Prevalence of radiographic changes in front feet and metacarpophalangeal joints of South African endurance racehorses

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By

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Submitted in fulfilment of the requirements for the degree
Master of Science in the Department of Companion Animal Clinical Studies at the Faculty of Veterinary Science, University of Pretoria

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PROJECT TITLE	**Prevalence of radiographic changes in South African Endurance racehorses- Part 1: Front feet and Meta-carpophalangeal joints**	
PROJECT NUMBER	**V041-18**	
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KINDLY NOTE:

Should there be a change in the species or number of animal/s required, or the experimental procedure/s - please submit an amendment form to the UP Animal Ethics Committee for approval before commencing with the experiment

APPROVED	Date	28 May 2018
CHAIRMAN: UP Animal Ethics Committee	Signature	

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ABSTRACT

Prevalence of radiographic changes in front feet and metacarpophalangeal joints of South African endurance racehorses.

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If the number of events alone is considered, endurance riding is the fastest growing Fédération Equestre Internationale (FEI) discipline and the second most popular FEI discipline. To the author's knowledge, no studies have been published investigating the prevalence of radiographic changes in the front feet and metacarpophalangeal joints of endurance racehorses. The current study followed an observational design and aimed to provide point prevalence and distributive data of radiographic changes in South African endurance horses. Radiographs were obtained from 100 horses competing during the 2018-2019 racing season. Radiographs included 7 standard views of each distal forelimb. Data analysis of the front feet revealed a large proportion of horses showed bilateral signs of dorsopalmar hoof imbalance; an abnormal digital axis, with a hyperextended proximal interphalangeal joint being the most common abnormality. Osteoarthritis of the proximal and distal interphalangeal joints was only observed in a few horses. Interestingly, the hoof-distal-phalanx-ratio of the majority of horses was more than 25% but none of these horses showed any other signs of chronic laminitis, indicating that hoof-distal-phalanx-ratio might not be a reliable indicator of chronic laminitis in this population of horses. Ossification of the ungular cartilages was observed in the majority of horses, either present at one or both distal phalanges. Descriptive data analysis of the metacarpophalangeal joints showed that a large proportion of horses displayed radiological signs of metacarpophalangeal joint osteoarthritis, with the majority being bilateral. Knowledge about the prevalence of specific radiographic changes would enable equine practitioners to better evaluate and manage horses that are affected and will act as a basis for further studies in South African endurance racehorses. The current study provides insight into radiographic changes and their prevalence in the distal front limbs of South African endurance racehorses. Although no correlations were made with age, speed or number of competitive kilometres competed, the current study may serve as comparison for future research.

List of Abbreviations

D15°PrPaDO	Dorsal 15° proximal palmar distal oblique
D45°MPaLO	Dorsal 45° medial palmar lateral oblique
D45°LPaMO	Dorsal 45° lateral palmar medial oblique
DPa	Dorsal to palmar
LM	Lateral to medial
Flexed LM	Flexed lateral to medial
MCIII	Third metacarpal bone
PSB	Proximal sesamoid bone
P1	Proximal phalanx
P2	Middle phalanx
P3	Distal phalanx
MCP	Metacarpophalangeal
PIP	Proximal interphalangeal
DIP	Distal interphalangeal
DDFT	Deep digital flexor tendon
LF	Left front
RF	Right front
DICOM	Digital imaging and communications in medicine
ERASA	Endurance Riding Association of South Africa
FEI	Fédération Equestre Internationale

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Chapter 1: Introduction

1.1 Background

The number of Fédération Equestre Internationale (FEI) endurance events had grown from 16 in 1994 to 276 in 2011 and 922 in 2018 (FEI, 2018). If the number of events alone is considered, endurance riding is the fastest growing FEI discipline and the second most popular FEI discipline after show-jumping (FEI, 2018; Nagy et al., 2012).

Radiographic examination of competing endurance racehorses as part of the pre-purchase evaluation, lameness examination and for the monitoring of disease progression, are common practice in South Africa.

1.2 Problem statement

To the author's knowledge, no studies have been published investigating the point prevalence of radiographic changes in the distal forelimb i.e. digits and metacarpophalangeal (MCP) joints of endurance racehorses in South Africa or worldwide.

1.3 Research question

What is the point prevalence of radiographic changes in the distal forelimb (digits and MCP joints) of competing endurance racehorses in South Africa in the 2018-2019 endurance season?

1.4 Hypothesis

Radiographic changes will be present in the distal forelimb (digits and MCP joints) of competing endurance racehorses in South Africa in the 2018-2019 endurance season.

1.5 Objective

The objective of the current study is to describe the point prevalence and distribution of radiographic changes in the distal forelimb (digits and MCP joints) of competing endurance racehorses in South Africa in the 2018-2019 endurance season.

1.6 Benefits of the current study

Knowledge about the point prevalence of specific radiographic changes would enable equine practitioners to improve their diagnostic skills by focusing on areas with the highest prevalence of changes, better understand the significance of specific radiographic changes, and better manage farriery and training of horses that show these types of radiographic abnormalities.

Very little information exists on orthopaedic injuries in endurance racehorses (Nagy et al., 2012). Dyson (2003) emphasises the importance of comparison of radiographs with a known normal example of similar age. The current study could also serve as a database for future reference both clinically and academically.

This knowledge could have financial as well as ethical implications for veterinarians, owners and team managers in the endurance industry. When one considers that pre-purchase radiographs are common practice (Suslak-Brown, 2004) in South Africa, knowledge about the prevalence of certain radiographic changes in competing endurance horses could influence prospective owners and selling price. Knowledge on the prevalence and clinical significance of lesions would help owners make decisions and manage horses better with regards to farriery and training.

The research was done as part of a degree of Master of Science in the Department of Companion Animal Clinical Studies in the Faculty of Veterinary Science, University of Pretoria.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In England and Wales, lameness is the most common veterinary problem affecting the majority of endurance racehorses at some point during their competitive career (Nagy et al., 2017) (Figure 1). Lameness is also considered to be the most common cause of elimination from endurance rides worldwide (Bennet and Parkin, 2018; Marlin et al., 2008; Nagy et al., 2014, 2010; Younes et al., 2016).

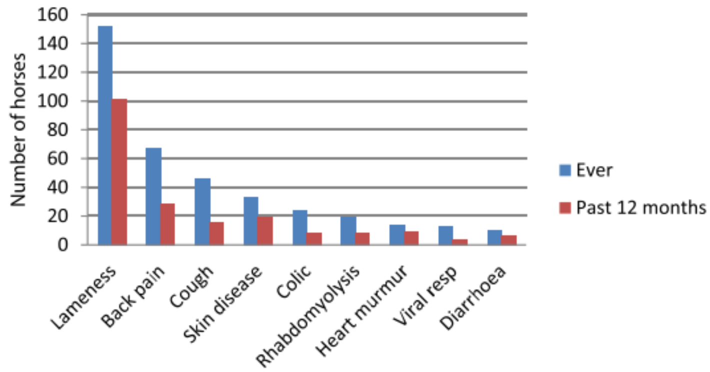

Figure 1: The number of horses suffering from veterinary problems at any time in a horse's career ('Ever') and in the 12 months preceding data collection (Nagy et al., 2017).

