Prevalence of radiographic changes in the metacarpal and carpal bones of South African endurance horses

By

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Master of Science in the Department of Companion Animal Clinical Studies at the
Faculty of Veterinary Science, University of Pretoria

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16 September 2019

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Annual Renewal
(Extension1)

AEC Reference No.: V040-18
Title: Prevalence of radiographic changes in South African endurance racehorses. Part II: Metacarpi and Carpi
Researcher: Miss TB Prior
Student's Supervisor: Dr Y Smit

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The **Annual Renewal** as supported by documents received between 2019-04-15 and 2019-09-10 for your research, was approved by the Animal Ethics Committee on its quorate meeting of 2019-09-10.

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Species and Samples	Number Available
Horses	100

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Yours sincerely

Prof V Naidoo
CHAIRMAN: UP-Animal Ethics Committee

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PROJECT TITLE	**Prevalence of radiographic changes in South African Endurance racehorses- Part 2: Metacarpi and Carpi**
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ANIMAL SPESIES/SAMPLES	**Equine**	
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Approval period to use animals for research/testing purposes		**May 2018-May 2019**
SUPERVISOR	**Dr Y Smit**	

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APPROVED	Date 28 May 2018
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Abstract

This study investigated the presence and prevalence of radiographic changes in the carpus and proximal metacarpus of endurance horses in South Africa during the 2018 endurance season. These regions were identified as areas that are subjected to multiples stressors due to the high impact of the endurance discipline, and so radiographic changes were expected to be present.

The metacarpi and carpi were digitally radiographed in a total of 100 endurance horses, registered with Endurance Ride Association of South Africa (ERASA) to compete in 2018. The standard views for each of these regions were taken, as well as one dorsal tangential view (dorsal 35° proximal dorsodistal oblique) of the carpi. The radiographs were evaluated individually by three experts, using Digital imaging and communications in medicine (DICOM) software and a consensus was used to confirm the presence of lesions. From the frequency of changes, the prevalence was calculated. Kappa statistics were used to calculate the Inter-rater reliability (IRR) and to determine the level of agreement between the analysers.

The results of this study demonstrated more radiological changes in the carpi than in the metacarpi, and more changes seen on the left than the right forelimb, correlating with the most commonly clinically identified lame limb in endurance horses.

In the carpus, the most prevalent changes included subchondral bone sclerosis of the third carpal bone (77%), a present first carpal bone (27%), carpal osteophytes (9%) and carpal enthesiophytes (8%).

The most prevalent changes in the proximal metacarpus included endosteal new bone formation at the proximopalmar aspect of the third metacarpal bone (34%), synostosis between the second and third metacarpal bones (9%), and periosteal new bone formation on the second metacarpal bone in 9% of horses.

A major downfall of this study was that it did not correlate the radiographic findings with signalment, endurance riding level or clinical significance. This study has provided a baseline of the prevalence of radiographic changes in the proximal metacarpi and carpi that future studies in the endurance discipline in South Africa can build upon.

List of Abbreviations

LM	Lateromedial
DPa	Dorsopalmar
DL-PaMO	Dorsolateral-palmaromedial oblique
DM-PaLO	Dorsomedial-palmarolateral oblique
D35°Pr-DDiO	Dorsal 35° proximal-dorsodistal oblique
D55°Pr-DDiO	Dorsal 55° proximal-dorsodistal oblique
D85°Pr-DDiO	Dorsal 85° proximal-dorsodistal oblique
MC2	Second metacarpal bone
MC3	Third metacarpal bone
MC4	Fourth metacarpal bone
C1	First carpal bone
C2	Second carpal bone
C3	Third carpal bone
C4	Fourth carpal bone
C5	Fifth carpal bone
RC	Radial carpal bone
IC	Intermediate carpal bone
UC	Ulnar carpal bone
AC	Accessory carpal bone
DJD	Degenerative joint disease
FFD	Focus-film distance
DICOM	Digital imaging and communications in medicine
ALARA	As low as reasonably achievable
MPD	Maximum permissible dose
ICRP	International Commission on Radiological Protection
FEI	Fédération Equestre Internationale
ERASA	Endurance Ride Association of South Africa
UV number	Afrikaans for “uithourit vereeninging” and translated to English as ‘endurance ride association’ number
EVIG	Endurance Veterinary Interest Group
IRR	Inter-rater reliability

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Chapter 1: Introduction

1.1 BACKGROUND

This study served to provide information on the prevalence of radiographic changes seen in the carpi and proximal metacarpi of endurance horses in South Africa. The knowledge of the prevalence and the understanding of potential implications of specific radiographic changes present in endurance horses are a prerequisite for veterinarians advising owners on a horse's future potential and for researchers to note which changes warrant further investigation (Kane et al., 2003, Robert et al., 2010). This study has served to provide baseline data on radiographic changes which can be used for future clinical studies.

1.2 PROBLEM STATEMENT

To the author's knowledge there have not been any studies published that investigate the prevalence of radiographic changes in the metacarpi and carpi of South African endurance horses. This radiographic study aimed to provide the prevalence and distributive data of metacarpal and carpal lesions that can serve as a comparative for future studies.

1.3 HYPOTHESIS

Radiographic changes are present in the metacarpal and carpal bones of competing South African endurance horses.

1.4 OBJECTIVE

The objective of this study is to describe the radiographic changes present in the proximal metacarpi and carpi of competing South African endurance horses. From the data collected the prevalence of such changes will be determined.

1.5 BENEFITS

This study will provide the prevalence of radiographic changes in the metacarpi and carpi of competing South African endurance horses. This information can be used by fellow equine veterinarians to improve their diagnostic abilities and focus on the areas in the carpus and metacarpus where more prevalent changes occur. This can aid in more efficient diagnosis and treatment of metacarpal and carpal disease endurance horses (Nagy et al., 2012). The prevalence of radiographic changes can also provide a basis for potential future studies, which could investigate how these changes are clinically significant.

Chapter 2: Literature Review

2.1 INTRODUCTION

Endurance events are one of the fastest growing FEI disciplines with the number of registered events having increased substantially worldwide in the last 20 years (from 1 event in 1998, to 204 events in 2008 and 309 registered events in 2018) (FEI, 2019). Endurance riding is becoming an extreme sport with longer distances being covered, at much faster speeds, and over varying terrains in the different countries that participate in the sport (Bennet and Parkin, 2018a, Robert, 2014). Maintenance of a sound gait during a race is one of the most important parameters assessed with the majority of horses being eliminated due to orthopaedic injuries (62.7% of horses eliminated) causing lameness (Adamu et al., 2014, Nagy et al., 2012). This pattern of elimination due to lameness is present in all countries where endurance riding occurs, including South Africa (Robert, 2014). The increased speeds and distances now covered have led to a change in the types and severity of injuries seen, and injuries more commonly associated with flat racehorses are occurring (Bennet and Parkin, 2018a). Research into these injuries and different measures to prevent them is required (Nagy et al., 2012, Robert et al., 2010).

2.2 COMPARATIVE STUDIES

Few publications on descriptive epidemiological data and clinical evidence-based studies on endurance horses exist, and there is little information regarding the type of orthopaedic injuries that occur. From previous studies it can be seen that the prevalence of lameness in horses competing in endurance riding is much higher than those competing in dressage or show jumping, but the prognosis for returning to competition is better (Nagy et al., 2012). Although lameness is the leading cause of elimination from endurance rides, often no diagnosis regarding the inciting cause is made (Nagy et al., 2012, Nagy et al., 2017, Robert, 2014).

Musculoskeletal problems have been associated with 18% of all injuries in endurance horses; most of these horses have been lame at least once in their career (Nagy et al., 2012). The most common cause of lameness documented is proximal metacarpal pain, followed by pain in the foot and then pain in the metacarpophalangeal (fetlock) region (Nagy et al., 2012). Tendon or ligament injuries are the most common diagnoses made, followed by foot pain and joint pain (Nagy et al., 2017). Osteoarthritis of the fetlock and tarsal joints are also a common occurrence causing joint pain (Robert, 2014). Non-septic polysynovitis often develops during or after a ride and usually involves the carpi, fetlocks, tarsi and stifles (Robert, 2014).

More recent studies have described fractures similar to those in flat racehorses occurring in endurance horses (Nagy et al., 2012, Robert, 2014). These can be linked to the increasing speeds in the discipline (Bennet and Parkin, 2018a). Fractures of the first and second phalanx, third metacarpal/ -tarsal bone, radius, humerus, scapula, femur, ischium and ilium have been recorded (Robert, 2014). It is speculated that more injuries of a similar nature to those in flat racehorses will be seen more frequently as the discipline progresses (Nagy et al., 2012, Robert, 2014, Robert et al., 2010).

To the author's knowledge no radiographic studies in endurance horses in South Africa have been performed prior to this.

2.3 THE RELEVANCE OF RADIOGRAPHS

Radiographs aid in the diagnosis of orthopaedic injuries and digital radiography allows a diagnosis to be made in a timeous and efficient manner (Ballegeer and Nelson, 2012, Dyson, 2011, McKnight, 2004). Portable digital radiography systems allow for taking radiographs in the field and are adequate for producing diagnostic quality images of the distal equine limb (Butler et al., 2017c). Radiographs provide diagnostic information about the bones, joints and soft tissues structures (tendons, ligaments and joint capsule insertions) within the distal limb (Dyson, 2011). They can be used for pre-purchase evaluations, routine veterinary consults and pre-race evaluations to establish if any underlying orthopaedic conditions are present and to diagnose the presence of changes in lame horses. The presence of radiographic changes is not always related to lameness, but can be indicative of past or potential future conditions that may arise and cause lameness. This can aid in the prevention of more severe injuries by identifying horses with underlying conditions which could put them at risk of injury.

2.4 RADIOGRAPHIC VIEWS

In order to obtain radiographs of diagnostic quality, a sufficient number of adequately exposed views from a correctly positioned and restrained horse must be taken. For every joint or region evaluated there is a standard technique and a minimum number (at least four views for the joints of the distal limb) of views required (Ballegeer and Nelson, 2012, Dyson, 2011).

The regions selected for investigation in this study were the proximal metacarpus and carpus. Due to endurance riding being a high impact discipline, radiographic changes in these areas are commonly present (Bennet and Parkin, 2018a, Nagy et al., 2012, Rajão et al., 2019, Robert, 2014). Another common area for radiographic changes in high impact disciplines is the metacarpophalangeal joint, and this was investigated in a concurrent radiographic study, which evaluated the foot and the metacarpophalangeal joints in the same pool of South African endurance horses (Hollenbach, 2020, Nagy et al., 2012).

2.4.1 The Metacarpus

There are 3 metacarpal bones in the equine forelimb, namely the second metacarpal bone (MC2), the third metacarpal bone (MC3) and the fourth metacarpal bone (MC4). In order to adequately evaluate the bones for lesions in this area four standard views are taken (Ballegeer and Nelson, 2012, Butler et al., 2017b, Dyson, 2011). See table 1. Additional views include variations of the oblique views and a flexed lateromedial view to better expose avulsion fractures at the origin of the *interosseous medius muscle* (suspensory ligament). Using a long, 43cm, cassette is helpful to obtain images of the majority of the length of the metacarpal region (Butler et al., 2017b).

Table 1: Standard views of the metacarpus

View:	**Notes on Radiography:**
Lateromedial	Highlights the dorsal aspect and cortex of the third metacarpus. Used to evaluate changes to the third metacarpal bone and soft tissue swelling of the metacarpus.
Dorsopalmar	Highlights the proximopalmar aspect and the cortex of the third metacarpal bone. Used to evaluate changes at the attachment of the suspensory ligament and changes in the cortices of the third metacarpal bone.
Dorsolateral palmaromedial oblique	Highlights the fourth metacarpal bone and the space between the third and fourth metacarpal bones. Used to evaluate the fourth metacarpal bone for new bone formation and fractures, and to evaluate syndesmopathy or synostosis of the third and fourth metacarpal bones.
Dorsomedial palmarolateral oblique	Highlights the second metacarpal bone and the space between the second and third metacarpal bones. Used to evaluate the second metacarpal bone for new bone formation and fractures, and to evaluate syndesmopathy or synostosis of the second and third metacarpal bones.

2.4.2 The Carpus

The carpus consists of three joints – the antebrachiocarpal, middle carpal and carpometacarpal joints. The bones of these joints articulate in such a manner that there are many superimposing structures, which can confuse interpretation of radiographs (Butler et al., 2017c, Murray and Dyson, 2018, Ruggles, 2012). The proximal row of carpal bones consists of the radial carpal (RC), intermediate carpal (IC), ulnar carpal (UC) and accessory carpal bones (AC). The distal row of carpal bones consists of the second carpal (C2), third carpal (C3), fourth carpal (C4), first carpal (C1) and fifth carpal bones (C5), if the latter two are present. The five standard views of the carpus are described in table 2 (Ballegeer and Nelson, 2012, Butler et al., 2017c). The possible additional views are shown in table 3 (Butler et al., 2017c, Dyson, 2011).

Table 2: Standard views of the carpus

View:	Notes on Radiography:
Lateromedial	Highlights the dorsal aspect of the carpus and the accessory carpal bone. Clearly delineates the antebrachiocarpal, middle carpal and carpometacarpal joints. Used to evaluate soft tissue swelling in and around the carpus, changes to the dorsal aspect of the intermediate and third carpal bones, and changes in the accessory carpal bone.
Dorsopalmar	Highlights the individual carpal bones and the carpal joints. Used to evaluate changes in radial, intermediate, ulnar, second, third and fourth carpal bones. Can sometimes visualise the presence of a first and fifth carpal bone.
Dorsolateral palmaromedial oblique	Highlights dorsomedial margin of the third and radial carpal bones. Highlights the accessory, ulnar and fourth carpal bones. Used to evaluate changes to these bones and the presence of a fifth carpal bone.
Dorsomedial palmarolateral oblique	Highlights dorsolateral margin of the third and intermediate carpal bones. Highlights the palmar aspect of the second and radial carpal bones. Used to evaluate changes to these bones and the presence of a first carpal bone.
Flexed lateromedial	Highlights the dorsodistal margin of radial and intermediate carpal bones (by opening up the intercarpal joints). Used to evaluate these areas especially for chip fractures, and subchondral bone opacity changes.

Table 3: Dorsal tangential views of the carpus

View:	Notes on Radiography:
Dorsal 35° proximal dorsodistal oblique	Highlights the dorsal aspect of the distal row of carpal bones (second, third and fourth carpal bones). Used to evaluate the presence of sclerosis, lysis and slab fractures in the third carpal bone.
Dorsal 55° proximal dorsodistal oblique	Highlights the dorsal aspect of the proximal row of carpal bones (radial, intermediate and ulnar carpal bones). Used to evaluate the presence of sclerosis, lysis and slab fractures in these bones.
Dorsal 85° proximal dorsodistal oblique	Highlights the cranial aspect of the distal radius and ulna. Used to evaluate changes and fractures of the distal radius and ulna.

2.5 RADIOGRAPHIC CHANGES

The following radiographic changes in the proximal metacarpal and carpal bones were speculated to be present in endurance horses due to the highly strenuous nature of the discipline, the suspicion that the increasing speeds will lead to lesions similar to those seen in Thoroughbred racehorses, and the clinical problems experienced by endurance veterinarians (Bennet and Parkin, 2018a, Daniel and Kawcak, 2014, Nagy et al., 2012).

2.5.1 Radiographic changes evaluated in the metacarpal bones

Soft-tissue swelling can usually be seen in the tissue surrounding the metacarpus when there is a primary soft tissue injury or when there is other underlying bone pathology (Butler et al., 2017b, Dyson, 2011, Dyson and Biggi, 2018, Richardson, 2012). The metacarpal bones have a major weight-bearing function in the forelimb and injury to these bones and associated structures often leads to lameness – this may be transient or performance limiting depending on the site and severity of the injury (Richardson, 2012).

Periostitis, which is inflammation of the periosteum with possible subperiosteal haematoma and periosteal new bone formation, can occur either due to direct trauma or microfractures. Direct trauma often affects MC2 or MC4, but can also affect MC3. This initially presents as new bone formation with irregular margins and a slightly increased mineralised opacity (indicating an immature periosteal reaction) and progresses to having a smoother outline and a further increased mineralised opacity as the bone is modelled and matures. The mineralisation pattern can lead to lucent lines which can mimic a fracture (Butler et al., 2017b, Dyson and Biggi, 2018). Periostitis is often associated with some degree of pain and lameness (Richardson, 2012).

