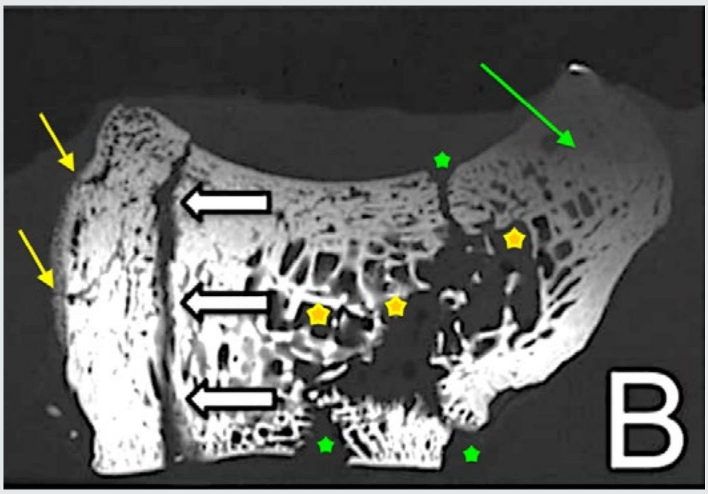
Yellow arrows point to the dorsal cortical bone of the Right CTB with multiple fissure cracks in the compacted bone.

Large White arrows point to dorsal fracture line with compacted Trabecular bone on either side.

Green stars highlight the mid body (Sagittal) fracture.

The top **Green star** and **Green arrow** highlight the compacted Trabeculae indicating *overload* with further damage seen below (yellow stars).

Yellow stars in the area of broken and resorbing trabecular struts presenting as low BMD. This is a Type IV or V fracture on the verge of catastrophic collapse.



A is the normal left CTB

B shows the fracture of the right CTB

This is a non-screen high-detail radiograph from Sagittal plane section, Burgh et al., 2010

Trabecular damage in the plantar zone of the CTB is a topic that requires further research with 4-view radiography and corresponding CT imaging. Current literature has not yet presented such a study.

Recurring microtrauma triggers osteoclastic activity which may cause thinning and/or perforation of trabeculae (Seeman, 2003). Once perforated, the bone loss becomes amplified with reduced *scaffolding* to support osteoblastic bone formation (Parfitt *et al*., 1983). As a result, the scaffold of trabecular struts starts to disconnect further and isolated struts become quickly resorbed and disappear (Mosekilde, 1993).

It appears that the breaking and resorption of the trabeculae within the distal plantar zone is a possible explanation for the dramatic demineralisation that occurs in the CTB before the collapse fracture.

It is the plantar zone of both left and right CTBs that has the largest trabecular pores (Hercock, 2010). The author agrees with this and proposes that the larger pore size provides flexibility and spring action for the entire CTB.

The plantar process of the CTB is not restricted by a major distal bone but has a small joint attachment to the tall and narrow T1 below. Due to the teacup shape of the plantar process (and presence of large flexible trabeculae), the author proposes that the plantar process of the CTB functions as a rocking 'heel cushion' for the entire CTB with T1 acting as a flexible vertical support. There is a small longitudinal tendon running in the medial groove of the plantar process that would also give flexible support.

The radiographs in the Lateral-oblique Overload Sequence highlighted a range of mineralisation phases in T1 with higher levels in the dogs with the CTB fracture (Dog #3 and Dog #4). *(Refer to results, Pg.19).* The author proposes that an overloaded CTB leads to damage and demineralisation of the flexible plantar trabeculae resulting in increased load passed onto T1 which then responds with adaptive mineralisation.

Overload – soft tissue mineralisation

Fracture of the CTB is common but the literature does not give a specific answer as to why only some CTBs are susceptible. The repetitive strain of circle running may lead to laxity in the supportive soft tissue which precedes many fractures (Blythe *et al*.,2007).

The tendons, ligaments and joint capsules have a common collagen composition of a triple helix which may become overstretched. The collagen structures rely on elastic recoil (Watkins, 2009) to provide the vital compressive support to the underlying bones. Laxity may create positional instability for the CTB within the entire tarsal structure.

The laxity of soft tissues is difficult to measure precisely, however, compromised function may be indicated by the radiographic detection of increased mineralisation within known location of tendons, ligaments and joint capsules. In this report on the Medio-lateral radiographs, these changes were seen on the plantar aspect of Dog #2, Dog #3 and Dog #6. *(Refer to Pg. 17)*

Limitations of this Report

The author acknowledges this report's small sample size due to restricted access to CT imaging and the need to keep newly introduced concepts simple. It was out of the scope of this report to include more than 6 images on a page in this comparative study.

Future studies could repeat this radiographic assessment technique on a larger number of dogs and compare left and right tarsi to observe differences in mineralisation. In addition, different time frames could be observed to analyse the effects of the continuity of racing on the CTB and T4 tarsal bones in racing greyhounds.

RADIOGRAPHIC TARSAL SCREENING GUIDELINES

The risk of fracture escalates within the first 12 months of racing, indicating that Tarsal Screening should be undertaken at the start of racing to establish a baseline and then at regular intervals in the racing career. Additionally, tarsal radiography should be considered for pre-purchase or for pre-insurance with potentially valuable breeding animals.

The Guidelines:

1. **Baseline.** The baseline should include the left and right tarsi. Subsequently, the Right tarsus is to be radiographed every 6 months and compared with the established baseline.