According to Nagy et al. (2017), the prevalence of lameness in endurance racehorses seemed to be higher than in dressage horses or elite show-jumpers. Despite this, a surprisingly low proportion of lameness episodes were investigated by veterinarians (Nagy et al., 2017).

2.2 COMPARATIVE STUDIES

Musculoskeletal injuries that previously were thought to be more common in flat-racing horses are now seen in endurance racehorses due to the constant increase in competition speeds (Misheff et al., 2010).

The authors go on to state that although endurance racehorses race and train at lower speeds than Thoroughbred flat-racehorses, the former are at risk of athletically induced bone pathology because of the long distances covered, at ever increasing speeds (Misheff et al., 2010).

Anecdotal information suggests that the types of radiographic changes and injuries have changed and increased in severity (Nagy et al., 2012). This information is supported to some extent by Misheff et al. (2010) who documented fractures previously only seen in racehorses and some of which were catastrophic in endurance racehorses (Misheff et al., 2010). More detailed evidence-based data is however required to draw conclusions.

Many previous studies investigated the prevalence of radiographic changes in Thoroughbred racehorses internationally (Contino et al., 2012; Furniss et al., 2011; Kane et al., 2003; Smit, 2014). To the author's knowledge, only two studies have been performed on South African Thoroughbred racehorses. Furniss et al. (2011) recorded the radiographic changes in 269 Thoroughbred Yearlings presented to the 2008 Germiston yearling sales. Smit (2014) recorded the prevalence of radiographic changes in 566 South African Thoroughbred racehorses at the yearling sales over a three-year period (2008-2010).

Similar studies have also been carried out in Standardbred trotters (Grøndahl and Engeland, 1995) and Quarter horses intended for cutting (Contino et al., 2012). To the author's knowledge, no studies have been published investigating the prevalence of radiographic changes in endurance racehorses in South Africa or internationally.

2.3 RADIOGRAPHIC VIEWS

According to May et al. (1986), the limitations of a radiograph in providing a two-dimensional image of a three-dimensional structure are well recognised and have led to the advice that the part under examination must be radiographed in a minimum of two planes to allow complete visualisation.

Dyson (2003) recommends a minimum of four views for joints distal to the elbow and stifle. The authors go on to say that lesions will be missed if an attempt is made to evaluate too much in a single view (e.g., the fetlock, pastern, and foot). The standard recommended views for the front foot and MCP joint are listed in Table 1.

Table 1: Standard radiographic views for the distal limb (Dyson, 2003).

	Standard views
Front foot	LM DPa DPr-PaDiO Pa45° Pr-PaDiO
MCP joint	LM Flexed LM DPa D45° L-PaMO D45° M-PaLO

2.4 RADIOGRAPHIC CHANGES

2.4.1 The digit

2.4.1.1 Hoof balance and length

There may be no other routine procedure performed on the equine athlete that has more influence on soundness than hoof preparation and regular shoeing (O'Grady and Poupard, 2003).

O'Grady and Poupard (2003) prefer the term "functional" foot; as "normal" foot does not consider genetics, breed, conformation, environmental influences, and athletic purpose. A functional foot consists of a parallel hoof-pastern axis (HPA), a thick hoof wall, sufficient sole depth, a solid heel base, and growth rings of equal size distal to the coronary band (O'Grady and Poupard, 2003).

Dorsopalmar hoof balance should be evaluated on horizontal lateromedial projections with the horse standing on a block. A vertical line drawn from the centre of the condyle of the middle phalanx (P2) should bisect the bearing surface of the sole in equal parts (Butler et al., 2017; O'Grady and Poupard, 2003) (Figure 2). Dorsopalmar hoof balance ensures equal loading of the entire solar surface of the distal phalanx (P3) during weight bearing so as to prevent overloading on any aspects of the sole and underlying bone (O'Grady and Poupard, 2003). Poor dorsopalmar balance contributes remarkably to the long toe/underrun heel conformation and the altered biomechanics that it causes (O'Grady and Poupard, 2003).

Long toes delay break over causing an excessive pull on the deep digital flexor tendon (DDFT) and associated structures (O'Grady and Poupard, 2003).

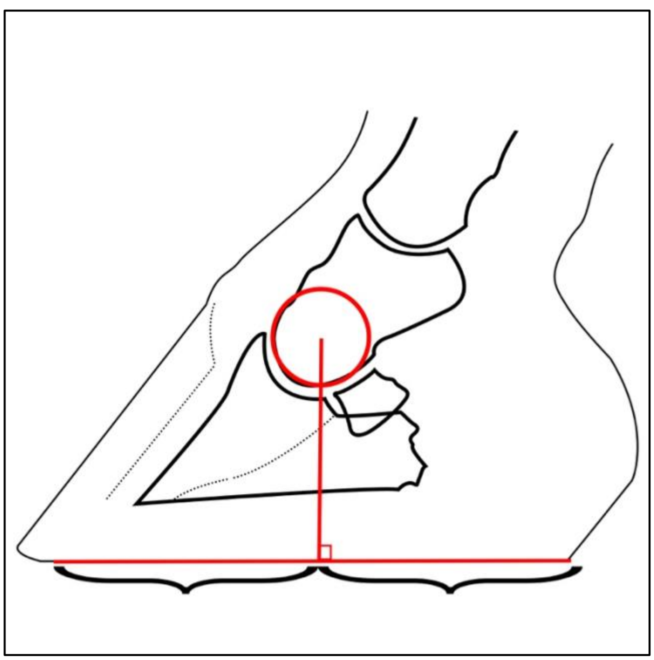

Figure 2: Dorsopalmar foot balance: The centre of rotation bisects the dorsopalmar length of the sole.

According to guidelines for hoof length based on the weight of a horse (O'Grady and Poupard, 2003), most endurance racehorses fall into the medium weight category (425-475kg) and should, therefore, have a hoof wall length of approximately 8.3cm (Table 2).

Table 2: Recommended hoof length based on the weight of a horse (O'Grady and Poupard, 2003).

Category	**Weight (kg)**	**Toe length (cm)**
Small	360–400	7.6
Medium	425–475	8.3
Large	525–575	8.9

Lateromedial hoof balance should be assessed on horizontal weight bearing dorsopalmar projections. The distal phalanx should appear approximately symmetrical within the hoof capsule in the normal foot (Sherlock and Parks, 2013).

The distance between the solar surface of P3 and the ground surface should be similar on both medial and lateral sides of the foot (Butler et al., 2017; Sherlock and Parks, 2013). Slight asymmetry is not uncommon and of no significance, if the DIP joint space is even. The parietal surfaces of the abaxial surface of the distal phalanx should be well demarcated, approximately the same length, diverge slightly distally and not have an upright appearance (Sherlock and Parks, 2013).