Periostitis that occurs from microfractures on the dorsal aspect of MC3 leads to dorsal metacarpal disease (sore or 'bucked' shins), which is often associated with pain and lameness in the horse (Richardson, 2012). These microfractures occur due to the cyclic loading of immature bones, during the young (2 – 3 year old) horse's training, where cortical modelling has occurred and can result in focal porous areas of the cortex. This phenomenon results in periostitis or endosteal new bone formation at the dorsal aspect of MC3, a thickened dorsal cortex of MC3 and vertical radiolucent lines (visible due to the differences in densities and stiffness of overlying bone) in the cortex of MC3 (Butler et al., 2017b, Dyson and Biggi, 2018, Richardson, 2012).

Syndesmopathy (alteration in the cortical or trabecular structure of adjacent bones with osseous spurs on the articular margins due to injury of the syndesmosis) or synostosis (fusion between bones) can form between MC2 or MC4 and MC3; usually about 7cm distal to the carpometacarpal joint (Butler et al., 2017b, Dyson and Biggi, 2018, Jackson and Auer, 2012). These lesions are often referred to as ‘splints’ and are usually associated with desmitis of the *interosseous medialis* (between MC2 and MC3), and the *interosseous lateralis* (between MC3 and MC4) ligaments (Butler et al., 2017b, Jackson and Auer, 2012). This is associated with varying degrees of lameness, especially in the acute stage of the disease, and present as horses that deteriorate with work, especially on harder surfaces (Butler et al., 2017b, Jackson and Auer, 2012). The acute stage, when lameness is typically seen, can show areas of increased radiopharmaceutical activity scintigraphically (Butler et al., 2017b).

Proximal *interosseous medius* (suspensory ligament) desmitis can lead to endosteal new bone (increased mineralised opacity of palmar subcortical bone) formation on the palmaroproximal aspect of MC3 where the suspensory ligament attaches. Tearing of this attachment can result in enthesiophyte (spurs of bone at the origin , insertion, attachment of ligaments, tendons or joint capsules to bone) formation in this region (Butler et al., 2017b, Dyson and Biggi, 2018). Ultrasonographic evaluation of the integrity in the proximal suspensory ligament is required to confirm the suspected diagnosis (Butler et al., 2017b). Proximal suspensory desmitis is usually associated with lameness in the forelimb (Butler et al., 2017b).

Chronic osteoarthritis or degenerative joint disease (DJD) of the carpometacarpal joint leads to a narrowing of the carpometacarpal joint which can result in periosteal reactions of the proximal aspect of MC2, MC3 or MC4 (Butler et al., 2017b, Dyson and Biggi, 2018). This can be seen with a chronic lameness (Butler et al., 2017b).

Injuries to the suspensory body or branches can lead to bone modelling of MC2 or MC4 (Butler et al., 2017b, Dyson and Biggi, 2018). The suspensory ligament originates on the distal row of carpal bones and the proximal palmar aspect MC3. Injury to the body or branches can be associated with lameness (Richardson, 2012). It is best to evaluate changes to the suspensory ligament with an ultrasonographic examination (Butler et al., 2017b).

Exostoses on the palmar aspect of MC3 result in linear mineralised radiopacities that can be associated with lameness due to impingement on the suspensory ligament (Butler et al., 2017b, Dyson and Biggi, 2018). This impingement occurs due to the close proximity of the suspensory ligament and the palmar aspect of MC3 (Richardson, 2012).

Enostosis-like lesions (focal thumbprint-like areas of increased mineralised radiopacity) near the nutrient foramen without cortical or periosteal reaction can also be found in MC3 (Butler et al., 2017b, Dyson and Biggi, 2018). These are often incidental findings but can be a cause of lameness if severe (Butler et al., 2017b). The lameness will usually resolve with rest, but can recur (Butler et al., 2017b)

2.5.2 Radiographic changes evaluated in the carpal bones

Intra-articular soft tissue swelling in the carpus can be from multiple origins but radiographically is seen as dorsal displacement or disappearance of the dorsal carpal fat pad and an increased amount of soft tissue opacity palmar to this (Butler et al., 2017c). Soft tissue swelling in the carpus is often associated with underlying bone pathology and subsequent lameness (Ruggles, 2012). Extra-articular soft tissue selling of the carpus is seen radiographically as an increased soft tissue opacity around the carpus without displacement of the dorsal fat pad (Butler et al., 2017c)

Intercarpal desmitis is not readily seen on radiographs but one can see enthesiophyte formation on the dorsal aspect of the RC and IC bones where the dorsal intercarpal ligaments attach (Butler et al., 2017c, Murray and Dyson, 2018). Intercarpal ligament desmitis is associated with reduced performance and lameness (Ruggles, 2012).

Osteoarthritis or DJD can be seen in the carpus, and most often affects the antebrachiocarpal and middle carpal joints. The radiographic changes seen with DJD are the formation of osteophytes (spurs of bone at the joint margin), rounding of the normally sharply angled carpal bone articular margins, narrowing of the joint spaces, lysis (lucent areas within the subchondral bone) and/or sclerosis (localised increased mineralised opacity within the bone) of the subchondral bone, and ankylosis, (Butler et al., 2017c, Daniel and Kawcak, 2014, Murray and Dyson, 2018). Osteoarthritis or DJD is usually associated with a more chronic type of lameness (Butler et al., 2017c).

Sclerosis of the radial facet of C3 (visualised on the D35°PrDDiO view) has been associated with lameness and is often seen bilaterally (Butler et al., 2017c, Murray and Dyson, 2018, Ruggles, 2012). The severity of sclerosis has been correlated with varying degrees of lameness in flat racehorses (Ruggles, 2012). Due to the increased speeds of endurance riding resulting in lesions similar to those found in flat racehorses it has been speculated that sclerosis will become a more prevalent lesion in endurance horses (Bennet and Parkin, 2018a, Nagy et al., 2012, Rajão et al., 2019).

Osseous cyst-like lesions or subchondral bone cysts (radiolucent lesions) associated with the carpal area have been seen in all the carpal bones, proximal metacarpal bones and the distal radius but only appear to be of significance if large and near the joint margins or present in the ulnar carpal bone (Butler et al., 2017c, Murray and Dyson, 2018, Daniel and Kawcak, 2014). Large lesions near joint margins or in the ulnar carpal bone frequently will present as a lameness (Butler et al., 2017c).

Osteochondral fragmentation or chip fractures (fracture of articular margin) are usually present on the distal dorsal aspect of RC and IC, the radial facet of C3, the distal border of the radius and on the palmar aspect of the carpus, and they are often seen bilaterally (Butler et al., 2017c, Murray and Dyson, 2018, Ruggles, 2012). These are commonly associated with lameness in the flat racehorse and are usually performance limiting (Ruggles, 2012). With the increasing speeds and distances of endurance riding it is suspected the more osteochondral fragmentation will be seen in endurance horses (Nagy et al., 2012, Rajão et al., 2019).

Osteochondral fractures or slab fractures (fractures extending from one joint surface to another) can be seen most commonly on the dorsal aspect of C3, and on the dorsal aspect of C4 and RC (Butler et al., 2017c, Daniel and Kawcak, 2014, Ruggles, 2012). These types of fractures are usually associated with a severe acute lameness in flat racehorses (Ruggles, 2012). The intense speeds now seen in endurance riding may lead to osteochondral fractures becoming more prevalent in this discipline (Nagy et al., 2012, Rajão et al., 2019).

Other fractures that can be seen in the carpus are fractures of the accessory carpal bone, the distal radius, sagittal fracture of C3 (third carpal bone), C2 (second carpal bone) and C4 (fourth carpal bone) (Butler et al., 2017c, Murray and Dyson, 2018, Daniel and Kawcak, 2014). Any of these fractures will likely result in lameness (Butler et al., 2017c, Ruggles, 2012)

Exostoses can be seen at the level of the distal physis on the caudal aspect of the radius, but are often subtle and difficult to detect radiologically. Exostosis, can result in other lesions, such as impingement of the deep digital flexor tendon which results in severe episodic lameness, but this is better diagnosed ultrasonographically (Butler et al., 2017c, Murray and Dyson, 2018).

Osteochondromata can be present on the distal caudal aspect of the radial diaphysis or metaphysis, usually 2-4cm proximal to the distal physis. Although these are rare and not articular lesions, they are usually visible on carpal radiographs and can result in lameness due to persistent irritation and injury to the overlaying soft tissue structures (Butler et al., 2017c, Daniel and Kawcak, 2014, Murray and Dyson, 2018, Ruggles, 2012).

C1 and C5 may also be seen on carpal radiographs and are an incidental finding. In one third of horses C1 is present and can usually be found bilaterally. In less than two percent of horses C5 is present and can be found bi- or unilaterally (Daniel and Kawcak, 2014, Butler et al., 2017c, Murray and Dyson, 2018).

2.6 SUMMARY

With the increasing speeds and distances travelled in the endurance discipline, leading to the nature of the injuries seen in endurance horses correlating to those seen in flat racehorses, radiographic evaluation of the distal limb can confirm the similarities of the injuries between to two disciplines (Adamu et al., 2014, Bennet and Parkin, 2018a, Nagy et al., 2012, Rajão et al., 2019). It will allow the prevalence of specific radiographic changes to be calculated and ultimately aid in bridging the current gap in knowledge, regarding injuries and the underlying radiographic changes, for the endurance discipline. This information will aid fellow veterinarians improve their diagnostic approach and subsequent ability to manage injured horses that compete in this discipline. Scientific evidence reporting the different types of injuries that occur in endurance horses from the different regions of the world and the prevalence thereof is still required (Nagy et al., 2012, Nagy et al., 2017). To the authors knowledge no such studies in South Africa have been performed to date. Once the prevalence of lesions has been obtained, further investigation into their clinical significance should be pursued.

Chapter 3: Materials and Methods

3.1 EXPERIMENTAL DESIGN

This study consisted of radiographic evaluation of the carpi and proximal metacarpi of 100 endurance horses that competed in the South African endurance events during 2018. Owners were offered the opportunity to volunteer their horses to have radiographs taken at the endurance rides after they had either completed, withdrawn or been eliminated from the ride. Owners were emailed a copy of their horses' radiographs and thus had the opportunity to have them analysed by their private veterinarian at their own request.

The inclusion criteria included any volunteered ERASA (Endurance Ride Association of South Africa) registered horses participating in South African endurance rides during 2018. Horses were identified during the participation in the study by a unique UV number (Afrikaans for "uithourit vereeninging" and translated to English as 'endurance ride association') number) allocated to each registered horse by ERASA.

Uncooperative horses were sedated, with informed owner consent and if normal on clinical examination, with Domosedan® (Detomidine 10mg/ml) at a dose of 0.01-0.02 mg/kg intravenously (Kahn, 2010, Plumb, 2008).

The radiographic sets taken of each horse included the four standard views of the distal metacarpus (LM, DL-PaMO, DM-PaLO and DPa), the five standard views of the carpus (LM, flexed LM, DPa, DL-PaMO, and DM-PaLO) and one dorsal tangential view of the carpus (D35°Pr-DDiO) to highlight the distal row of carpal bones, especially C3 (Butler et al., 2017c, Butler et al., 2017b, Dyson, 2011).

The radiographs were acquired using the Cuattro EQ Digital Slate 6 Radiography System (Cuattro, Golden, CO) sponsored by IMV Technologies for this study and a mobile x-ray generator (PXP-40HF, Poskom Co., Gyeonggi-do, Republic of Korea) loaned from the Department of Radiology at the University of Pretoria. As each radiograph was acquired the diagnostic quality and positioning was checked, to ensure that only diagnostic quality radiographs were used in this study (Allio et al., 2006, Ballegeer and Nelson, 2012, Butler et al., 2017c, Butler et al., 2017b). A pre-programmed radiographic protocol was added to the system to ensure that no views were omitted and complete sets of radiographs were acquired for each horse.

The radiographs were analysed in a blinded manner by three specialist observers using DICOM imaging software and discrepancies were settled by a consensus of opinions (Butler et al., 2017a). The radiographic changes were categorised in detail by each observer, using a checklist in the form of an Excel spreadsheet (Appendix A) (Kane et al., 2003).

3.2 EXPERIMENTAL PROCEDURES

At all the endurance ride locations radiographs were taken in a stable or a removable gazebo with a two-metre radius from the public.

Owners with participating horses completed the consent form (Appendix B) prior to registration of the horse on the Cuattro EQ Digital Slate 6 Radiography System (Ballegeer and Nelson, 2012).

Horses were restrained by a skilled handler using a halter and lead rope (Ballegeer and Nelson, 2012, Butler et al., 2017a). The radiographs were taken of each front limb as per the pre-set radiographic protocol. All parties involved in taking the radiographs were appropriately dressed in the required radiation safety attire (Dyson, 2011, Thrall and Widmer, 2018). All parties not involved were requested to leave the demarcated radiographic area before the taking of the radiographs commenced (Axt et al., 2018, Dyson, 2011, Thrall and Widmer, 2018, Butler et al., 2017a).

The exposure factors were set according to the Cuattro EQ Digital Slate 6 Radiography System's recommendations to ensure diagnostic radiographs were acquired. A focus-film distance (FFD) of 100cm was used (Butler et al., 2017a, Thrall and Widmer, 2018). The positioning of the horse, x-ray generator and cassette were done according to the radiographic positioning guidelines for each view (Allio et al., 2006, Butler et al., 2017a). A lead marker was placed on the cassette (laterally on DPa or oblique views and dorsally on lateral views) to identify the limb being radiographed (Allio et al., 2006, Ballegeer and Nelson, 2012).

The radiographic process was directed by the principle investigator to ensure that repeated views were kept to a minimum (McKnight, 2004). After the radiographs were completed the horse was returned to the owner. If the horse had been sedated the owner was requested to withhold food for a minimum of 1 hour (Plumb, 2008).

3.3 CATEGORISATION OF RADIOGRAPHIC CHANGES

The criteria used for the specific radiographic changes evaluated are presented in Appendix A and further discussed below (Kane et al., 2003, Smit, 2014):

3.3.1 The Metacarpus

- Diagnostic proximal metacarpal radiographs were obtained and evaluated for the 100 horses in this study.
- The metacarpi were analysed for soft tissue swelling in all views, especially the LM.
- The presence of periosteal new bone formation on the second, third and fourth metacarpal bone were noted. This was classified as smooth margined and well defined mineralised opacity (inactive bony lesion); or irregular margined and poorly defined mineralised opacity (active bony lesion) if present (Butler et al., 2017a, Butler et al., 2017b).
- The presence of vertical radiolucent lines in the cortex of the third metacarpal bone were noted (Butler et al., 2017b).
- The formation of endosteal new bone (increased mineralised opacity within the medullary cavity) on the dorsal aspect of the third metacarpal bone was also analysed especially in the LM view (Butler et al., 2017b).
- The proximopalmar aspect of MC3 was observed on the dorsopalmar view for enthesiophytes and endosteal new bone. These changes may also be seen on the LM view when excessive (Butler et al., 2017a, Butler et al., 2017b).
- The two oblique views of the metacarpus highlighted the syndesmosis between the third and the second or fourth metacarpal bones and were analysed for presence of syndesmopathy and/ or synostosis (Butler et al., 2017b). Syndesmopathy was characterised by the presence of an irregular cortical or trabecular structure of the two adjacent bones, irregularity of the articular margins and the presence of osseous spurs on the articular margins (Butler et al., 2017b). Syndesmosis was characterised by the fusion of the two adjacent bones with clear articular margins no longer being present and prominent mineralised new bone formation between the two bones (Butler et al., 2017b).
- The presence of avulsion fractures at the proximopalmar aspect of MC3 where the suspensory ligament attaches and longitudinal incomplete fatigue fractures of the palmar cortex of MC3 were noted (Butler et al., 2017b).
- Fractures of MC2 and MC4 were assessed for on the two oblique views (Butler et al., 2017b).

3.3.2 The Carpus

- Diagnostic carpal radiographs were obtained and analysed for 100 horses evaluated in this study.
- The carpi were analysed for intra- and extra-articular soft tissue swelling.
- The presence of osteophytes were assessed for especially on the proximal and distal dorsal RC; and the proximodorsal C3 and IC (Butler et al., 2017c).
- The presence of enthesiophytes were observed on the dorsal aspects of the RC and IC, and the axial aspects of C3 and C4 (Butler et al., 2017c).
- Circular lucencies in the UC were assessed for (Butler et al., 2017c).
- Subchondral bone cysts or osseous cyst-like lesions were classified as solitary circular lucent areas within the carpal bones (Butler et al., 2017a, Butler et al., 2017c).
- Separate osseous fragments or chip fractures were highlighted on the flexed lateral view (Butler et al., 2017c).
- Fractures of the accessory carpal bone were categorised as vertical or slightly oblique lucent lines through the bone (Butler et al., 2017c).
- The D35°PrDDiO view was used to highlight subchondral bone lysis, sclerosis or slab fractures of C3 (Allio et al., 2006, Butler et al., 2017c).
- The presence of C1 or C5 was noted (Butler et al., 2017c).