2. **Right Hind Leg Function.** Tarsal radiography should also be undertaken on any greyhound that displays tarsal pain or any reduced performance related to the right hind leg function that cannot be attributed to another significant injury location. Signs of reduced right hind leg function include slowing down when cornering or running wide when cornering.

3. **Perform 4-View Radiography.** Perform a minimum of 4 viewing angles when taking radiographs of the tarsus. The views to include are: 1) Plantar-dorsal, 2) Lateral, 3) Medio-oblique and.4) Lateral-oblique.

4. **Apply Diagnostic Radiographic Markers.** When examining radiographs, scan all the tarsal bones for signs of the Diagnostic Radiographic Markers outlined on Page 10. An assessment of the state of adaptive load or overload within the whole tarsal structure can be made when differing mineralisation levels are observed.

5. **Observe Changes in Adaptive Load.** Adaptive load changes are indicated by increased white contrast (mineralisation) within the tarsal structure. All 4 radiographic views need to be assessed however, a common vertical stress line descending through the talus and CTB may be detectable on the Plantar-dorsal and Medio-oblique radiographs. Observation of the orientation of the mineralised trabecular struts will give an estimation of direction of stress load within each bone.

6. **Observe Changes Within the Bone.** Increased black contrast (demineralisation) occurring within the tarsal structure indicates overload changes within the bones. All 4 radiographic views need to be assessed. The Medio-oblique and Lateral views may reveal demineralisation in T4 and the l;ateral-oblique view may reveal demineralisation in the plantar aspect of the CTB.

7. **Observe Changes in Soft Tissues.** Increased white contrast (mineralisation) within the tarsal joint indicates overload changes within soft tissues. All 4 radiographic views need to be assessed; however, the Lateral view may reveal plantar ligament mineralisation.

Management options when demineralisation is found on radiography

Depending on the location and severity of the demineralisation there will be differing management options including:

- Exercise modification including restricted racing on only straight tracks with radiographic review in 4-12 weeks.
- Supportive measures to counteract potential laxity in the soft tissues of the tarsal structure. Examples include compressive bandaging.
- Extracorporeal Shockwave Therapy (ESWT) to stimulate healing.
- Surgical options may include screw placement or simple drilling between areas of differing mineralisation. This will assist blood flow into compromised zones and allow bone fusion to reinforce impaired interosseous ligament function. The most likely location will be between CTB and T4.
- Referral for CT imaging to assist decision making.

RECOMMENDATIONS

Into the Future...

In light of the continued prevalence of tarsal fractures, the following recommendations will help to improve the welfare of the racing greyhound worldwide.

1. Notification to each State (or other jurisdiction) Racing Authority and their Welfare department of the statistical reality of the greyhound tarsal injury problem. The recording and publication of race injury statistics should specify the specific number of tarsal injuries. This will enable the tracking of injury statistics over time.

2. Establish a Tarsal Screening Scheme where all racing greyhounds have radiography of their tarsus at the start of their racing career and then at 6 monthly intervals.

3. Education of greyhound trainers and veterinarians about the risks of suppressing tarsal pain and the benefits of early radiographic investigation of joint pain of both tarsus and carpus. Some veterinarians recommend the post-race use of non-steroidal anti-inflammatory medication which carries the significant risk of suppressing the low- grade pain associated with demineralisation. A similar scenario is seen in the racehorse where pain suppression and undetected trabecular bone damage can lead to fracture at a subsequent race (Brokken, 2015) and (Stewart and Kawcak, 2018).

4. Establishment of a veterinary protocol to use of a minimum of 4 views with standard radiography to investigate joint pathology in the racing greyhound.

5. Initiate investigation into causation of the most common reason for catastrophic fracture requiring immediate euthanasia, fracture of the radius and ulna (GWIC, 2022). In the thoroughbred horse racing industry, there is a reported link between catastrophic fracture of the front cannon bone and trabecular

bone disease in the lower joints (Stewart and Kawcak, 2018). Therefore, the author's finding of trabecular bone injury in the distal radius and carpus should stimulate thought about a possible similar relationship in the greyhound.

CONCLUSION

This Report highlights the two main welfare concerns with tarsal fractures in racing greyhounds:

1. An increased risk of fracture, by 400% after only 12 months of racing
2. The primary cause of the demineralisation that may lead to fracture, can remain clinically undetected until an injury occurs.

The addition of 2 oblique views to the standard radiographic protocol creates the opportunity to expand the investigation of tarsal injuries beyond the search for fracture lines. Why is this of value? Because the two standard radiographic views may reveal the two main fracture lines that occur in the CTB whilst the oblique views may reveal the demineralisation that precedes fracture in the CTB and T4.

The collaborative use of CT imaging with 4-view radiography assists in observing the correlation of radiographic changes in mineralisation to specific changes in trabecular structure. This enhances the 3D visualisation for future radiographic interpretation.

The radiographs presented in this report reveal a number of diagnostic markers that can be used for decision making about whether a dog should be rested from racing, if it appears to be at risk. Therefore, the implementation of the Radiographic Tarsal Screening Guidelines *(Refer to Pg. 22)* may prove to be an important form of tarsal fracture prevention and reduce the numbers of Major racetrack fractures and euthanasia.

Despite the sample size of only 6 cases, this report presents a new approach to radiology that can provide the basis for preventing one of the most prevalent injuries in the racing greyhound industry.

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I dedicate this report to all the greyhounds with fractured hocks that I had to euthanise or surgically repair, and to all of the dogs whose injuries may be prevented by the introduction of radiographic screening.

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My own rescued greyhound, Star, never made it to the track, and I thank her, for her unsurpassed dedication and companionship.

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