Poor lateromedial orientation of the hoof is associated with conditions like sheared heels, distorted hoof walls and hoof cracks (O'Grady and Poupard, 2003) due to disproportionate forces placed on the hoof during the landing phase of the stride. An abnormal medial-to-lateral hoof balance may also play an important role in the development of distal interphalangeal joint subchondral trauma, and later in the development of osteoarthritis, subchondral lucency, and fracture (Ross, 1998).

2.4.1.2 Hoof-pastern and digital-axis

The ''ideal'' hoof angulation (O'Grady and Poupard, 2003) is achieved when a line drawn down the dorsal surface of the hoof wall and a line drawn along the surface of the heel is parallel to a line drawn through the three phalanges (Figure 3). The dorsal surface of the hoof wall and the dorsal surface of the distal phalanx should be parallel or almost parallel (Dyson et al., 2011; Linford et al., 1993).

The hoof-pastern axis is traditionally thought to be straight in most sound horses (Sherlock and Parks, 2013). Although it has previously been described that the dorsal surface of the hoof wall and heels should be parallel, more recently it has been noted that the heel angle of sound horses is slightly more acute (43.5 ± 6.3°) than the dorsal hoof wall angle (Dyson et al., 2011). The mean dorsal hoof wall angle in the front feet of normal horses have been reported as 52.2 ± 3.7° (Dyson et al., 2011).

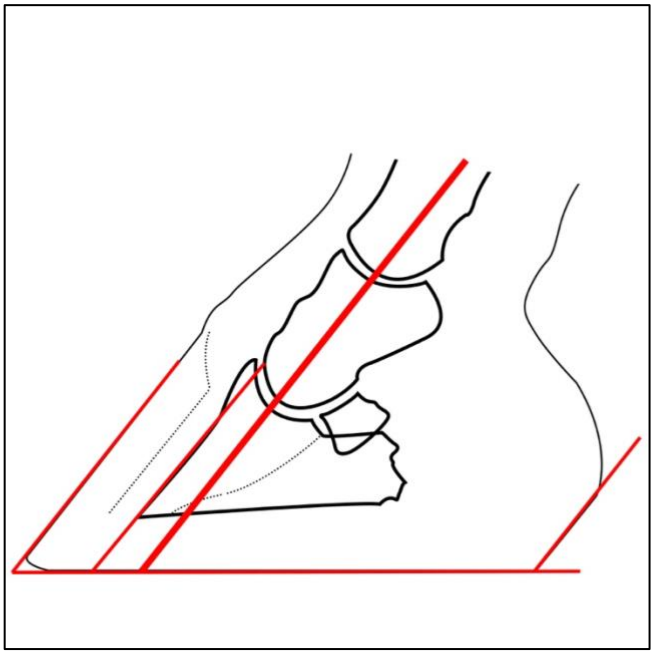

Figure 3: Ideal hoof angulation: a line drawn down the dorsal surface of the hoof wall and a line drawn along the surface of the heel is parallel to a line drawn through the three phalanges.

2.4.1.3 Solar angle

Inversion of the distal phalanx is defined when the palmar/plantar processes of the distal phalanx are lower than its dorsodistal tip. The solar angle is thus negative (≤0º). This has been associated with more proximal sites of pain, causing lameness (Dyson, 2003). The solar angle of most sound horses is 3-8º (Sherlock and Parks, 2013), but some authors describe an angle or 3-10º as normal (Butler et al., 2017), see Figure 4.

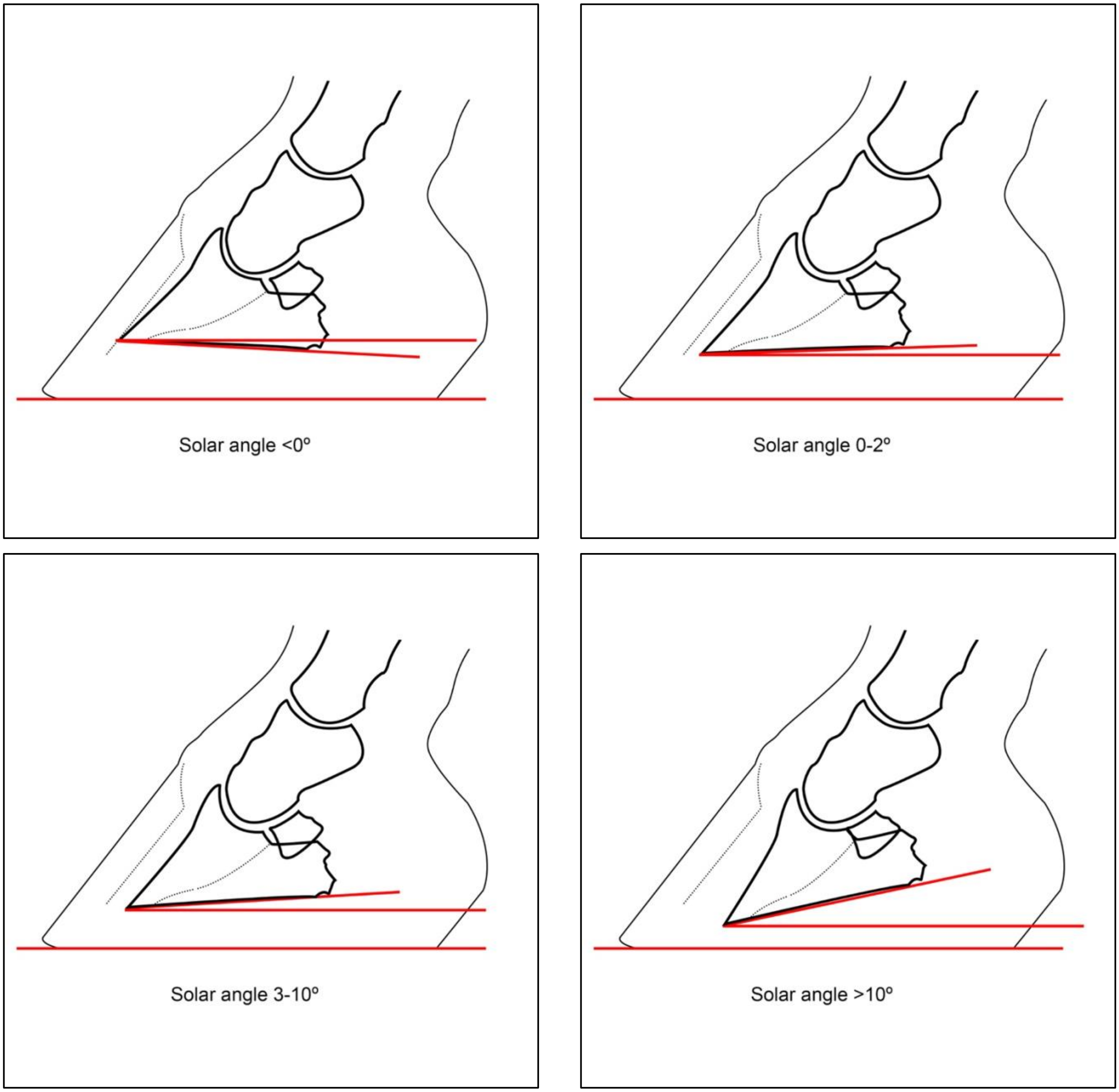

Figure 4: Schematic diagram of solar angles seen on weight-bearing lateromedial radiographs.