3.4 DATA ANALYSIS

The frequency of radiographic changes listed above was obtained for both limbs of each horse radiographed. The prevalence of each change was then calculated from the frequency, i.e. dividing the number of times a specific lesion occurred by the number of limbs evaluated. Changes were recorded in such a manner that one could differentiate whether they were present on the left or right limb and medially or laterally. This allowed us to differentiate changes that were bilateral or biaxial.

3.5 INTER-RATER RELIABILITY

The inter-rater reliability (IRR) was evaluated for this study by calculating the p-value and kappa statistics for each of the radiographic changes that the analysers observed. (See Appendix D). The IRR is used to demonstrate consistency between multiple analysers for observational ratings (Hallgren, 2012).

Based on the calculations the agreement between analysers was considered statistically significant if the p-value was <0.05 and not statistically significant in the p-value was >0.05. If the agreement was considered to be statistically significant then kappa was interpreted based on the table below (Hallgren, 2012). Lesions that were not observed as prevalent by any of the analysers were not interpreted.

Table 4: Kappa Interpretation for IRR extrapolated from (Hallgren, 2012)

Kappa Value	**Interpretation**
0.0 - 0.2	Slight agreement
0.21 - 0.40	Fair agreement
0.41 - 0.60	Moderate agreement
0.61 - 0.80	Substantial agreement
0.81 - 1.0	Almost perfect or perfect agreement

3.6 ETHICAL CONSIDERATIONS

Obtaining radiographs is a part of routine equine practice, and is not seen as an invasive procedure to a horse. Thus no major ethical considerations were foreseen. The radiographs were taken at endurance rides, and strict safety precautions were taken to ensure the safety of bystanders (Butler et al., 2017a, Thrall and Widmer, 2018). To prevent accidental radiation exposure, the correct radiation safety protocols were adhered to as discussed below under "3.6 Biosecurity and Safety".

Radiographs form part of the horse's medical record and so confidentiality is an important ethical consideration. Radiographs were permanently labelled with the patient's and owner's details on the digital system (DOH, 2015). Radiographs were distributed to the owner of the horse radiographed via email (McKnight, 2004). Radiographs will be kept for a minimum of 5 years on an external hard drive at the University of Pretoria (Butler et al., 2017a). Patient confidentially was maintained by all persons involved in the study and no medical records, apart from the copy of radiographs emailed to the owner, were shared.

3.7 BIOSECURITY AND SAFETY

This study involved taking radiographs, which involves the use of potentially harmful ionising radiation, and correct radiation safety measures were practised to ensure that the individuals involved and bystanders were not unnecessarily exposed to radiation during the process (DOH, 2015, Thrall and Widmer, 2018). Careful planning of the procedure helped eliminate/ reduce the radiation exposure of bystanders and the people involved, although low levels of radiation exposure for the persons involved with taking the radiographs is permissible (Thrall and Widmer, 2018).

The ALARA (as low as reasonably achievable) principles were adhered to (DOH, 2015, Jaquith, 2014, Thrall and Widmer, 2018). These included reducing the time of exposure, reducing the number of repeated or unnecessary images taken and sedating uncooperative patients; increasing the distance from the primary beam by correctly placing the cassette, generator and person taking the radiographs; and the use of protective lead clothing (Jaquith, 2014, Thrall and Widmer, 2018).

Despite the field conditions, radiographs were ideally taken in an access controlled, well demarcated/ sign-posted and walled area where possible (DOH, 2015, Dyson, 2011, Thrall and Widmer, 2018). Radiation intensity follows the inverse square law and so by increasing the distance from the source (x-ray generator), the exposure to the public and people taking the radiographs is reduced (Butler et al., 2017a).

In the event that a walled area (stable) was not available an isolated area (with a removable gazebo) of at least a two metre radius from the public was used (Axt et al., 2018, Butler et al., 2017a). In this way the equipment was protected from dust or rain, shade was available and the public was protected from radiation exposure (Axt et al., 2018, Butler et al., 2017a, DOH, 2015, Dyson, 2011, Thrall and Widmer, 2018).

The primary beam was properly collimated and correctly directed to reduce the amount of scatter radiation. The portable generator was held by hand, was properly maintained and had adequate shielding with no damage or cracks (Ballegeer and Nelson, 2012, DOH, 2015, Dyson, 2011, Thrall and Widmer, 2018).

The number of people involved with the radiographs was kept to a minimum, namely four people (Butler et al., 2017a, Dyson, 2011). No other people were allowed in the radiograph room/ area and were required to stand at least two meters away from the perimeter of the radiographic area (Axt et al., 2018). Each person involved with taking the radiographs wore the appropriate radiation safety attire - a lead apron, lead thyroid shield and a dosimeter to monitor their radiation exposure (DOH, 2015, Dyson, 2011, Thrall and Widmer, 2018). The individual holding the cassette in addition to above also wore lead gloves (Dyson, 2011). The dosimeters were sent away for analysis after each endurance ride where radiographs were taken. The readings were monitored for everyone involved to ensure that all exposures remained below the MPD (Maximum Permissible Dose) (DOH, 2015, Thrall and Widmer, 2018). The ICRP (International Commission on Radiological Protection) has set the whole-body exposure limit for radiation workers to 20mSv per year and for the public 1mSv per year (DOH, 2015, Thrall and Widmer, 2018).

Chapter 4: Results

4.1 STUDY POPULATION

The study population consisted of 100 horses that were ERASA registered to compete in the 2018 endurance rides in South Africa. The average age of the study population was 9 years, with a range of ages from 6 to 18 years. Of the horse that participated in this study there were 36 mares, 59 geldings, and 5 stallions. The breeds seen in this study, as defined by ERASA, were purebred Arabian (47%), Arabian cross (19%), part bred Arabian (15%), Anglo Arab (13%), crossbreed with unknown parentage (2%), South African Boerperd cross (3%), and South African Boerperd (1%).

4.2 DATA ACQUISITION

Radiographs were acquired by the author and assisting team (assistant, handler and supervisor). The radiographs were analysed on site for diagnostic quality and non-diagnostic views were repeated.

4.3 DATA ANALYSIS

There were 100 horses' radiographs (200 forelimbs) evaluated in this study. These consisted of both left and right forelimb views of the carpus and proximal metacarpus for each horse.

4.3.1 The Metacarpus

The radiographic changes present in the metacarpus are recorded in Table 5.

Soft tissue swelling of the metacarpus was seen in 2% of the horses. It was associated with the left metacapus in 1% and the right metacarpus in 1% of the horses and was not seen bilaterally (Figure 1).

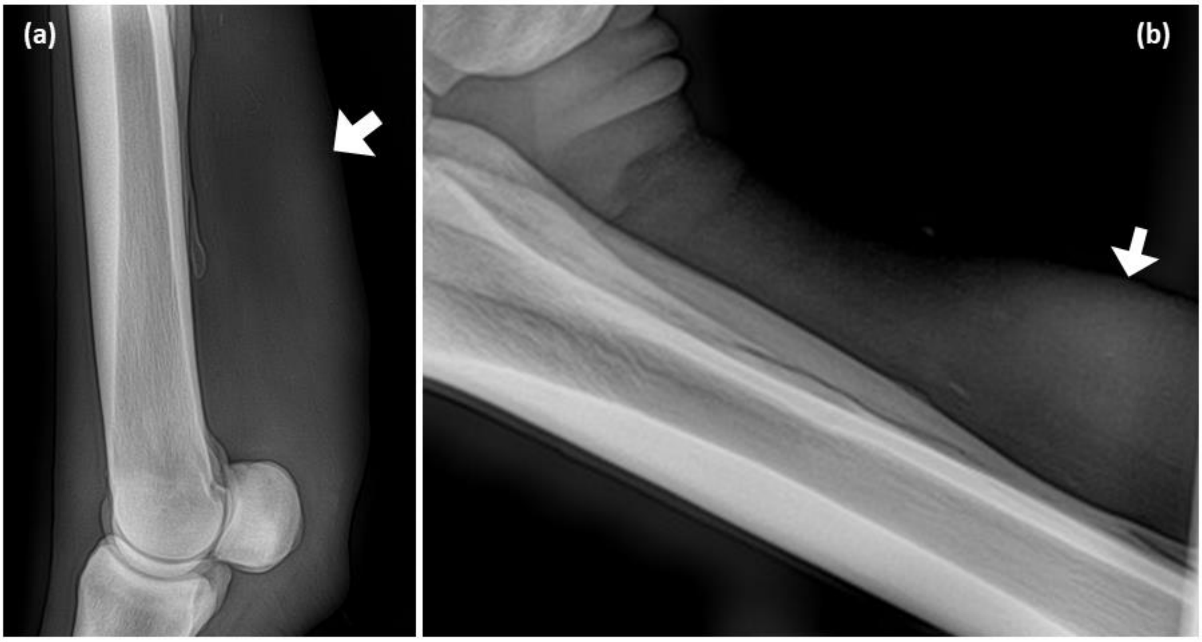

Figure 1: (a) Lateromedial and (b) flexed lateromedial views of the right distal metacarpus of horse 21 with a marked soft tissue swelling palmarly to the distal metacarpus and fetlock in the region of the digital flexor tendon sheath (white arrow).

Periosteal new bone formation on MC2 was seen in 13% of the horses. Smooth and well-defined new bone formation was present in 9% of horses, 7% on the left MC2 and 4% on the right MC2, with 2% bilaterally. Irregular and poorly defined new bone formation was present in 4% of horses, 2% on the left MC2, 2% on the right MC2, and none bilaterally (Figures 2 and 3).

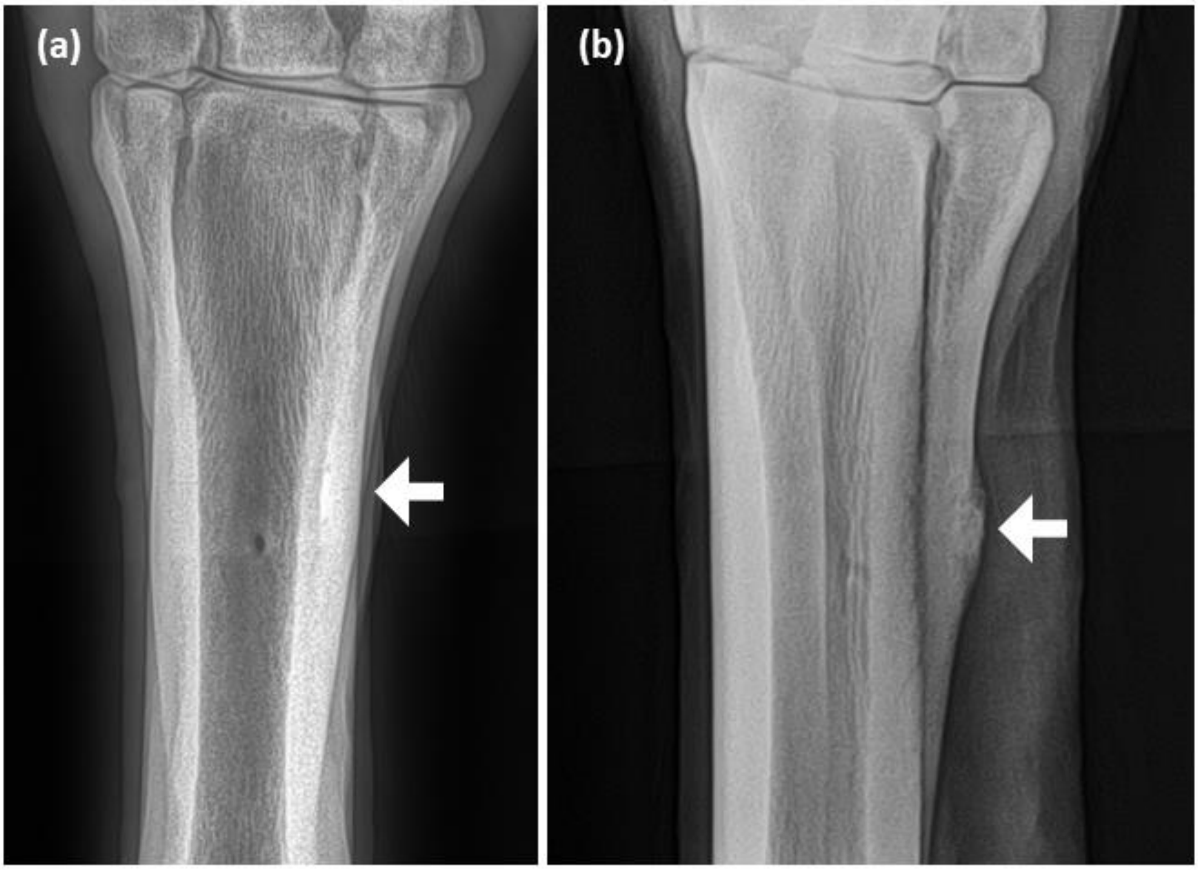

Figure 2: (a) Dorsopalmar and (b) dorsomedial palmarolateral oblique views of the left proximal metacarpus of horse 26 with smooth, well defined, focal, solid periosteal new bone formation medially and palmaromedially on the second metacarpal bone (white arrows).

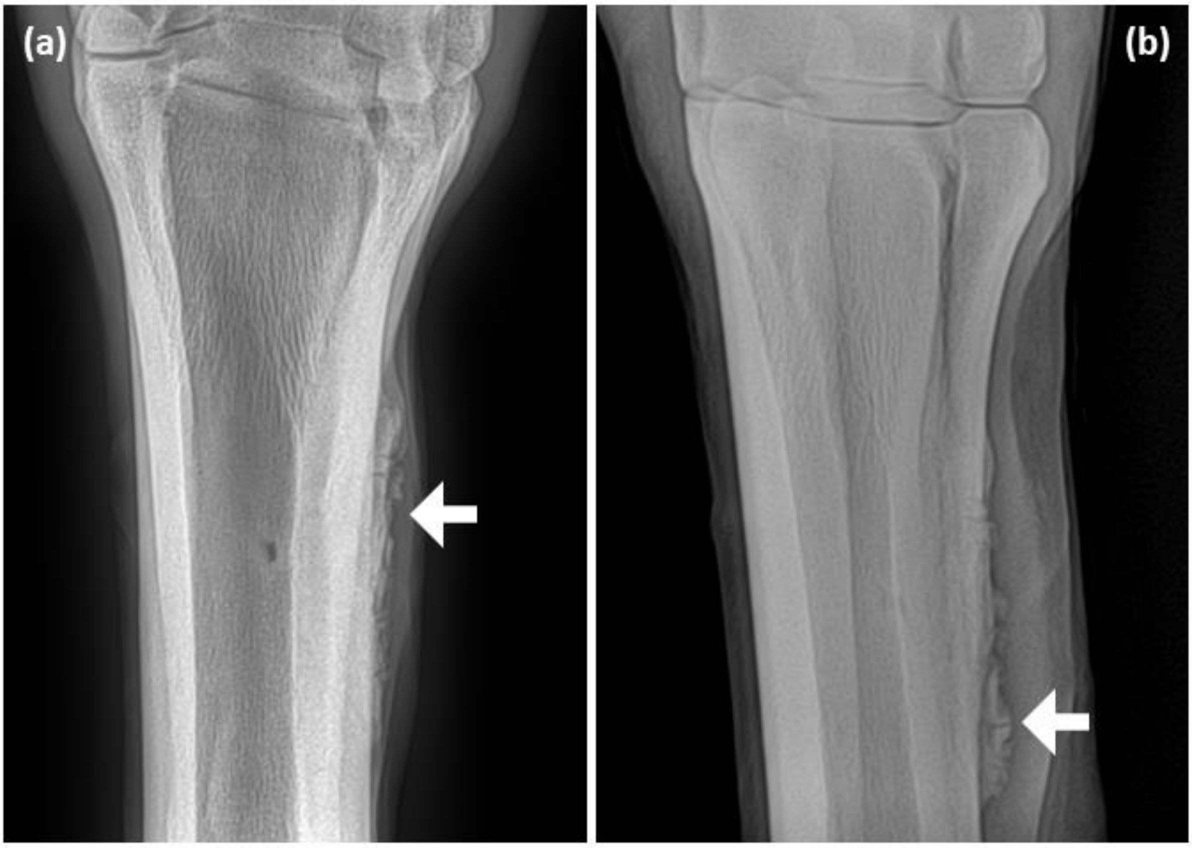

Figure 3: (a) Dorsopalmar and (b) dorsomedial palmarolateral oblique views of the left proximal metacarpus of horse 29 with irregular, poorly defined, multi-focal, interrupted periosteal new bone formation palmaromedially on the second metacarpal bone (white arrows).