2.4.1.4 Pedal osteitis complex

Pedal osteitis implies active inflammation of the distal phalanx; however, some authors prefer the term “Pedal osteitis complex” due to the broad spectrum of radiographic changes present in the distal phalanx and their possible aetiologies. Pedal osteitis complex is commonly associated with forelimb lameness in horses (Butler et al., 2017).

Radiographically pedal osteitis is characterised in the current study as the presence of osseous proliferation or resorption on the dorsal or solar surface and modelling of the dorsodistal tip of the distal phalanx. These changes are best viewed on horizontal lateromedial projections of the foot.

2.4.1.5 Hoof ratio

The dorsal hoof wall should be straight and smooth in most horses; however, mild concavities (32%) and convexities (18%) have been noted on the dorsal surface of the hoof wall in sound horses (Dyson et al., 2011).

The dorsal hoof width is the shortest distance from the dorsal surface of the distal phalanx to the dorsal surface of the hoof wall. In most normal adult feet, the hoof width should be similar along the entire proximal to distal length of the distal phalanx, such that the dorsal hoof wall is parallel to the dorsal parietal surface of the distal phalanx (Redden, 2003) (Figure 3).

There are variations in the width depending on the breed and size of the horse (Redden, 2003). In most Thoroughbreds, Quarter Horses and other light breeds, the width is 14–18 mm (Linford et al., 1993). The majority of endurance racehorses are Arabian or Arabian crossbreeds and should therefore fall in this category. In Warmbloods, hoof ratio is reported as 18–20 mm, while in heavier older Standardbred broodmares and stallions, it may be even wider at 20–22 mm (Redden, 2003).

To overcome the wide individual variation in the dorsal hoof width measurement, some authors describe the dorsal hoof width as a percentage of the palmar length of the distal phalanx (Figure 5) measured from the tip of the distal phalanx to its articulation with the navicular bone (Linford et al., 1993; Peloso et al., 1996). According to Sherlock and Parks (2013), the dorsal hoof width in normal horses should be <30% of the palmar length of the distal phalanx, but other authors (Butler et al., 2017) advocate that it should be <25% ±3%. In their opinion a ratio >25% could be indicative of chronic laminitis.

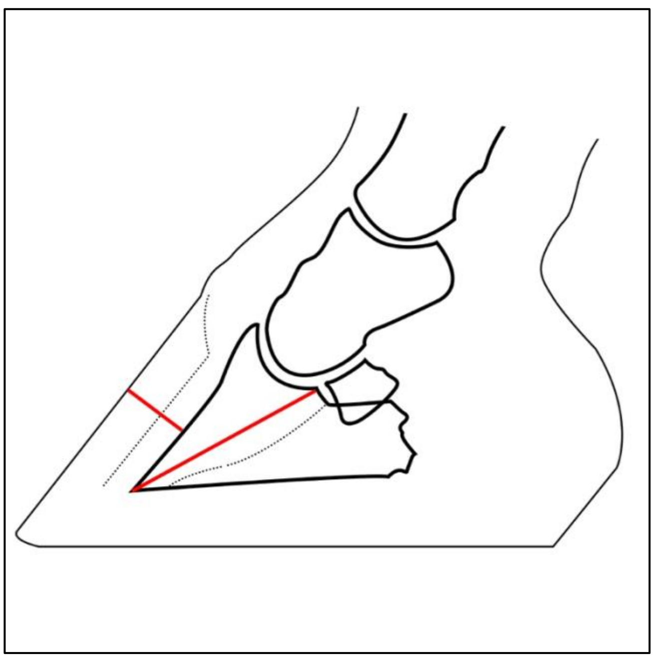

Figure 5: Schematic diagram of dorsal hoof wall thickness as a percentage of palmar cortical length of the distal phalanx.

2.4.1.6 Hoof wall separation

There should be no radio-opacities or -lucencies within the hoof of normal sound horses (Sherlock and Parks, 2013).

Focal areas of radiolucency of varying sizes, configurations and shapes consistent with “gas lines” may appear within the dorsal hoof at varying times in horses with laminitis. Thin regular lines parallel with the hoof wall generally occur during acute and subacute laminitic episodes while large irregular air spaces are found in horses with more chronic laminitic disease after significant rotation or sinking of the distal phalanx has occurred (Sherlock and Parks, 2013).

Separation of the hoof wall may occur for a number of reasons other than laminitis and infection (Belknap and Geor, 2016). Excessive length of horn at the toe may result in the dorsal aspect of the hoof wall lifting away from the distal phalanx. A radiolucent area will then become evident palmar to the hoof wall, although it frequently becomes packed with radiopaque material (Butler et al., 2017). Belknap and Geor (2016) mention that separation can also occur as a result of an acute traumatic incident, e.g. jumping on hard uneven ground.

Hoof wall separation or gas lines are best evaluated on horizontal lateromedial projections of the foot.

2.4.1.7 Ungular cartilage ossification

A grading system to describe the proximodistal extent of ungular cartilage ossification seen on a weight-bearing dorsopalmar projection has been described (Butler et al., 2017; Dyson et al., 2010; Jones and Dyson, 2015; Ruohoniemi et al., 1993) (Table 3 and Figure 6).

Table 3: Ungular cartilage ossification as described by Ruohoniemi et al. (1993).

Grade	**Description / radiographic criteria**
0	No ossification
1	Ossification up to the level of the medial or lateral margins of the distal interphalangeal joint
2	Ossification up to the level of the mid sagittal aspect of the distal interphalangeal joint
3	Ossification up to the most proximal aspect of the distal sesamoid (navicular) bone (excluding proximal enthesophytes)
4	Ossification up to the midpoint of the middle phalanx (based on the most proximal aspect of the joint surface)
5	Ossification extends proximally to the midpoint of the middle phalanx.