Periosteal new bone formation on MC4 was seen in 2% of the horses. This was smooth and well defined on the left MC4 in one horse (not present on the right MC4 or bilaterally). This was irregular and poorly defined on the right MC4 in the other horse (not present on the left MC4 or bilaterally) (Figure 4 and 5).

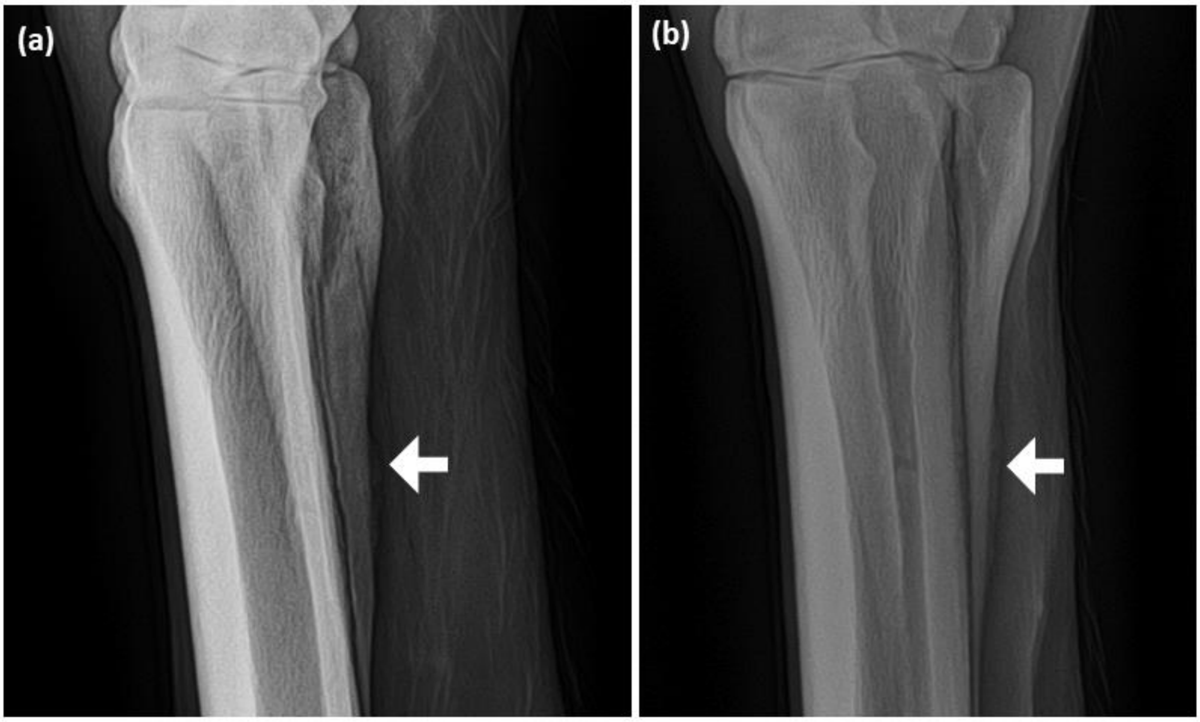

Figure 4: (a) Lateromedial and (b) dorsolateral palmaromedial oblique views of the left proximal metacarpus of horse 33 with smooth, well defined, focal, solid periosteal new bone formation palmarly and palmarolaterally on the fourth metacarpal bone (white arrows).

Figure 5: (a) Lateromedial and (b) dorsolateral palmaromedial oblique views of the right proximal metacarpus of horse 19 with irregular, poorly defined, focal, interrupted periosteal new bone formation palmarly and palmarolaterally on the fourth metacarpal bone (white arrows).

Endosteal new bone on the dorsal aspect of MC3 was present on the right MC3 2% of the horses and not seen on the left MC3 or bilaterally (Figure 6).

Figure 6: Lateromedial view of the right proximal metacarpus of horse 45 with focal, solid endosteal new bone formation on the dorsal aspect of the third metacarpal bone (white arrow).

Syndesmopathy was present between the MC2 and MC3 in 6% of the horses (2% on the left forelimb, 4% on the right forelimb and none bilaterally) (Figure 7).

Figure 7: Dorsomedial palmarolateral oblique view of the left proximal metacarpus of horse 50 with subtle syndesmopathy of the second and third metacarpal bones (white arrow).

Syndesmopathy was present between the MC3 and MC4 in 4% of the horses (1% on the left forelimb, 4% on the right forelimb and 1% bilaterally) (Figure 8).

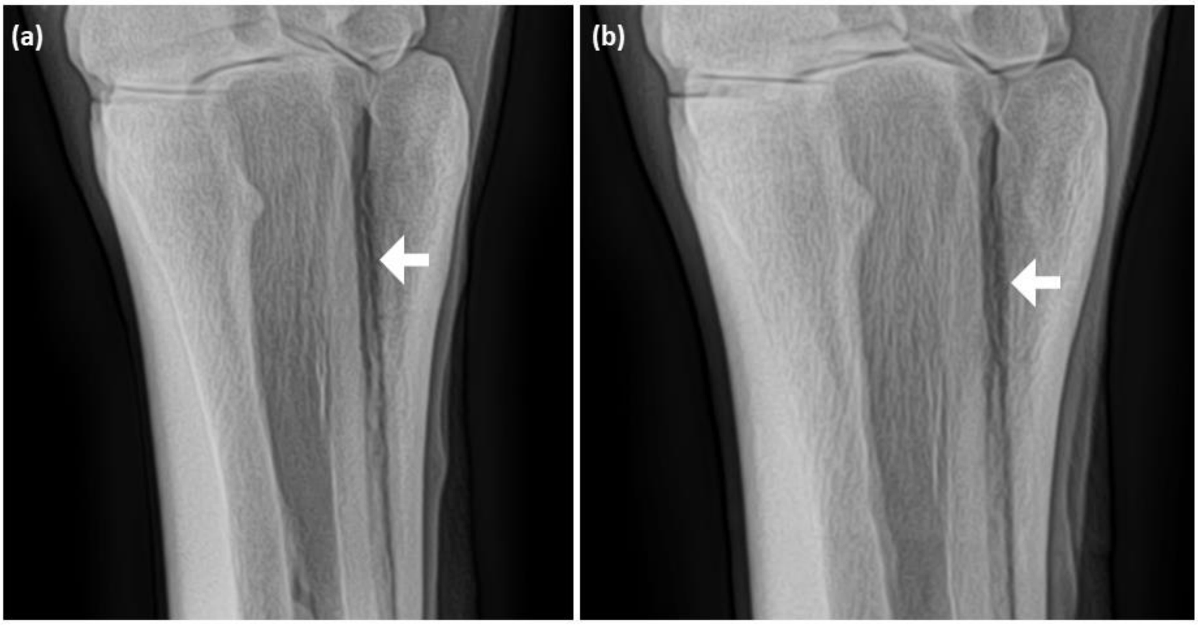

Figure 8: Dorsolateral palmaromedial oblique view of (a) the left and (b) the right proximal metacarpus of horse 88 with bilateral subtle syndesmopathy of the third and fourth metacarpal bones (white arrows).

Synostosis was present between the MC2 and MC3 in 9% of the horses (7% on the left forelimb, 5% on the right forelimb and 3% bilaterally). Synostosis was present between the MC3 and MC4 in 2% of the horses (1% on the left forelimb, 2% on the right forelimb and 1% bilaterally) (Figure 9).

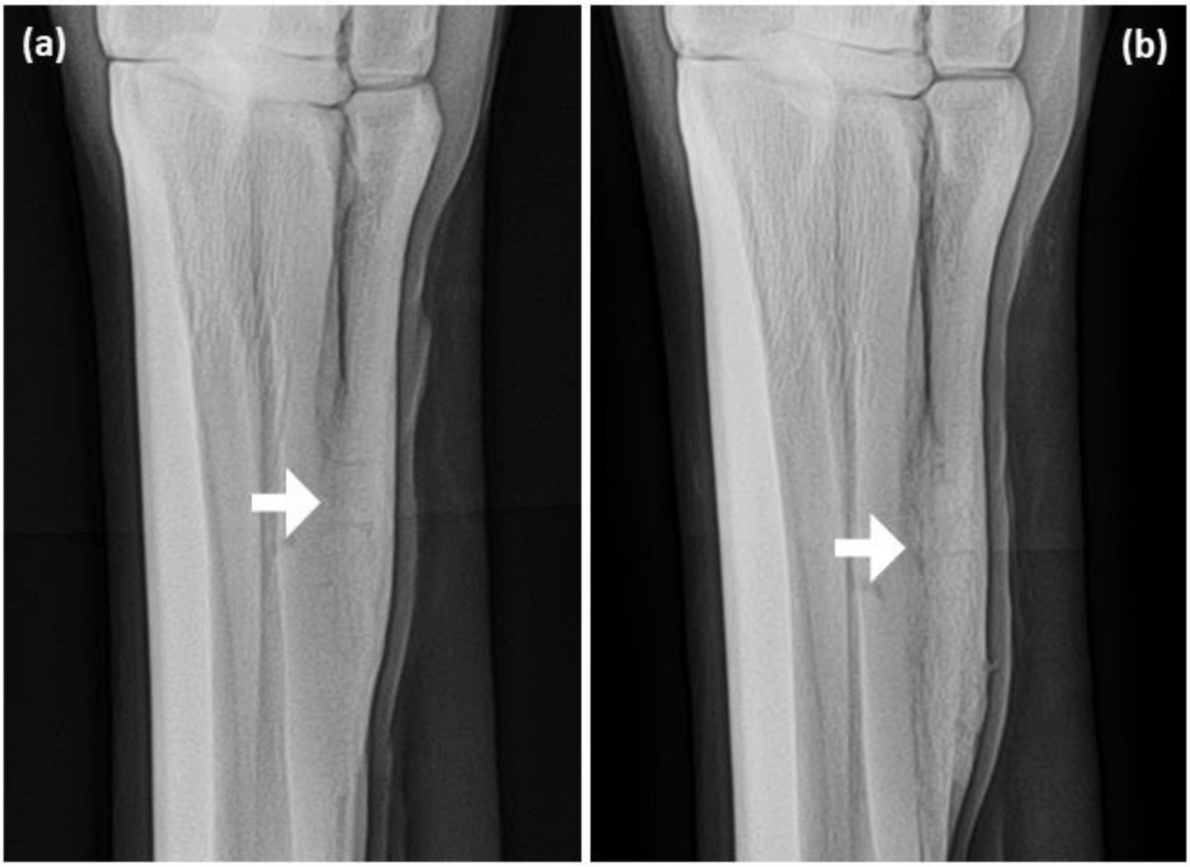

Figure 9: Dorsomedial palmarolateral oblique view of (a) the left and (b) the right proximal metacarpus of horse 77 with bilateral marked synostosis of the second and third metacarpal bones (white arrows).

Endosteal new bone formation at the proximopalmar aspect of the MC3 was present in 34% of the horses. This was present on the left MC3 in 28%, the right MC3 in 23% and bilaterally in 17% of the horses (Figure 10).

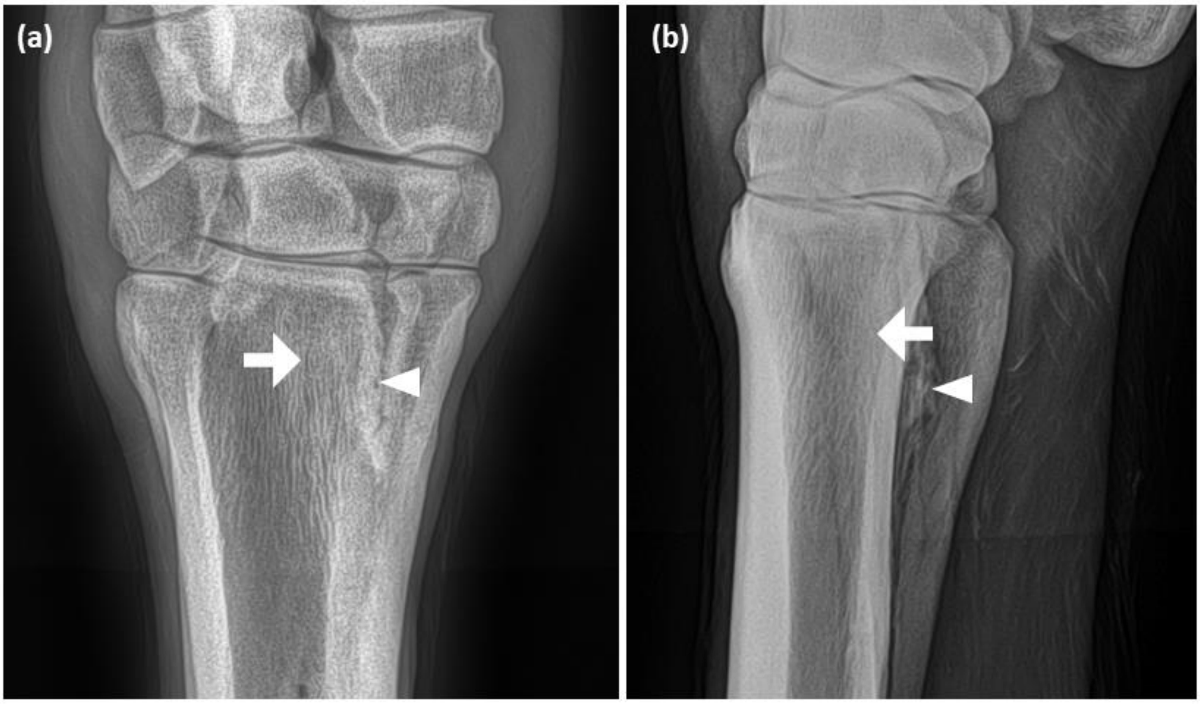

Figure 10: (a) Dorsopalmar and (b) lateromedial views of the left proximal metacarpus of horse 2 with endosteal new bone formation at the proximopalmar aspect of MC3 (white arrows) and marked synostosis of the proximal second and third metacarpal bones (white arrow heads).

Fractures of the MC2 were seen on the left MC2 in 1% and were not seen at all on the right MC2 or bilaterally (Figure 11).

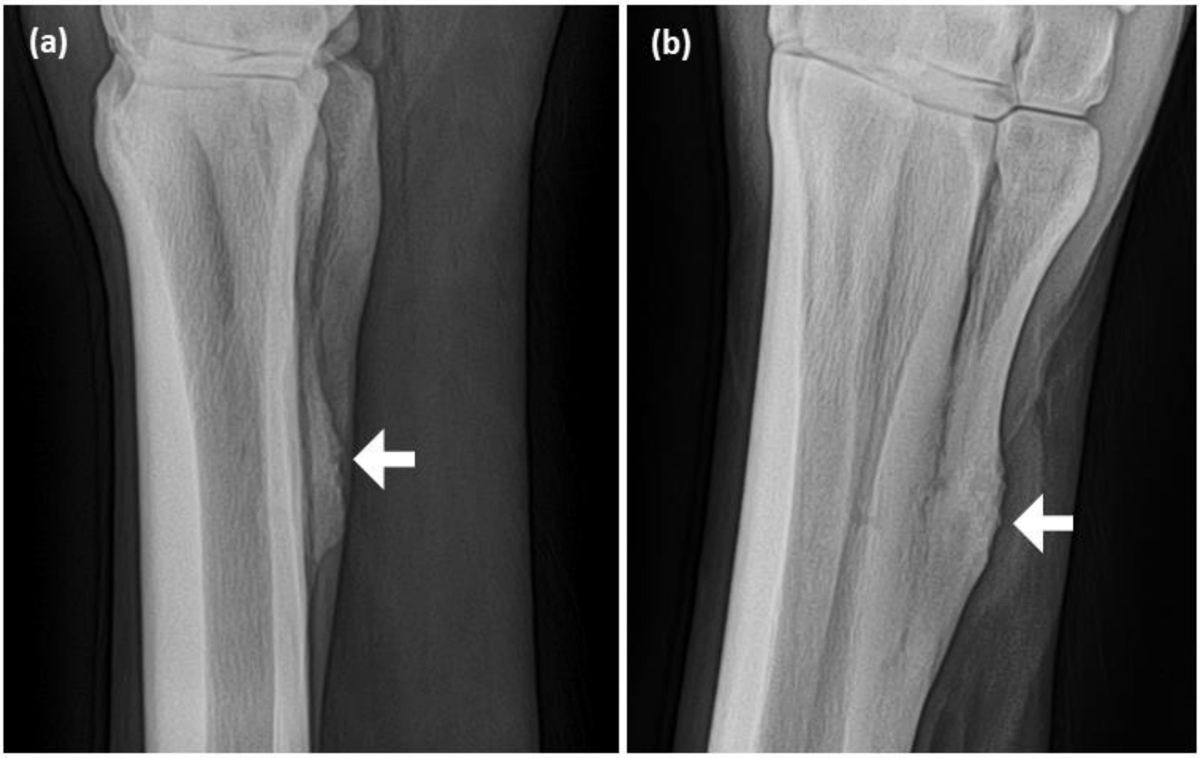

Figure 11: (a) Lateromedial, and (b) dorsomedial palmarolateral oblique views of the left proximal metacarpus of horse 9 with a chronic healing mid diaphyseal fracture of the second metacarpal bone with a mature callus (white arrows).