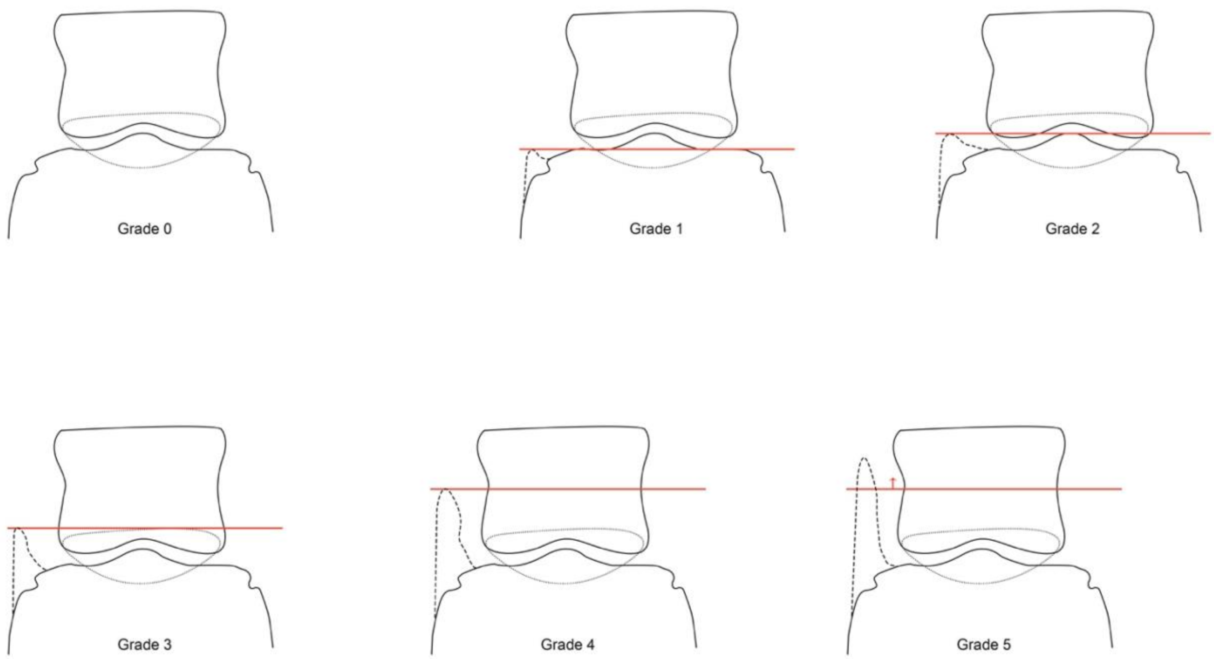

Figure 6: Schematic diagram of ungular cartilage ossification (adapted from Jones and Dyson (2015)).

The clinical significance of ossification of the ungular cartilages of the foot, colloquially known as sidebone, is controversial (Jones and Dyson, 2015). Ossification is commonly more extensive in the lateral than the medial cartilage (Jones and Dyson, 2015). Although sidebone is regarded as a potential problem in working draught horses, it was previously thought to be of little clinical significance in ridden horses (Butler et al., 2017; Ruohoniemi et al., 2010); however, there is increasing evidence suggesting that extensive ossification (grade 3-5) or severe lateromedial asymmetry of ossification may be predisposing factors for fracture and contribute to foot-related pain (Ruohoniemi et al., 2010).

Ossification results in stiffening of the ungular cartilages. Forces may be transmitted differently through the rigid structure, compared with unossified cartilages. Ossified cartilages may be less able to dissipate energy, which may predispose to further modelling, adaptive changes or fracture (Dyson, 2013).

Inward or outward curvature as well as a palmar curve or bulbous shape of ossified ungular cartilages are significant risk factors for modelling. Increased modelling in turn predisposes to fracture and injury to an ossified cartilage was identified as a source of foot pain contributing to lameness (Jones and Dyson, 2015).

Radiographic differentiation of the junction between a separate center of ossification and the distal ossified cartilage versus fracture of an ossified cartilage may be difficult (Jones and Dyson, 2015; Ruohoniemi et al., 1993). According to Jones and Dyson (2015), dorsoproximal-palmarodistal oblique, flexed dorsolateral-palmaromedial oblique and flexed dorsomedial-palmarolateral oblique views are useful in detecting fractures of the ungular cartilages. Ungular cartilage ossification was graded on weight-bearing dorsopalmar projections (Jones and Dyson, 2015; Ruohoniemi et al., 1993).

2.4.1.8 Fractures of the distal phalanx

Common fracture sites of the distal phalanx in foals and adult horses have previously been described and a fracture classification has been proposed (Butler et al., 2017; Kidd, 2011), although not all fractures fit into this model. See Table 4.

Table 4: Pedal bone fracture classification as described by Kidd (2011).

Type	Description
1	Non-articular abaxial fractures of a palmar or plantar process
2	Articular fractures that are not midsagittal and extend from the distal interphalangeal joint to the medial or lateral aspect of the solar margin
3	Articular mid-sagittal fractures of the distal phalanx
4	Extensor process fractures
5	Multi-fragment fractures
6	Non-articular fractures involving the solar margin, and extending from one point of the solar margin to another
7	Non-articular solar fractures dorsal to the palmar or plantar process of the distal phalanx in foals

2.4.1.9 Enthesophyte and osteophyte formation in the phalanges

Osteophytes refer to the new bone formation that is evident at the osteochondral margins of joints. These changes are considered important radiographic abnormalities as they often occur in the presence of articular cartilage disease (Smit, 2014).

Entheseous new bone reflects the bone's response to the stress applied through soft tissue structures, such as ligamentous tearing or capsular traction (Dyson, 2003). Entheseous new bone does not necessarily reflect osteoarthritis, but it often occurs when osteoarthritis is present. It may reflect slight joint instability, which itself may predispose to the development of osteoarthritis (Dyson, 2003). Fracture of an enthesophyte and mineralisation within the tendon or ligament attachment also may occur.

In the current study osteophytes and enthesophytes were recorded if present on the extensor process of the distal phalanx and the dorsoproximal margin of middle phalanx (P2).

The extensor process of the distal phalanx may normally show a wide spectrum of radiographic shapes that are seen on a lateromedial view and should not be recorded as radiographic abnormalities (Butler et al., 2017). New bone formation on the extensor process at the insertion of the common digital extensor tendon is, however, classified as enthesophyte and may be a source of pain and lameness (Smit, 2014).

2.4.1.10 Chronic laminitis

Displacement of the distal phalanx relative to the hoof wall is the most common radiographic finding made in chronic laminitis cases (Herthel and Hood, 1999). Displacement of the distal phalanx is best assessed on a weightbearing lateromedial projection (Belknap and Geor, 2016). Phalangeal displacement can be classified as rotational or vertical. Rotational displacements can further be classified into capsular and phalangeal rotation.

Capsular rotation is defined as the non-uniform increase in the hoof-distal-phalanx-distance resulting in a larger distance between the dorsal hoof wall and the dorsal parietal surface of the distal phalanx distally so that the two surfaces are no longer parallel (Herthel and Hood, 1999). According to other authors (Parks and Belknap, 2016) however, the parietal surface of the distal phalanx is normally angled 0–2º more acutely to the ground than the dorsal hoof capsule that is, it is normal for there to be 0–2º of capsular rotation.

Normal hoof pastern and digital axis was discussed above (see 2.4.1.2). Phalangeal rotation is commonly defined as a divergence of the dorsal surface of the distal phalanx from the axis of the first and second phalanges in a palmar/plantar direction such that the DIP joint becomes flexed (Parks and Belknap, 2016).

Vertical displacement of the distal phalanx results in an increased CE distance (vertical distance from the coronary band to the extensor process of the distal phalanx), uniform increase in the hoof-distal-phalanx-distance and a decreased sole thickness (Figure 7). Normal CE distance varies between sources and breeds (Table 5). The CE value is a more valuable tool for assessing displacement of the distal phalanx in serial radiographs (Belknap and Geor, 2016).