Radiolucent lines in the cortex of the MC3, periosteal new bone formation on the MC3, enthesiophytes at the proximopalmar aspect of the MC3, avulsion fractures at the proximopalmar aspect of the MC3, fractures of the MC4 and longitudinal fractures on the palmar cortex of the MC3 were not present in any of the horses' radiographs evaluated.

Table 5: Prevalence of radiographic changes recorded of the left and right metacarpi of South African endurance horses (n=100)

Radiographic change	Category	Left front		Right front		Bilateral		Horses	
		No.	%	No.	%	No.	%	No.	%
Soft tissue swelling around the metacarpus	**Yes**	1	1%	1	1%	0	0%	2	2%
	No	99	99%	99	99%	98	98%	98	98%
New bone formation second metacarpal bone	**None**	91	91%	94	94%	87	87%	87	87%
	Smooth, well defined	7	7%	4	4%	2	2%	9	9%
	Irregular, poorly defined	2	2%	2	2%	0	0%	4	4%
New bone formation third metacarpal bone	**None**	100	100%	100	100%	100	100%	100	100%
	Smooth, well defined	0	0%	0	0%	0	0%	0	0%
	Irregular, poorly defined	0	0%	0	0%	0	0%	0	0%
New bone formation fourth metacarpal bone	**None**	99	99%	99	99%	98	98%	98	98%
	Smooth, well defined	1	1%	0	0%	0	0%	1	1%
	Irregular, poorly defined	0	0%	1	1%	0	0%	1	1%
Endosteal new bone dorsal third metacarpal bone	**Yes**	0	0%	2	2%	0	0%	2	2%
	No	100	100%	98	98%	98	98%	98	98%
Radiolucent line at cortex of third metacarpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Syndesmopathy between second and third metacarpal bones	**Yes**	2	2%	4	4%	0	0%	6	6%
	No	98	98%	96	96%	94	94%	94	94%
Synostosis between second and third metacarpal bones	**Yes**	7	7%	5	5%	3	3%	9	9%
	No	93	93%	95	95%	91	91%	91	91%
Syndesmopathy between third and fourth metacarpal bones	**Yes**	1	1%	4	4%	1	1%	4	4%
	No	99	99%	96	96%	96	96%	96	96%
Synostosis between third and fourth metacarpal bones	**Yes**	1	1%	2	2%	1	1%	2	2%
	No	99	99%	98	98%	98	98%	98	98%
Enthesiophyte on proximopalmar third metacarpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Endosteal new bone formation on proximopalmar third metacarpal bone	**Yes**	28	28%	23	23%	17	17%	34	34%
	No	72	72%	77	77%	66	66%	66	66%
Avulsion fracture of proximopalmar third metacarpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Longitudinal fracture of palmar cortex of the third metacarpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Fracture of the second or fourth metacarpal bones	**Yes**	1	1%	0	0%	0	0%	1	1%
	No	99	99%	100	100%	99	99%	99	99%

4.3.2 The Carpus

The radiographic changes present in the carpus are recorded in Table 6.

Soft tissue swelling of the carpus was present in 5% of the horses. This was present in the left carpus in 2% and in the right carpus in 3% of the horses. Soft tissue swelling of the carpus was not seen bilaterally (Figure 12).

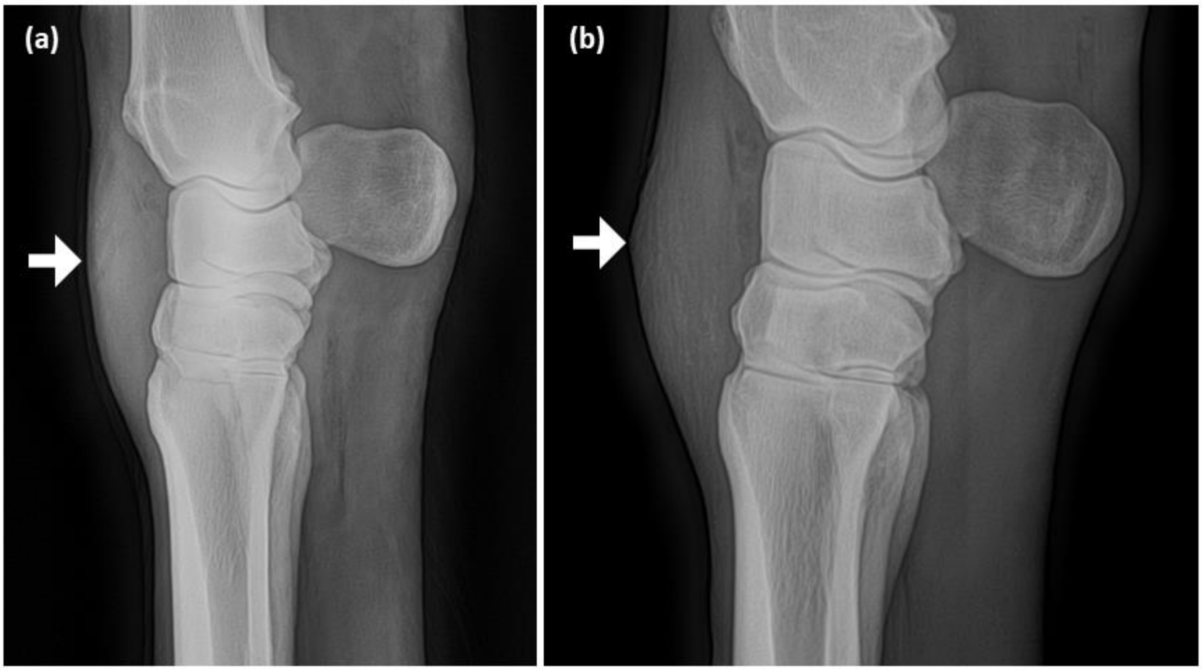

Figure 12: Lateromedial view of the right carpi of (a) horse 9 with mild extra-articular soft tissue swelling dorsal to the carpus present (white arrow) and (b) horse 51 with substantial extra-articular soft tissue swelling dorsal to the carpus present (white arrow).

Osteophytes in the carpus were seen in 9% of the horses. They were seen in the left carpus in 4% and in the right carpus in 5% of the horses and none were seen bilaterally. The specific location of the osteophytes was not noted (Figure 13).

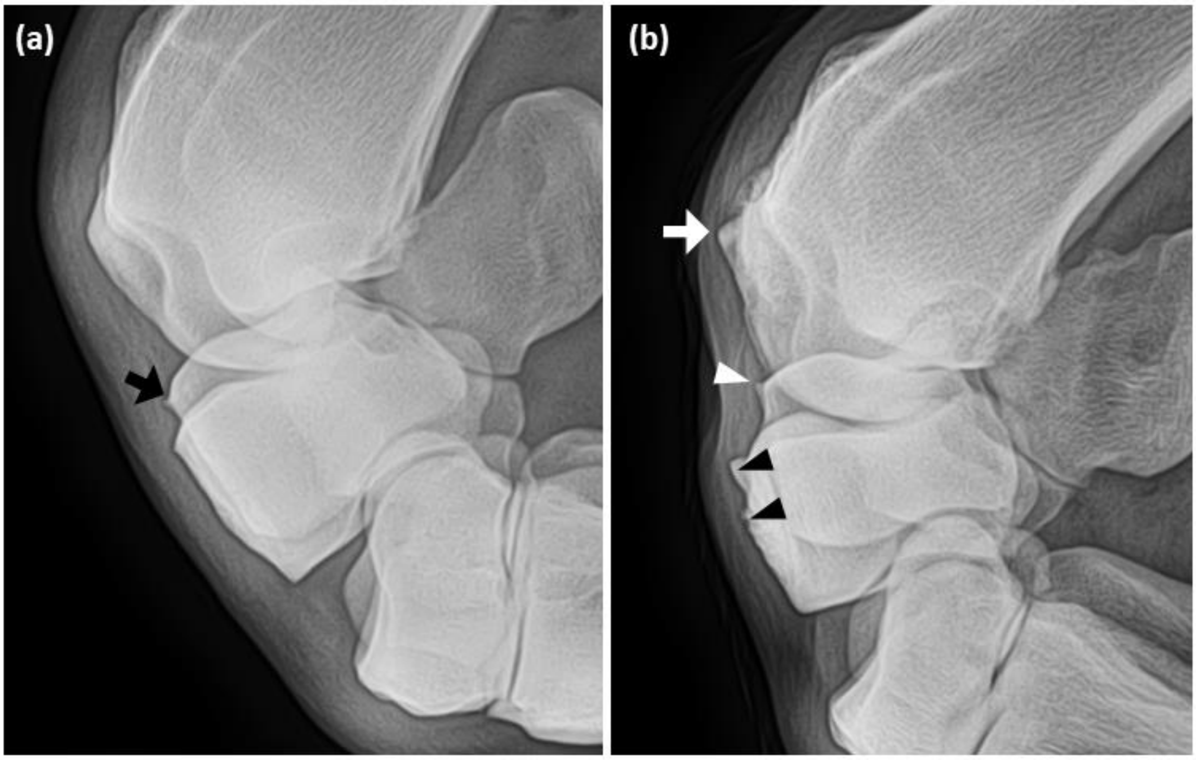

Figure 13: (a) A flexed lateromedial view of the right carpus of horse 29 with a small osteophyte (black arrow) on the dorsoproximal aspect of the intermediate carpal bone and (b) a flexed lateromedial view of the left carpus of horse 18 with multiple larger osteophytes on the dorsodistal aspect of the radius (white arrow), the dorsoproximal aspect of the intermediate carpal bone (white arrow head) and the dorsoproximal aspect of radial carpal bone (black arrow heads).

Enthesiophytes in the carpus were seen in 8% of the horses. They were seen in the left carpus in 5%, in the right carpus in 5% and bilaterally in 2% of the horses. The specific location of the enthesiophytes was not noted (Figure 14).

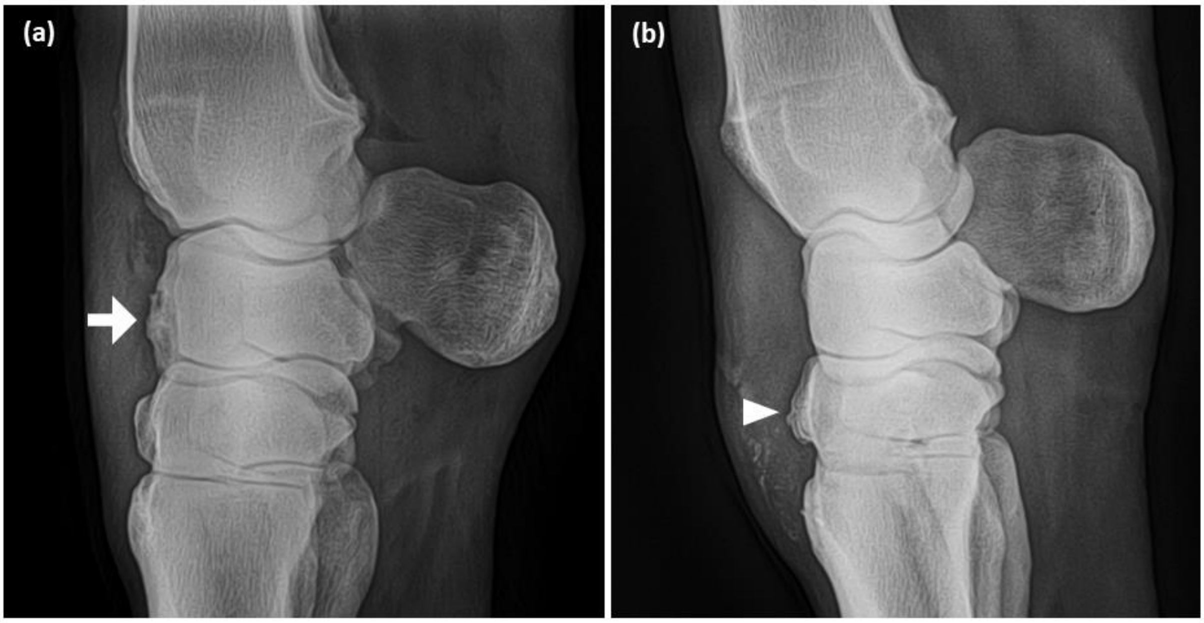

Figure 14: Lateromedial views of the left carpus (a) of horse 3 with enthesiophyte formation on the dorsal aspect of radial carpal bone of the first horse (white arrow) and (b) of horse 14 with enthesiophyte formation on the dorsal aspect of the third carpal bone of the second horse (white arrow head). Horse 14 (b) also has some extra-articular soft tissue swelling dorsal to the carpus.

A circular lucency in the UC was seen in the left UC in one horse but was not seen in the right UC or bilaterally (Figure 15).

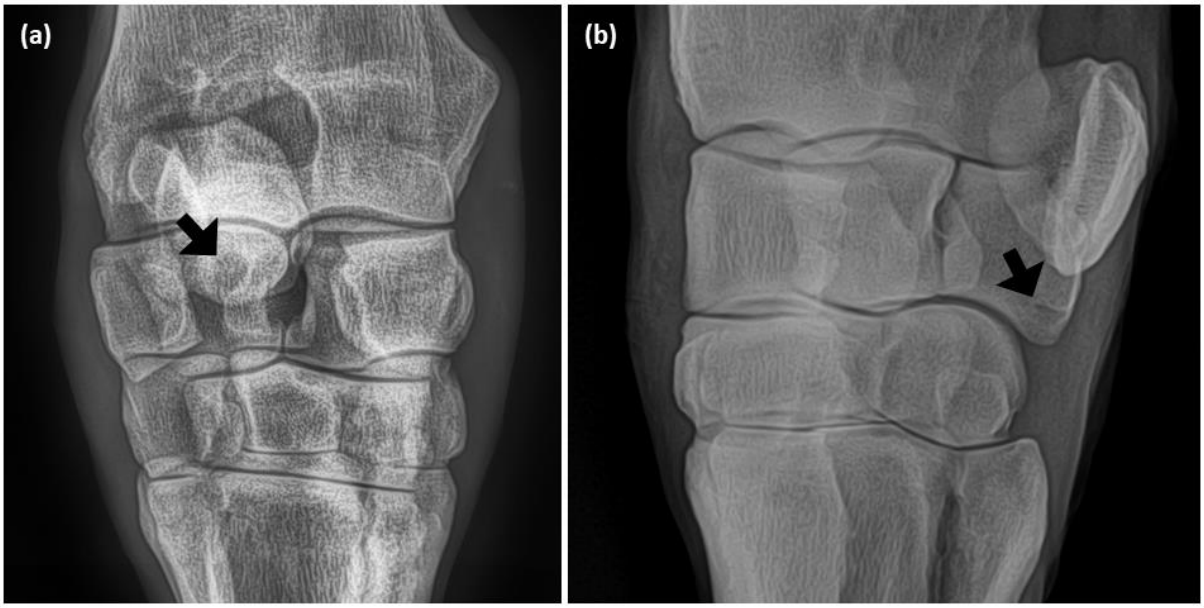

Figure 15: (a) Dorsopalmar and (b) dorsolateral palmaromedial oblique views of the left carpus of horse 19 with a small circular lucency in the palmar aspect of the ulnar carpal bone (black arrows).