Table 5: Normal coronary extensor process (CE) distance according to different authors.

Source	**(Sherlock and Parks, 2013)**	**(Grundmann et al. 2015)**	**(Belknap and Geor, 2016)**
CE (founder) distance	-2–15 mm	4.5-8.3 mm	-2-14mm

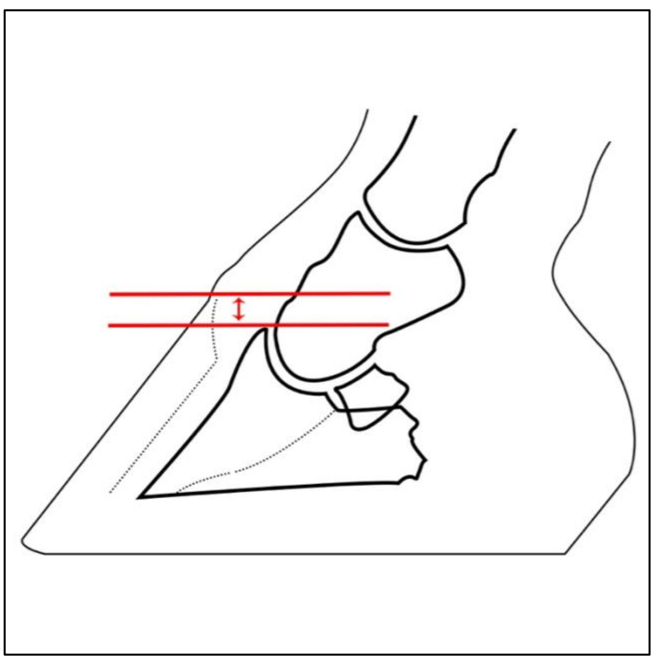

Figure 7: Schematic diagram of coronary extensor process (CE) distance.

Parks and Belknap (2016) states that during laminitis, capsular rotation is always present in horses with phalangeal rotation, but that phalangeal rotation is not always present in horses with capsular rotation. This most commonly occurs in conjunction with symmetrical distal (vertical) displacement of the distal phalanx.

The parietal surface of the distal phalanx is normally straight or slightly convex and smooth (Dyson, 2003; Parks and Belknap, 2016). A slight increase in convexity of this surface due to roughening mid-way between its proximal and distal limits may occasionally be the only evidence of a prior episode of laminitis (Parks and Belknap, 2016).

Increased pressure on the dorsal solar margin of the distal phalanx results in remodelling of the dorsodistal tip, usually by the development of a dorsally projecting lip, and is indicative of chronic laminitis (Belknap and Geor, 2016).

2.4.2 The metacarpophalangeal joint

Many pathological radiographic changes in the MCP joints are associated with osteoarthritis. According to Dyson (2003), radiographic abnormalities associated with osteoarthritis include the following:

- Periarticular osteophyte formation
- Narrowing of the joint space
- Subchondral lucent zones, either well or poorly defined
- Subchondral bone sclerosis; loss of trabecular pattern
- Thickening of the subchondral bone plate
- Joint capsule distension and soft tissue swelling
- Suprachondylar lysis of the third metacarpal bone

2.4.2.1 Metacarpophalangeal soft tissue swelling

Soft tissue swelling in the MCP joint region can be observed radiographically alone or in conjunction with other radiographic abnormalities (Butler et al., 2017). Radiographs are however often insufficient to determine the reason for the swelling.

Joint effusion and synovitis can be observed radiographically as distention of the MCP joint capsule and are best seen on the dorsal aspect of the MCP joint on lateromedial (flexed) projections (Butler et al., 2017). Chronic proliferative synovitis, also known as villonodular hypertrophic synovitis, may also be seen radiographically as a soft tissue opacity in the same area. It may result in modelling (lucency or depression) of the distal dorsal cortex of MCIII just proximal to the sagittal ridge.

Soft tissue swelling laterally and medially on dorsopalmar projections may indicate collateral ligament injury (Butler et al., 2017).

2.4.2.2 Metacarpophalangeal osteophytes and enthesophytes

On dorsopalmar projections of the MCP joint osteophytes on the medial and lateral articular margins of the proximal phalanx indicate degenerative joint disease (Butler et al., 2017).

Enthesophytes of the MCP joint capsule often accompany peri-articular osteophytes and indicate abnormal stress on the joint capsule insertion. Abnormal stress on the MCP joint capsule, as is the case with synovitis or chronic joint distention, may lead to the formation of enthesophytes at its insertion. It is most common at the insertion of the joint capsule proximally on the dorsodistal aspect of MCIII and distally on the dorsoproximal aspect of the proximal phalanx. This can be visualised on a lateromedial projection. This does not indicate degenerative joint disease but is often seen in conjunction with it (Butler et al., 2017).

2.4.2.3 Osteochondral fragmentation of the dorsoproximal proximal phalanx

Dorsoproximal osteochondral fragmentation is best visualised on flexed and/or extended LM view or D45°MPaLO and D45°LPaMO views. Small well-rounded fragments on the medial dorsoproximal border of the proximal phalanx are a common radiographic finding and are not always related with clinical signs (Butler et al., 2017). Their aetiology is unknown, but they may be a manifestation of developmental orthopaedic disease.

Although they are only sometimes associated with joint effusion, the majority of horses show arthroscopic evidence of synovitis and cartilage fibrillation (Butler et al., 2017). The presence of more than one fragment or fragments in horses older than seven years of age were risk factors associated with lameness (Butler et al., 2017; Declercq et al., 2008).

2.4.2.4 Subchondral cyst-like lesions in MCIII or the proximal phalanx

Subchondral cystic lesions (SCL) have been identified either affecting the distal MCIII and/or the proximal part of the proximal phalanx. Acute injuries of the proximal aspect of the proximal phalanx result in a focal ill-defined radiolucent line or an osseous cyst-like lesion in the subchondral bone, with subsequent development of a diffuse area of sclerosis distally. Subchondral cystic lesions can also be related to developmental orthopaedic disease in young horses.

According to Dyson (2003), SCL occur on the weight bearing surface of the MCP joint (mostly on the medial MCIII condyle) and horses usually show obvious lameness exacerbated by distal limb flexion. These lesions carry a poor prognosis (Butler et al., 2017).

The more radiographic change in the subchondral bone, the more likely that clinical signs will be present (Dyson, 2003). Cyst-like lesions that are close to an articular surface and possibly communicate with it, are more likely to be associated with lameness (Dyson, 2003). It is always important to evaluate radiographically the joint in its entirety since evidence of secondary osteoarthritis warrants a more guarded prognosis (Dyson, 2003).

2.4.2.5 Changes in the distal third metacarpal bone

Remodelling of the dorsodistal aspect of MCIII is a relatively common radiographic change (Smit, 2014). Great variability in radiographic appearance of the distal dorsal MCIII may be normal but common changes include a notch, radiolucency and fragmentation.