A subchondral cyst-like lesion was seen in the right carpus in one horse but was not present in the left carpus or bilaterally. The subchondral cyst was located on the proximal aspect of C4 on the right forelimb (Figure 16).

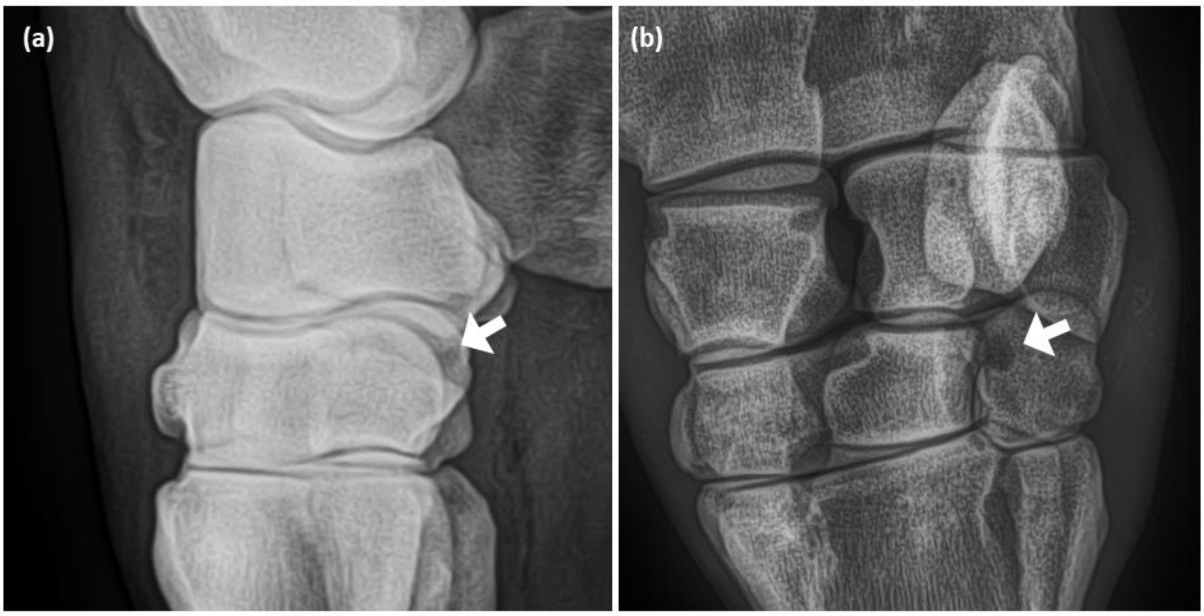

Figure 16: (a) Lateromedial and (b) dorsopalmar views of the right carpus of horse 56 with a subchondral cyst-like lesion on the proximal palmar aspect of the fourth carpal bone (white arrow).

Subchondral bone lysis of the C3 was seen in 2% of the horses. This was present in the left C3 in 2%, in the right C3 in one of the horses and bilaterally in one of the horses. Subchondral bone sclerosis of the C3 was present in 77% of the horses. This was seen in the left C3 in 70%, in the right C3 in 68% and bilaterally in 61% of the horses (Figure 17).

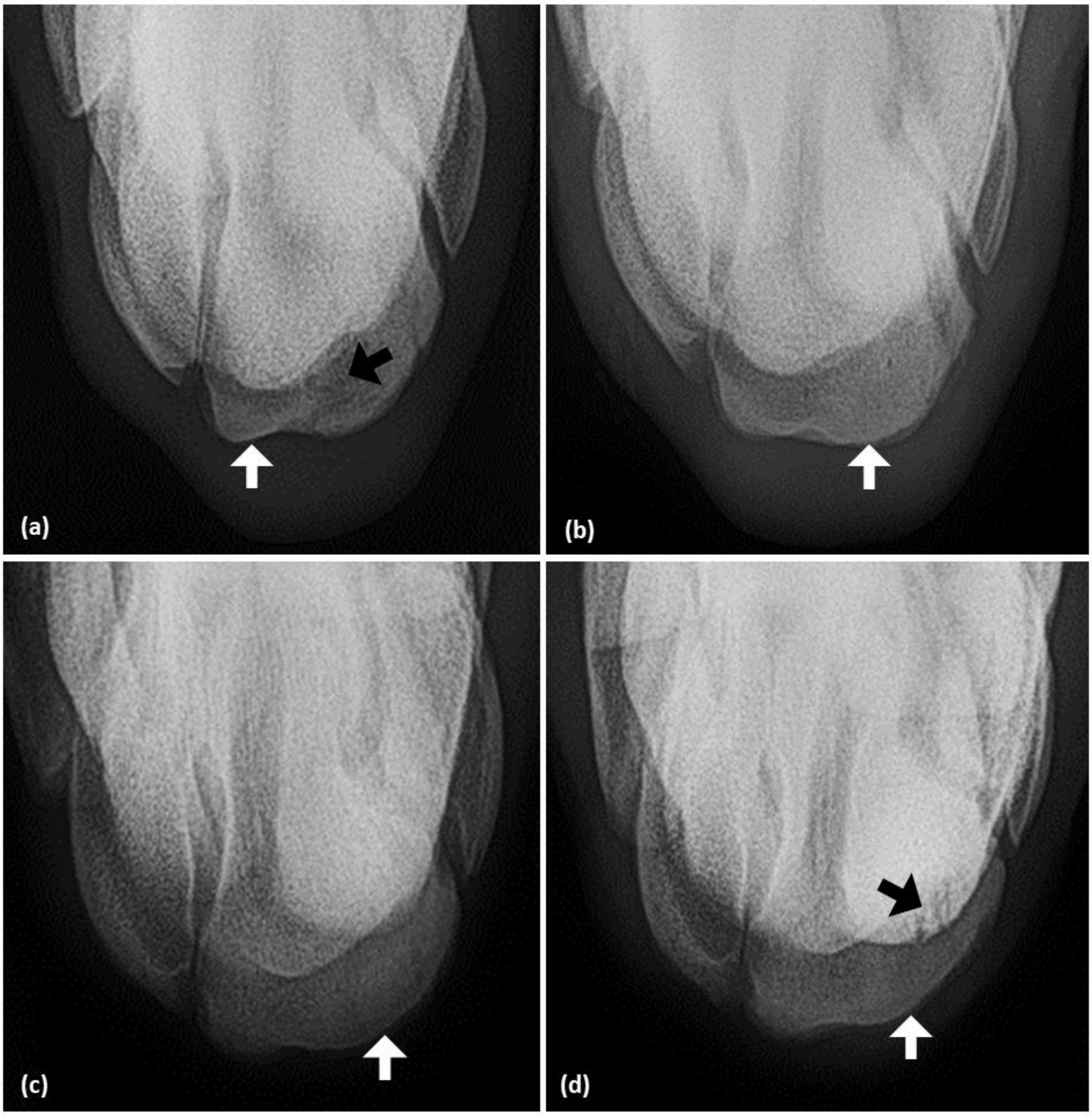

Figure 17: Dorsal 35° proximal dorsodistal oblique views of (a) the left and (b) the right carpus of horse 36, and of (c) the left and (b) the right carpus of horse 47. Both horses have bilateral subchondral bone sclerosis (white arrows) and unilateral subchondral lysis (black arrows) present on the dorsal aspect of the radial facet of the third carpal bone.

A C1 was present in 27% of the horses. They were seen in the left carpus in 23%, in the right carpus in 19% and bilaterally in 15% of the horses. A C5 was seen bilaterally in one horse (Figure 18 and 19).

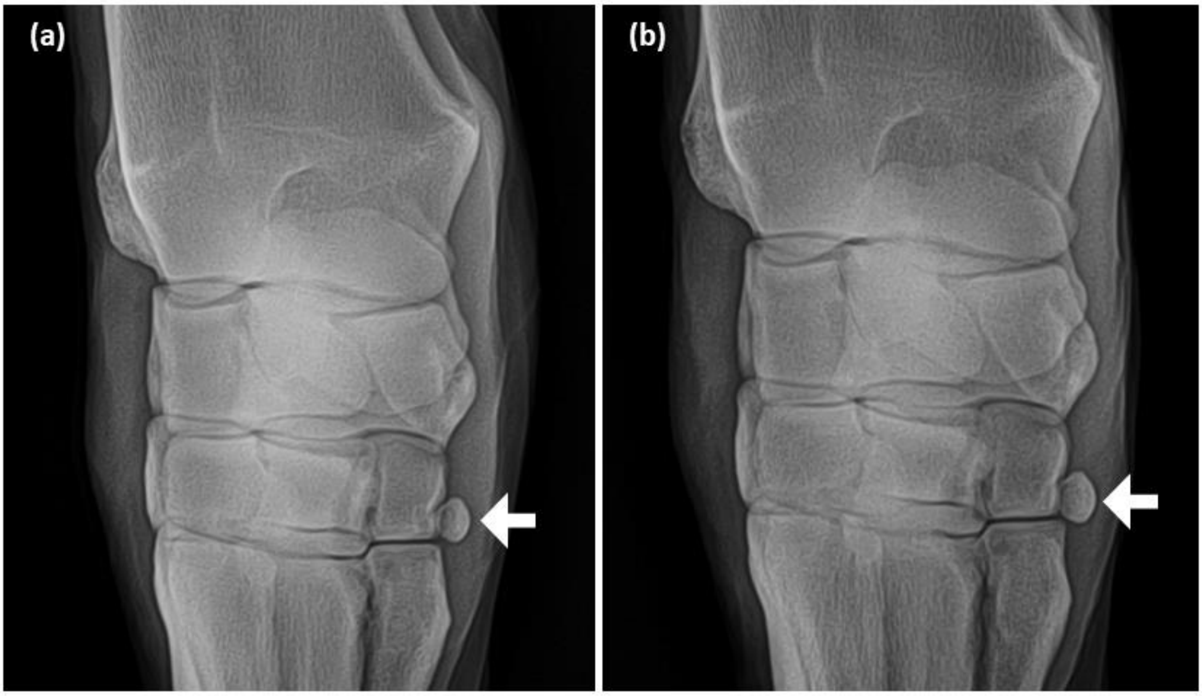

Figure 18: Dorsomedial palmarolateral oblique views of (a) the left and (b) the right carpus of horse 10 with the first carpal bone present bilaterally (white arrows).

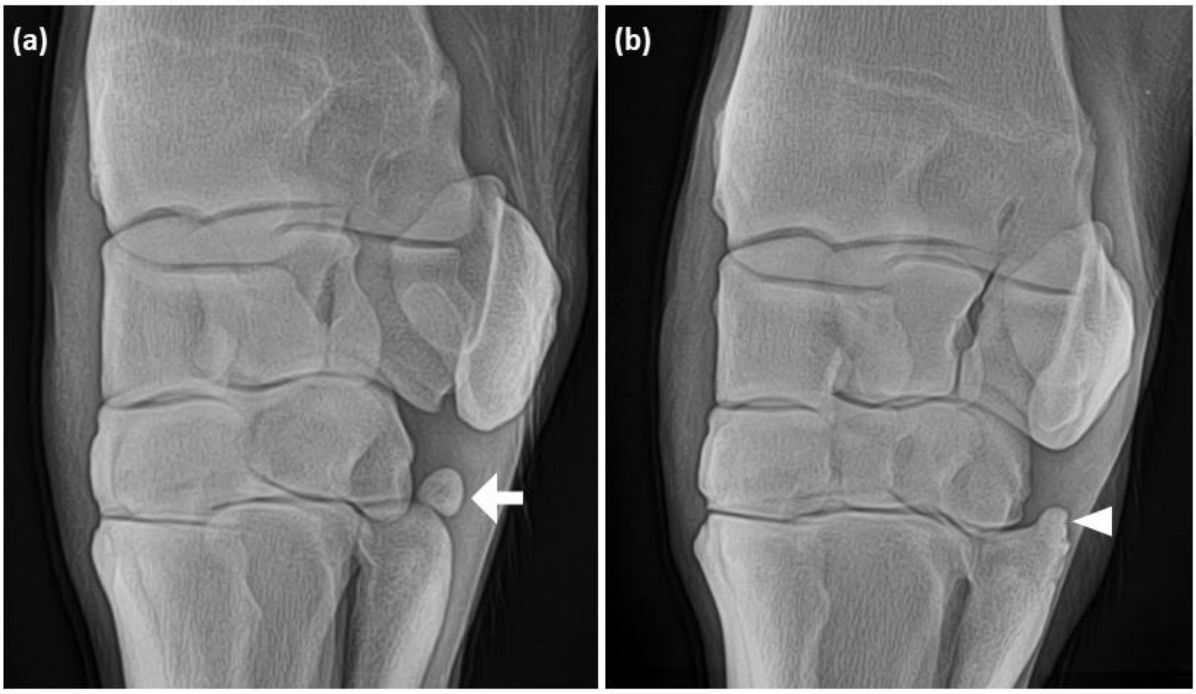

Figure 19: Dorsolateral palmaromedial oblique views from horse 59 of (a) the left carpus with a fifth carpal bone (white arrow), and (b) the right carpus with a fifth carpal bone fused to the proximal aspect of the fourth metacarpal bone (white arrow head).

Osteochondromata were present in 2% of the horses analysed on the distopalmar aspect of the radius. One horse had small osteochondromata bilaterally. The other horse had an irregular shaped osteochondroma on the right distocaudal aspect of the radius (Figure 20 and 21).

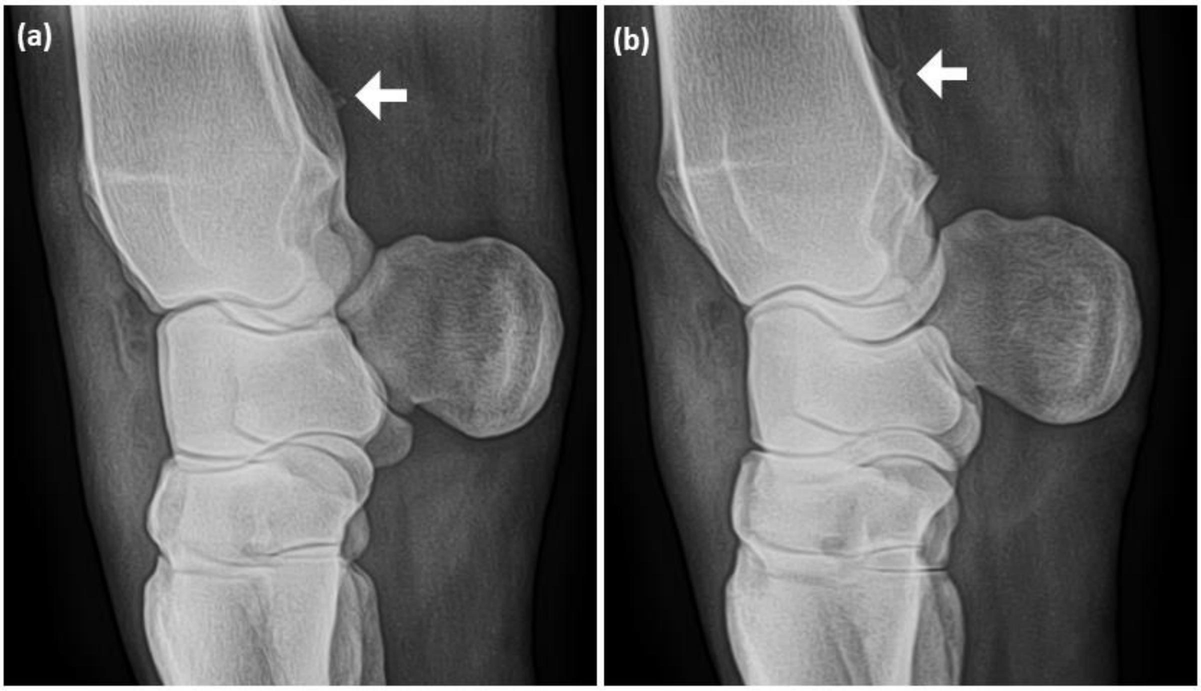

Figure 20: Lateromedial views of (a) the left and (b) the right carpi of horse 44 with small bilateral osteochondromata on the distopalmar aspect of the radius (white arrows).

Figure 21: Lateromedial view of the right carpus of horse 65 with a proximally-hooked osteochondroma on the distopalmar aspect of the radius (white arrow).