Changes to the dorsodistal sagittal ridge are best visualized on a dorsopalmar view or a flexed lateromedial view and are seen as a flattening or presence of a lucency representing bone loss beneath the cartilage surface at the dorsal sagittal ridge. According to Kane et al. (2003), this is the most common site of osteochondrosis in the MCP joint but these changes did not correlate with poor race performance in Thoroughbred yearlings.

Pathology on the distopalmar MCIII is best visualised on lateromedial radiographs and can be seen as flattening, lysis or sclerosis of the palmar condyle. According to Kane et al. (2003), these changes are classified as palmar metacarpal disease or traumatic osteochondritis dissecans (OCD). Subchondral microfractures in the palmar metacarpal condyle result in ischaemia causing progressive modelling of distal MCIII. Sclerosis can also be seen on dorsopalmar projections where the change in subchondral bone has been associated with degenerative joint disease (Butler et al., 2017).

Palmar supracondylar lysis describes bone loss affecting the palmar cortex of the MCIII at the level of the palmar pouch of the MCP joint. It can be classified as slight, moderate or severe and is best seen on horizontal lateromedial projections. It is associated with the fibrous proliferation of the synovial membrane which occurs during degenerative joint disease (Butler et al., 2017).

2.4.2.6 The Proximal sesamoid bones

Radiographic changes present in PSB identified during pre-purchase radiographic studies include sesamoid fractures, osteophytes, enthesophytes, sesamoid elongation, atypical shapes, circular lucencies as well as the total number of vascular channels where both irregular and regular vascular channels are identified (Contino et al., 2012; Kane et al., 2003; Smit, 2014).

Sesamoiditis refers to active inflammation of the PSB and is a widely used term that includes both new bone formation and radiolucent areas within the PSB (Kamm, 2015). During sesamoiditis the radiographic appearance of the PSB is variable, ranging from a number of radiolucent areas along the palmar aspect of the bones, with minimal new bone formation, to extensive new bone on the axial and abaxial surfaces, with an apparently normal internal structure of the bone (Butler et al., 2017). These abnormalities are best assessed on medial and lateral oblique views (Butler et al., 2017; Kamm, 2015; McLellan and Plevin, 2014).

The number of regular vascular channels vary in normal horses depending on breed and work history (Butler et al., 2017). Sesamoids demonstrating any number of regular vascular channels (<2mm wide with parallel borders) did not negatively affect racing performance (Spike-Pierce and Bramlage, 2010).

Wide or abnormally shaped lucent areas, however, are likely to be associated with clinical lameness. Two or more irregular vascular channels in yearling Thoroughbreds was associated with decreased performance, when compared with horses with normal vascular channels (Kane et al., 2003). The greater the number of irregular vascular channels, the more likely there is to be poor performance and associated lameness (Spike-Pierce and Bramlage, 2010).

Fractures of the PSB occur frequently, particularly those involving the apical portion (Nixon, 2012). Other configurations include basal, midbody, abaxial, sagittal, and comminuted fractures (Figure 8). Most PSB fractures occur because of excessive tension from the suspensory apparatus and their significance depends on their position and the degree of associated soft-tissue injury.

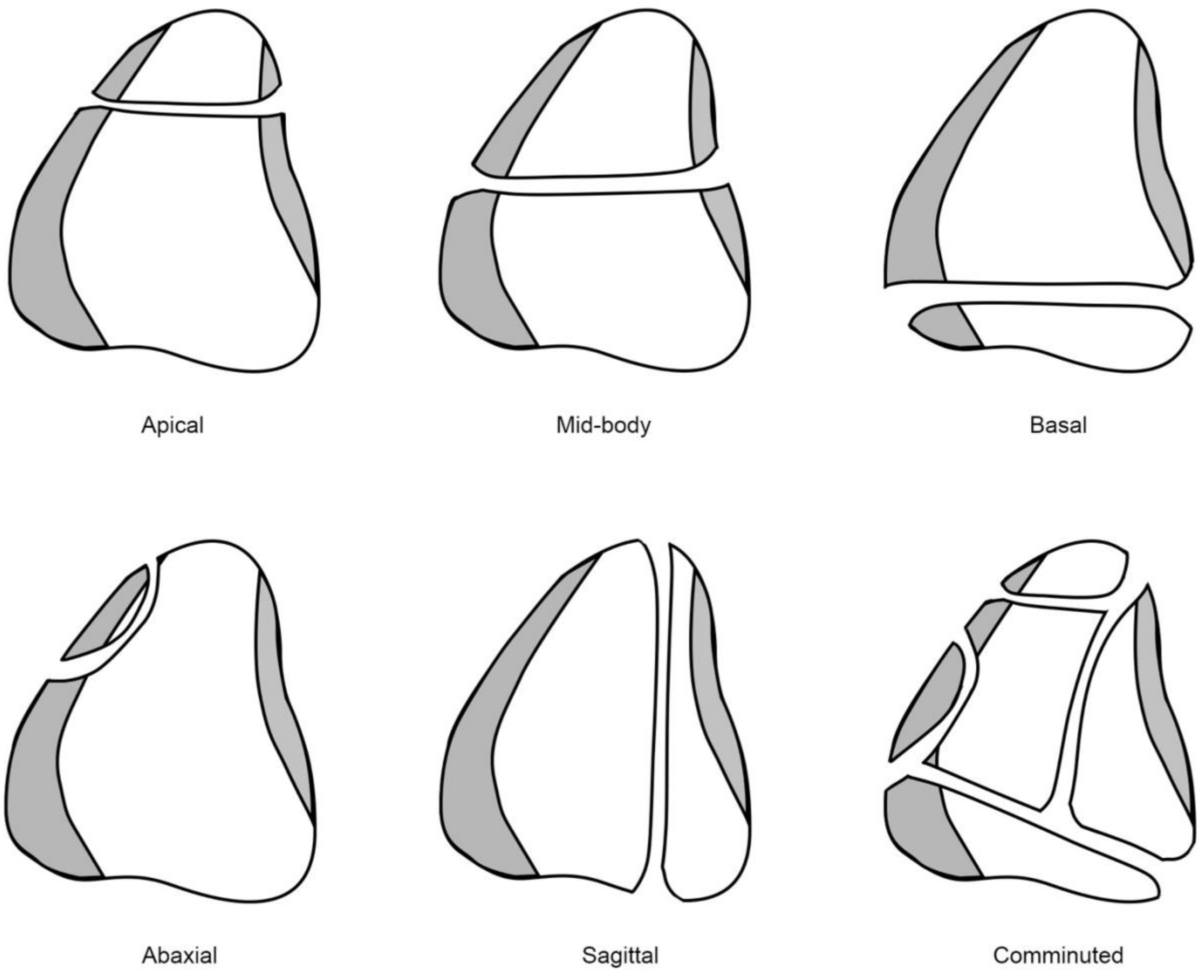

Figure 8: Schematic diagram of proximal sesamoid bone fracture configurations (adapted from Auer and Stick (2019)).