A metallic foreign body was seen in 1% of horses on the craniodistal aspect of the right radius. It appeared to be a piece of wire, likely included in the *extensor carpi radialis* muscle (Figure 22).

Figure 22: Four views [(a) dorsopalmar, (b) flexed lateromedial, (c) dorsolateral palmaromedial oblique and (d) dorsomedial palmarolateral oblique] of the right carpus of horse 35 with a small metallic foreign body proximal to the carpus (white arrows).

Osteochondral fragments, fractures of the AC, and slab fractures C3 were not seen in any of the radiographs taken in this study.

Table 6: Radiographic changes recorded of the left and right carpi of South African endurance horses (n=100)

Radiographic change	Category	Left front		Right front		Bilateral		Horses	
		No.	%	No.	%	No.	%	No.	%
Soft tissue swelling in and around the carpus	**Yes**	2	2%	3	3%	0	0%	5	5%
	No	98	98%	97	97%	95	95%	95	95%
Osteophyte in the carpus	**Yes**	4	4%	5	5%	0	0%	9	9%
	No	96	96%	95	95%	91	91%	91	91%
Enthesiophyte in the carpus	**Yes**	5	5%	5	5%	2	2%	8	8%
	No	95	95%	95	95%	92	92%	92	92%
Circular lucency ulnar carpal bone	**Yes**	1	1%	0	0%	0	0%	1	1%
	No	99	99%	100	100%	99	99%	99	99%
Fragment in the carpus	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Subchondral cyst in the carpal bones	**Yes**	0	0%	1	1%	0	0%	1	1%
	No	100	100%	99	99%	99	99%	99	99%
Fracture of the accessory carpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
Subchondral bone lysis of the third carpal bone	**Yes**	2	2%	1	1%	1	1%	2	2%
	No	98	98%	99	99%	98	98%	98	98%
Subchondral bone sclerosis of the third carpal bone	**Yes**	70	70%	68	68%	61	61%	77	77%
	No	30	30%	32	32%	23	23%	23	23%
Slab fracture of the third carpal bone	**Yes**	0	0%	0	0%	0	0%	0	0%
	No	100	100%	100	100%	100	100%	100	100%
First carpal one present	**Yes**	23	23%	19	19%	15	15%	27	27%
	No	77	77%	81	81%	73	73%	73	73%
Fifth carpal bone present	**Yes**	1	1%	1	1%	1	1%	1	1%
	No	99	99%	99	99%	99	99%	99	99%
Osteochondroma present	**Yes**	1	1%	2	2%	1	1%	2	2%
	No	99	99%	98	98%	98	98%	98	98%

4.4 INTER-RATER RELIABILITY

Based on the statistical analysis and the interpretation of kappa, when in agreement, the analysers were mostly in moderate (16.13%), fair (14.52%) and slight (12.9%) agreement. There was almost perfect agreement between analysers 4.84% of the time and substantial agreement 1.61% of the time. There was no significant agreement 37.1% of the time.

The changes that were more prominent radiographically had a better repeatability between analysers as was expected (see appendix D). Some examples of these more prominent lesions are the presence of a C1 (kappa value of 0.88 for the left limb and 0.89 for the right limb), the presence of osteochondromata (kappa value of 0.5 for the left limb and 0.80 for the right limb) and the presence of a C5 (kappa value is 0.5 for the left limb and 0.33 for the right limb).

The level of experience was similar between all 3 analysers and they were kept the same throughout the study. Other factors such as the contrast of the images, viewing screen and DICOM programme used to view the images may have affected the repeatability between analysers, but were kept as constant as possible in the study.

Overall the IRR of this study fits with what is typically expected in a subjective observational study with multiple analysers (Hallgren, 2012).

Chapter 5: Discussion

This is the first comprehensive study to provide data on the prevalence of radiographic changes seen in the carpi and proximal metacarpi of competing South African endurance horses. Radiologically, more changes were seen in the carpi than in the metacarpi. In the carpi, the most common changes were subchondral bone sclerosis of the third carpal bone, the presence of a first carpal bone, and osteophyte and enthesiophyte formation. The most common changes in the metacarpi included endosteal new bone formation at the proximopalmar aspect of the third metacarpal bone, new bone formation on the second metacarpal bone; and synostosis between the second and third metacarpal bones. The lesions demonstrated in our study are different from the most prevalent lesions described in Thoroughbred yearlings (Axling et al., 2016, Kane et al., 2003, Smit, 2014). More changes were seen in the left forelimb than the right forelimb, which correlates to the most commonly identified lame limb in endurance horses clinically (Nagy et al., 2017). This may be linked to a reign preference from either horse or rider, as endurance riding does not dictate a specific reign to be used at events, but there are no studies currently that investigate this further.

Comparisons to earlier studies on the prevalence of radiographic changes in equines were done with caution. The majority of these radiographic studies have been performed on yearling Thoroughbreds intended for use in flat racing (Contino et al., 2011). It is speculated that the large amount of radiographic data available in this breed is due to the large number of readily accessible radiographs in this racing industry. A full set of distal limb radiographs is required for Thoroughbred yearling sales in many countries and they are stored in the repository archives post sales, making them readily retrievable for permitted studies (Axling et al., 2016, McKnight, 2004).

The average age for horses in this study was 9 years old with the predominant breeds being Arabian (47%) and Arabian crosses (48%). Thus, the difference in prevalence of changes compared with previous studies could be due to age related changes, breed differences, or even differences between the injuries seen in the respective disciplines. To date there are few studies investigating possible differences in the prevalence of changes in different breeds, ages or disciplines (Contino et al., 2011, Malone et al., 2003, Rajão et al., 2019). The prevalence of radiographic changes in horses other than Thoroughbred yearlings is an area that requires more research, as it can aid veterinarians in prognosticating about horses' careers and changes that require further investigation (Contino et al., 2011, Kane et al., 2003, Malone et al., 2003, Rajão et al., 2019).

Subchondral bone sclerosis of the radial facet of the third carpal bone was the most prevalent lesion seen in this study (77%). A mild increase in opacity in the third carpal bone is considered to be a normal adaptive response in young flat racehorses in training and in endurance horses (Butler et al., 2017c, Murray and Dyson, 2018, Peat and Kawcak, 2015, Ross, 2003). This is due to the increased loading of the carpus with the high speeds and distances in these disciplines (Bennet and Parkin, 2018b, Murray and Dyson, 2018, Peat and Kawcak, 2015). This adaptive modelling provides increased strength to the area (third carpal bone) that sustains high loads, although excessive sclerosis reduces the elasticity of the underlying bone resulting in a more brittle bone that is predisposed to fracture (Murray and Dyson, 2018, Peat and Kawcak, 2015, Rajão et al., 2019). Thus, a marked increase in opacity of the third carpal bone is considered pathological (Butler et al., 2017c, Hopper et al., 2004, Ross, 2003). As the degree of opacity, which correlates to the severity of sclerosis (Hopper et al., 2004), was not assessed in this study, the high prevalence of this lesion may or may not be a normal adaptive response (Murray and Dyson, 2018, Peat and Kawcak, 2015), and further investigation is warranted (Hopper et al., 2004).

Radiolucent areas (subchondral bone lysis) near the joint margin of the third carpal bone often develop in conjunction with sclerosis (Butler et al., 2017c, Murray and Dyson, 2018). These are thought to be a result of continued loading of the area causing significant damage to the cartilage and subchondral bone (Butler et al., 2017c, Murray and Dyson, 2018). Subchondral bone lysis of the third carpal bone was not very prevalent in this study (2%). This, in conjunction with the high prevalence of sclerosis seen, is suggestive that these changes are more likely an adaptive response, with a low degree of subchondral bone damage, to the high intensity exercise of the endurance discipline (Peat and Kawcak, 2015, Murray and Dyson, 2018).

First carpal bones were seen in 27% of horses, and it is considered normal for one third of horses (various ages and breeds) to have a first carpal bone (Butler et al., 2017c, Murray and Dyson, 2018). The first carpal bone is also described as usually being present bilaterally more often when found than unilaterally, and it was present bilaterally (15%) more than unilaterally (12%) in this study (Butler et al., 2017c). Fifth carpal bones were present in one horse (1%) and which is also a normal finding if present in less than 2% of horses (Butler et al., 2017c, Murray and Dyson, 2018).

In this study osteophytes in the carpus (9%) were more prevalent than those described in Thoroughbred yearlings (1.7% (Kane et al., 2003) and 7.6% (Smit, 2014)). Osteophytes are often associated with DJD and the finding thereof should be further investigated (Butler et al., 2017c, Murray and Dyson, 2018). Osteophytes and DJD have been found to be associated with the presence of lameness (Butler et al., 2017c, Contino et al., 2011, Kane et al., 2003, Murray and Dyson, 2018). The precise location and size of the osteophytes seen was not noted in this study, but they have been noted to be more prevalent on the radial and intermediate carpal bone in studies in Thoroughbred yearlings (Kane et al., 2003).

Enthesiophytes in the carpus were seen in 8% of the horses in this study. Enthesiophyte formation is indicative of ligamentous or capsular damage which can reveal the presence of or even predispose to degenerative joint disease (Butler et al., 2017c, Murray and Dyson, 2018). Small bony changes at the joint margins can be an incidental finding in older sound horses at work and their significance would need to be assessed in association with the horse's age, conformation, lameness status, and current and future work requirements (Butler et al., 2017c, Murray and Dyson, 2018). As the average age of the horses used in this study was 9 years old, one needs to be considerate of the increased prevalence of incidental age-related changes in comparison to the studies done on Thoroughbred yearlings (Malone et al., 2003).

Circular lucencies in the ulnar carpal bone were much less common (1%) than that described in studies on Thoroughbred flat racehorse yearlings (20.1% (Kane et al., 2003) and 14% (Smit, 2014)). These lucencies are speculated to be associated with previous intercarpal ligament avulsions (Butler et al., 2017c, Murray and Dyson, 2018). Lesions with an avulsion fragment at the interosseous ligament attachment to MC3 have been associated with lameness in flat race horses but when seen alone, and not near the bone margins, are often thought to be an incidental finding of unknown origin not associated with lameness (Butler et al., 2017c, Murray and Dyson, 2018, Ross, 2003).

Conformational changes around the carpus are associated with an increased risk of developing carpal lameness in flat racehorses (Ross, 2003). As the conformation was not assessed in this study no correlation can be made between the lesions seen and the endurance horse's conformation. This could potentially be used for a future study, to correlate the changes seen with conformation and lameness.

Proximal metacarpal pain is the most common cause of lameness described in endurance horses (Nagy et al., 2012). Bony changes in this area included endosteal new bone formation, syndesmopathy, synostosis and periosteal new bone formation.

Endosteal new bone formation at the proximopalmar aspect of the third metacarpal bone was present in 34% of the horses and was present bilaterally 17% of the time and unilaterally 17% of the time. Endosteal new bone formation of the proximopalmar aspect of the third metacarpal bone can be associated with tearing of the attachment of the suspensory ligament (Butler et al., 2017b). Although usually enthesiophyte formation will occur in the area (Butler et al., 2017b), this was however not seen in this study, nor were avulsion fractures in this area seen. It was expected that more bony changes associated with the suspensory ligament would be seen due to the high speeds and distances of endurance riding resulting in repetitive loading of the tendons and ligaments and thus the subsequent injuries (Bennet and Parkin, 2018b, Kane et al., 2003, Murray and Dyson, 2018, Nagy et al., 2017, Peat and Kawcak, 2015). Only actively competing horses were evaluated in this study, which could explain the low prevalence of the above changes, as bony changes are more often seen with chronic or severe injuries which are usually career ending (Anderson et al., 2014, Butler et al., 2017b, Dyson and Biggi, 2018). Ultrasonography of the suspensory ligament and/or computed tomography of this region would provide better diagnostic and prognostic information than radiographs (Butler et al., 2017b, Dyson, 2003, Launois et al., 2009, Peat and Kawcak, 2015). The prevalence of synostosis (11%) and the prevalence of syndesmopathy (10%) were very similar. Literature suggests syndesmopathy is more often seen in the proximal third of the metacarpus and can have an associated synostosis distally (Butler et al., 2017b, Dyson and Biggi, 2018). Synostosis and syndesmopathy were more prevalent between the second and third metacarpal bones (9% and 6% respectively) than the third and fourth metacarpal bones (2% and 4% respectively). The second metacarpal bone is medially/ axially situated and carries more load than the fourth metacarpal bone (laterally/ abaxially situated) in the forelimb (Butler et al., 2017b, Dyson and Biggi, 2018, Richardson, 2012). The increased changes seen medially compared to laterally can be expected due to the increased load carried by the area during strenuous exercise (Butler et al., 2017b, Dyson and Biggi, 2018, Richardson, 2012). In the forelimb ossification between the second and third metacarpal bone has been described as occurring more frequently and is usually present bilaterally (Butler et al., 2017b, Dyson, 2003, Dyson and Biggi, 2018). Syndesmopathy seen in conjunction with an increased radiopharmaceutical uptake in the region is indicative of an active lesion which can be associated with lameness (Butler et al., 2017b). In this study scintigraphy was not utilised and this could potentially be used in future studies to determine whether lesions are active or not. Lesions between the second (or fourth) and third metacarpal bone are more common in young horses than older horses and are often not associated with lameness (Dyson, 2003, Dyson and Biggi, 2018).

Horses in which the metacarpus is laterally offset (bench knees) from the carpus and antebrachium or where an angular limb deformity is present (such as a carpal valgus) are more predisposed to developing both synostosis between the second and third metacarpal bones as well as new bone on the medial aspect of the second carpal bone as per Wolff's law on bone modelling (Butler et al., 2017b, Dyson, 2003, Dyson and Biggi, 2018). Angular limb deformities were not evaluated in this study, but could potentially be evaluated in future studies to determine whether the changes seen in this study correlate with specific angular limb deformities. The above mentioned changes in the metacarpus are often not associated with lameness (Butler et al., 2017b, Dyson and Biggi, 2018).

It was postulated that more fractures similar to those in flat racehorses would be seen in endurance horses due to the increasing speeds of the sport (Nagy et al., 2012, Robert, 2014), but this was not found in this study. The prevalence of fractures was low. The only fracture seen in this study was a chronic healing fracture of the second metacarpal bone. The most common fractures described in flat race horses are chip fractures within the carpus (Butler et al., 2017c, Murray and Dyson, 2018) and none were seen in this study. The low number of fractures seen could be due to one of the inclusion criteria for this study being that the horses needed to be registered to compete (fit and able to compete). Differences in the terrain used for endurance riding in South Africa, compared to internationally, may also have influenced the low number of fractures seen (Murray and Dyson, 2018, Nagy et al., 2012, Nagy et al., 2017, Robert, 2014). Further investigation into the varying terrains and associated radiological changes and lameness would need to be performed.

Dorsal metacarpal disease, or the syndrome of periostitis, was not very prevalent in this study. Periostitis usually occurs due to the microfractures that often occur during young horses training, due to the cyclic loading of immature bones. Radiologically, periostitis is associated with endosteal new bone formation and vertical radiolucent lines on the dorsal aspect of MC3 (Butler et al., 2017b, Dyson and Biggi, 2018). Endosteal new bone on the dorsal aspect of the MC3 was only seen in two horses in this study and no radiolucent lines in the cortex of MC3 were seen. Thus it is postulated that sore or 'bucked' shins are an unlikely occurrence in endurance horses, even though they are frequently described and seen in thoroughbred flat racehorses (Butler et al., 2017b, Dyson and Biggi, 2018, Kane et al., 2003, Smit, 2014). This low prevalence in endurance horses could be due to the older age at which training commences compared to flat race horses – meaning that the metacarpal bones are more mature before they are subjected to the cyclic loading that training induces. Further investigation would need to be done to confirm or reject this suspicion.

It has been suggested that many of the radiographic changes seen in this study are caused by repetitive cyclic loading of the limbs resulting in an accumulation of micro damage rather than once off acute incidents and that some of the changes may be adaptive modelling to cope with the strenuous nature of the endurance discipline (Murray and Dyson, 2018, Peat and Kawcak, 2015). The longer distances being ridden (Bennet and Parkin, 2018b, Nagy et al., 2012, Rajão et al., 2019), the intensive training regimes of endurance horses (Robert, 2014) and the hard terrains (Murray and Dyson, 2018) would lead to repetitive cyclic loading of the joints and may be the reason for the prevalence of the radiographic changes seen in this study (Rajão et al., 2019). Further investigation comparing the distances of individual horses in training, the length of time in training, age of the horse, age at the start of training, the distances that they have competed and the terrains on which they ride would need to be investigated (Bennet and Parkin, 2018b).

One of the major limitations of this study is the small sample population evaluated, namely 100 horses (1.6%) out of the 5922 registered endurance horses in South Africa, and the small geographical area (250km radius around the Onderstepoort campus) where the sample population was selected (ERASA, 2019). To improve this study, radiographs of horses from a larger geographical area should be performed. This could be done via random sample selection from a country wide distribution. Due to the very focal area that the sample population was selected from - the prevalence of lesions may be biased. To validate the prevalence of changes found in this study a sample population would need to be selected by simple random sampling of registered horses throughout South Africa.

Another limitation of this study was the lack of correlation between the radiological changes seen and age, conformation, the influence of training, terrain, total kilometres raced etc. (Malone et al., 2003, Rajão et al., 2019). These would need to be investigated further to identify specific associations to the radiographic changes seen. This could then be analysed to determine whether or not they are adaptive changes in response to a horses' training, will affect the horses' performance or are the result or cause of lameness.

The radiographic findings in this study were also not correlated to lameness or performance and thus could all potentially be incidental findings. Further research to correlate the radiographic findings of this study with lameness, and thus investigate potential causes of lameness in endurance horses is required.

5.1 CONCLUSION

This study has collected and provided data describing the prevalence of radiological changes in a small sample population of endurance horses in South Africa. As there is relatively little evidence-based information on radiological lesions seen in endurance horses worldwide, it is difficult to compare whether or not the findings of this South African specific study are in line with global findings (Adamu et al., 2014, Nagy et al., 2012, Nagy et al., 2017, Robert et al., 2010). In a study done that compared the radiographic findings of high level endurance horses to that of show jumpers, it was concluded that the presence of mild to moderate radiographic changes is expected at a high level of competition (Robert et al., 2010).

The majority of radiological changes in this study were found within the carpi. The most prevalent of these were subchondral bone sclerosis of the third carpal bone in 77% of horses, a C1 in 27% of horses, carpal osteophytes in 9% of horses and carpal enthesiophytes in 8% of horses. The most prevalent changes present in the metacarpus were endosteal new bone formation at the proximopalmar aspect of the MC3 in 34% of horses, synostosis between the MC2 and MC3 in 9% of horses, and periosteal new bone formation on the MC2 in 9% of horses. The majority of changes were present on the left forelimb, which correlates to the most commonly clinically identified lame limb in endurance horses (Nagy et al., 2017).

In order to validate the findings of this study, further radiographic investigation of endurance horses in the rest of South Africa and internationally would need to be performed. Data for different geographical regions also needs further investigation for comparisons to be made regarding changes seen on the different terrains and speeds (Bennet and Parkin, 2018a). Additional research into the causes of the changes found; associations with lameness, conformation, age and genetic lineages; and future career potential could also be performed in future studies (Malone et al., 2003, Rajão et al., 2019).

There are still so many aspects of orthopaedic injuries in endurance horses that warrant more research, due to the ever growing popularity of the sport and the relatively small amount of information currently available (Adamu et al., 2014, Nagy et al., 2012, Nagy et al., 2017). Further studies would aid veterinarians in their diagnostic skills and early detection of lesions induced by endurance riding (Bennet and Parkin, 2018b, Nagy et al., 2012, Peat and Kawcak, 2015). This would improve the ability to manage endurance horses by allowing veterinarians to prevent career changing injuries occurring by early detection (Adamu et al., 2014, Peat and Kawcak, 2015) and improving the overall welfare status of the horses competing in the discipline (Nagy et al., 2012).

It may be considered in the future for endurance horses in South Africa and potentially other geographical regions to submit a full set of radiographs, similar to those submitted at the Thoroughbred yearling sales, upon registration with an endurance ride association (Contino et al., 2011, Kane et al., 2003, Smit, 2014). This would greatly aid the availability of data for future studies of radiographic changes and orthopaedic injuries in endurance horses (Malone et al., 2003, Nagy et al., 2012, Nagy et al., 2017, Rajão et al., 2019).

Due to the limited information available on this topic currently, this study has begun to build the foundation on which future research into radiographic changes and/or orthopaedic injuries in endurance horses in South Africa, and potentially internationally, can expand on.

5.2 DECLARATION OF CONFLICT OF INTEREST

The author of this paper did not have a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of this study.

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Appendices

APPENDIX A: RADIOGRAPHIC CHANGES CRITERIA

Each horse's radiographs were analysed for both the left and right limb separately.

Variable	Category
UV Number	Unique per horse
Limb	Left Right
Soft tissue swelling around metacarpus	Yes No
New bone formation MC2	None Smooth, well defined Irregular, poorly defined
New bone formation MC3	None Smooth, well defined Irregular, poorly defined
New bone formation MC4	None Smooth, well defined Irregular, poorly defined
Endosteal new bone dorsal MC3	Yes No
Radiolucent line in MC3 cortex	Yes No
Syndesmopathy between MC2 & MC3	Yes No
Synostosis between MC2 & MC3	Yes No
Syndesmopathy between MC3 & MC4	Yes No
Synostosis between MC3 & MC4	Yes No
Enthesiophyte at proximopalmar MC3	Yes No
Endosteal new bone formation proximopalmar MC3	Yes No

Avulsion fracture at proximopalmar MC3	Yes No
Longitudinal incomplete fracture of palmar cortex of MC3	Yes No
MC2/MC4 fracture	Yes No
Soft tissue swelling in / around carpus	Yes No
Osteophyte in carpus	Yes No
Enthesiophyte in carpus	Yes No
Circular lucency ulnar carpal bone	Yes No
Fragment in carpal joints	Yes No
Subchondral cyst in carpus	Yes No
Fracture accessory carpal bone	Yes No
Subchondral bone lysis C3	Yes No
Subchondral bone sclerosis C3	Yes No
Slab fracture of C3	Yes No
Presence of C1	Yes No
Presence of C5	Yes No

APPENDIX B: OWNER CONSENT FORM

<table>
<tr><td colspan="4">Owner Details</td></tr>
<tr><td>Surname</td><td></td><td>Name</td><td></td></tr>
<tr><td>Email Address
Phone Number</td><td></td><td>Copy of radiographs</td><td>Yes / No</td></tr>
<tr><td colspan="4">Horse Details</td></tr>
<tr><td>Name</td><td></td><td>UV no.</td><td></td></tr>
<tr><td>Microchip no.</td><td></td><td>Breed</td><td></td></tr>
<tr><td>Sex</td><td>Mare/ Gelding/ Stallion</td><td>DOB</td><td></td></tr>
<tr><td>Estimated Weight</td><td></td><td>Eliminated</td><td>Yes/ No</td></tr>
<tr><td>If (Yes) - Reason for elimination</td><td>Lameness/ metabolic/ other</td><td>If (No) - Race completed</td><td>Yes/ No</td></tr>
<tr><td>If other please specify</td><td></td><td>Total KMs completed</td><td></td></tr>
</table>

I ____________________________________ hereby give consent for the above mentioned horse to be radiographed as part of the study titled “The prevalence of radiographic changes in the metacarpal and carpal bones of South African endurance horses”. I am responsible for and able to give consent for the above mentioned horse.

I am aware that no individual radiographic report will be issued by the authors, but that I will have access to a copy of the radiographs via email if I would like them. These radiographs can be evaluated by a private veterinarian of my choice.

I consent for my horse to be handled for the duration of the radiographic procedure by the experienced handler provided. I acknowledge that I am still responsible for the horse for the duration of the procedure.

______________________________________ ______________________________________

Signature of Person Responsible *Date*

If I decline the use of the handler provided:

The handler, of my choice, and I have been made aware of the risk of exposure to radiation and the safety measures that will be taken during the radiographs to reduce the exposure to the handler.

Please note that no pregnant women or children under the age of 18 will be allowed to hold the horse while it is radiographed.

____________________	____________________	____________________
Signature of Person Responsible	*Signature of Handler*	*Date*

Additional consent for chemical restraint if required

I hereby give consent for the above mentioned horse to be sedated with intravenous Domosedan so that the radiographs for the above mentioned study can be taken. I am aware that it is not permitted for my horse to be sedated before or during the competition and that I may need to wait to take the radiographs if my horse needs to be sedated.

I am aware that after sedation my horse may not have food for a minimum of 1 hour

I have been made aware of the risk of sedation in horses.

____________________	____________________
Signature	*Date*

FOR OFFICIAL USE ONLY:

Ride		Ref no.	

APPENDIX C: INTER-RATER RELIABILITY RESULTS OBTAINED USING KAPPA STATISTICAL ANALYSIS

Index	Lesion	Side	Animals	Total "yes"	Total n	Proportion	MSD sum	Kappa	Lower CI	Upper CI	P value	Interpretation
1	Soft tissue swelling around metacarpus	L	100	8	300	0,03	3,33	0,36	0,24	0,47	0,00	Fair agreement
2	Soft tissue swelling around metacarpus	R	100	7	300	0,02	4,00	0,12	0,01	0,24	0,03	Slight agreement
3	Smooth, well defined new bone formation MC2	L	100	23	300	0,08	8,00	0,43	0,32	0,55	0,00	Moderate agreement
4	Smooth, well defined new bone formation MC2	R	100	19	300	0,06	8,67	0,27	0,16	0,38	0,00	Fair agreement
5	Irregular, poorly defined new bone formation MC2	L	100	9	300	0,03	4,67	0,20	0,09	0,31	0,00	Slight agreement
6	Irregular, poorly defined new bone formation MC2	R	100	6	300	0,02	1,33	0,66	0,55	0,77	0,00	Substantial agreement
7	Smooth, well defined new bone formation MC3	L	100	6	300	0,02	4,00	-0,02	0,00	0,09	0,72	No significant agreement
8	Smooth, well defined new bone formation MC3	R	100	3	300	0,01	2,00	-0,01	0,00	0,10	0,86	No significant agreement
9	Irregular, poorly defined new bone formation MC3	L	100	0	300	0,00	0,00					
10	Irregular, poorly defined new bone formation MC3	R	100	1	300	0,00	0,67	0,00	0,00	0,11	0,95	No significant agreement
11	Smooth, well defined new bone formation MC4	L	100	6	300	0,02	3,33	0,15	0,04	0,26	0,01	Slight agreement
12	Smooth, well defined new bone formation MC4	R	100	4	300	0,01	2,67	-0,01	0,00	0,10	0,81	No significant agreement
13	Irregular, poorly defined new bone formation MC4	L	100	1	300	0,00	0,67	0,00	0,00	0,11	0,95	No significant agreement
14	Irregular, poorly defined new bone formation MC4	R	100	3	300	0,01	1,33	0,33	0,21	0,44	0,00	Fair agreement

15	Endosteal new bone dorsal MC3	L	100	28	300	0,09	18,67	-0,10	0,00	0,01	0,07	No significant agreement
16	Endosteal new bone dorsal MC3	R	100	32	300	0,11	20,00	-0,05	0,00	0,06	0,39	No significant agreement
17	Radiolucent line at cortex of MC3	L	100	65	300	0,22	43,33	-0,28	0,00	-0,16	0,00	No significant agreement
18	Radiolucent line at cortex of MC3	R	100	64	300	0,21	42,67	-0,27	0,00	-0,16	0,00	No significant agreement
19	Syndesmopathy between MC2 & MC3	L	100	22	300	0,07	13,33	0,02	0,00	0,13	0,74	No significant agreement
20	Syndesmopathy between MC2 & MC3	R	100	27	300	0,09	15,33	0,06	0,00	0,18	0,27	No significant agreement
21	Synostosis between MC2 & MC3	L	100	23	300	0,08	10,67	0,25	0,13	0,36	0,00	Fair agreement
22	Synostosis between MC2 & MC3	R	100	19	300	0,06	9,33	0,21	0,10	0,33	0,00	Fair agreement
23	Syndesmopathy between MC4 & MC3	L	100	7	300	0,02	4,00	0,12	0,01	0,24	0,03	Slight agreement
24	Syndesmopathy between MC4 & MC3	R	100	23	300	0,08	12,67	0,11	0,00	0,22	0,07	No significant agreement
25	Synostosis between MC4 & MC3	L	100	5	300	0,02	2,67	0,19	0,07	0,30	0,00	Slight agreement
26	Synostosis between MC4 & MC3	R	100	8	300	0,03	4,00	0,23	0,12	0,34	0,00	Fair agreement
27	Enthesiophyte at proximopalmar MC3	L	100	7	300	0,02	4,67	-0,02	0,00	0,09	0,68	No significant agreement
28	Enthesiophyte at proximopalmar MC3	R	100	3	300	0,01	2,00	-0,01	0,00	0,10	0,86	No significant agreement

29	Endosteal new bone formation proximopalmar MC3	L	100	98	300	0,33	28,00	0,36	0,25	0,48	0,00	Moderate agreement
30	Endosteal new bone formation proximopalmar MC3	R	100	91	300	0,30	27,33	0,35	0,24	0,47	0,00	Moderate agreement
31	Avulsion fracture at proximopalmar MC3	L	100	5	300	0,02	3,33	-0,02	0,00	0,10	0,77	No significant agreement
32	Avulsion fracture at proximopalmar MC3	R	100	2	300	0,01	1,33	-0,01	0,00	0,11	0,91	No significant agreement
33	Longitudinal fracture of palmar cortex of MC3	L	100	0	300	0,00	0,00					
34	Longitudinal fracture of palmar cortex of MC3	R	100	0	300	0,00	0,00					
35	MC2/MC4 fracture	L	100	6	300	0,02	2,00	0,49	0,38	0,60	0,00	Moderate agreement
36	MC2/MC4 fracture	R	100	2	300	0,01	1,33	-0,01	0,00	0,11	0,91	No significant agreement
37	Soft tissue swelling in/ around the carpus	L	100	5	300	0,02	2,00	0,39	0,28	0,50	0,00	Fair agreement
38	Soft tissue swelling in/ around the carpus	R	100	10	300	0,03	4,67	0,28	0,16	0,39	0,00	Fair agreement
39	Carpal osteophyte	L	100	21	300	0,07	7,33	0,44	0,32	0,55	0,00	Moderate agreement
40	Carpal osteophyte	R	100	28	300	0,09	12,67	0,25	0,14	0,36	0,00	Fair agreement
41	Carpal enthesiophyte	L	100	24	300	0,08	8,67	0,41	0,30	0,52	0,00	Moderate agreement
42	Carpal enthesiophyte	R	100	20	300	0,07	7,33	0,41	0,30	0,52	0,00	Moderate agreement
45	Fragment in carpus	L	100	0	300	0,00	0,00					
46	Fragment in carpus	R	100	0	300	0,00	0,00					

48	Subchondral cyst in carpus	R	100	12	300	0,04	7,33	0,05	0,00	0,16	0,43	No significant agreement
49	Fracture accessory carpal bone	L	100	0	300	0,00	0,00					
50	Fracture accessory carpal bone	R	100	0	300	0,00	0,00					
51	Subchondral bone lysis C3	L	100	11	300	0,04	6,00	0,15	0,04	0,26	0,01	Slight agreement
52	Subchondral bone lysis C3	R	100	14	300	0,05	8,67	0,03	0,00	0,14	0,65	No significant agreement
53	Subchondral bone sclerosis C3	L	100	201	300	0,67	38,00	0,14	0,03	0,25	0,01	Slight agreement
54	Subchondral bone sclerosis C3	R	100	197	300	0,66	41,33	0,08	0,00	0,20	0,15	No significant agreement
55	Slab fracture of C3	L	100	0	300	0,00	0,00					
56	Slab fracture of C3	R	100	1	300	0,00	0,67	0,00	0,00	0,11	0,95	No significant agreement
57	C1	L	100	67	300	0,22	4,00	0,88	0,77	1,00	0,00	Almost perfect or perfect agreement
58	C1	R	100	54	300	0,18	3,33	0,89	0,77	1,00	0,00	Almost perfect or perfect agreement
59	C5	L	100	2	300	0,01	0,67	0,50	0,38	0,61	0,00	Moderate agreement
60	C5	R	100	3	300	0,01	1,33	0,33	0,21	0,44	0,00	Moderate agreement
61	Osteochondroma	L	100	2	300	0,01	0,67	0,50	0,38	0,61	0,00	Moderate agreement
62	Osteochondroma	R	100	5	300	0,02	0,67	0,80	0,68	0,91	0,00	Almost perfect or perfect agreement

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