2.5 RADIOGRAPHIC SAFETY

Radiography of animals outside defined x-ray rooms or areas is likely to add to the radiation risks. The lack of ancillary and protective equipment, the lack of adequate immobilisation and the inability to prevent the presence of unauthorised persons are all contributing risk factors (Lee, 1989). Although the amount of scatter during each individual exposure is low, if protective principals are not followed, the total radiation exposure will accumulate with time and may exceed the threshold and increase the risk for carcinogenic side effects (Tyson et al., 2011).

Lee (1989) recommends that when it is necessary to radiograph animals outside defined x-ray rooms one should ensure that the necessary precautions are met. Equipment, such as cassette holders, should be available, sufficient protective clothing is worn by all persons taking part, the number of assistants should be minimised, the nature of the procedure and the precautions should be carefully explained to the assistants before any radiographic exposures are made, adequate precautions should be taken to prohibit the access of unauthorised persons to the area during radiography (e.g. by display of warning signs), adequate support for the x-ray tube assembly and cassettes are provided, means are provided to achieve the correct alignment of the x-ray beam to the cassette and to ensure that the x-ray beam is collimated to an area equal to or less than the cassette (Lee, 1989; Tyson et al., 2011).

CHAPTER 3: MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

The current study followed an observational study design.

Radiographs were obtained from 100 horses competing in endurance rides within a two-and-a-half-hour radius of the University of Pretoria during the 2018-2019 endurance racing season. Appendix A lists endurance rides where radiographs were taken.

All horses competing in the 2018-2019 endurance season whose owners gave informed consent were eligible to be radiographed. Other inclusion criteria required that horses be microchipped, have a valid passport, up to date vaccinations (African Horse Sickness and Equine influenza) and be registered with ERASA (Endurance Riding Association of South Africa).

The first 100 horses where a complete series of radiographic images of diagnostic quality were obtained were included in the study (n = 100). No additional selection was made. Radiographic examinations comprised of 7 views of each distal forelimb and included the forefeet, MCP joints (Table 6). Radiographs were obtained using a Cuattro EQ Digital Slate 6 Radiography System (Cuattro, Golden, CO) sponsored by IVM Imaging, and a mobile x-ray generator (PXP-40HF, Poskom Co., Gyeonggi-do, Republic of Korea) from the University of Pretoria.

Table 6: Radiographic views obtained in the current study.

	Study views
Front foot	LM
	DPa
MCP joint	LM
	Flexed LM
	D15ºPrPaDiO
	D45ºLPaMO
	D45ºMPaLO

After completion of the endurance season and data collection, all radiographic images were independently evaluated by three observers (YS, MR, CLR – Table 7) using the DICOM system. All three observers evaluated all 100 horse's radiographs making this a fully crossed study design. It is unlikely that radiographic changes were missed by all three examiners.

Table 7: Radiographic observer qualifications.

Observer	***Qualification***
Dr. Y. Smit	*BSc, BVSc, MSc, MMedVet (Equine Surgery)*
Dr. C. le Roux	*BVSc Hons MMedVet (Diag Im) DipECVDI*
Dr. M. Robert	*DVM, Dipl.ECVS*

A survey containing a detailed categorised datasheet of radiographic changes (Appendix B) was completed by each observer for each series of radiographs. Observers did not have to judge normality or make associated diagnoses. Discrepancies were settled by consensus where possible. If no consensus could be reached the mathematical mode was recorded as the judgement. Inter-rater reliability was then calculated using Fleiss Kappa. Intra-rater repeatability was not assessed as each observer evaluated the radiographs once.

3.2 EXPERIMENTAL PROCEDURE

One hundred horses were volunteered by their owners and met the above-mentioned inclusion criteria. Physical restraint included a halter, lead and experienced handler. All radiographs were taken at completion of ride or after a horse was eliminated, no radiographs were taken prior to start of race. Where it was difficult to take the radiographs in a safe manner, chemical restraint was offered to the owner. If the horse was clinically stable, not fatigued or metabolically compromised, it was sedated with intravenous detomidine (Equidine®) (Dosage: 0.01-0.02mg/kg) after completion of the endurance race. The owner was required to give separate consent for sedation (Appendix C).

The forelimbs were prepared for radiographs by removing excess dirt by brushing or cold hosing to minimise artefacts, and the front feet were cleaned with a hoof pick prior to exposure where necessary. Horses were made to stand on two 5cm thick blocks whilst forefoot exposures were made. A standard and constant source to image distance of 1.0 m was maintained throughout exposures.

Radiographs were obtained using a Digital Radiography (DR) system and DICOM images recorded on the DICOM system. The cassette was protected with a light neoprene sheet. Radiographs were marked according to the standardized nomenclature system for radiographic projections used in veterinary medicine (Smallwood et al., 1985). Radiopaque markers (LF/RF) were placed either laterally on DPa and oblique views, or dorsally on LM views.

A list of views to be taken was listed on the back of each consent form and was ticked off as exposures were made. A radiographic protocol was also added to the DR system to ensure that all views were acquired (Appendix C). Radiographs were taken by the author.

In an attempt to minimise radiation, the ALARA (as low as reasonably achievable) principles were applied during the current study. These included reducing time of exposure, reducing the number of repeated or unnecessary images taken and sedating uncooperative patients. Protective clothing (lead gowns, glasses, thyroid shields and gloves) was worn by all persons involved.

3.3 CATEGORISATION OF RADIOGRAPHIC CHANGES

Radiographic changes are discussed below, and the datasheet is presented in Appendix A.

3.3.1 The digit

Forefeet radiographs were obtained with the horse standing square on wooden blocks and examined for lateromedial and dorsopalmar foot balance, solar angle, hoof length, normality of the digital axis, evidence of DIP or PIP osteoarthritis, signs of chronic laminitis, ossification of the ungular cartilages and distal phalanx fractures. Measurements were made on RadiAnt DICOM viewer (Medixant, Poland) or Horos (4.0.0 RC3) DICOM viewer software.

Medial and lateral solar thickness were evaluated on horizontal dorsopalmar projections. The distance was measured from the medial and lateral distal border of the distal phalanx to the ipsilateral solar surface and were divided into five categories (<5mm, 5-9mm, 10-14mm, 15-19mm, >20mm).

The angle of the solar margin of the distal phalanx to the ground is the angle created between the distal (solar) surface of the hoof capsule and the solar margin of the distal phalanx (Sherlock and Parks, 2013). This angle was measured and divided into four categories (≤0º, 0-2º, 3-10º, ≥10º).

Dorsopalmar hoof balance was evaluated on horizontal lateromedial projections. A vertical line from the centre of the condyle of P2 was categorised as either bisecting the solar surface of the hoof capsule or being more dorsal or more palmar. The centre of the condyles were determined using the oval or circle tool in DICOM viewer software. Further the angle of the heel to the ground was measured and this angle was categorised as being smaller, equal or larger than that of the angle between the dorsal hoof wall and the ground.

Dorsal hoof wall length was measured and was divided into three categories (≤7.6 cm, 7.6-8.9 cm, ≥8.9 cm).

The digital axis was evaluated on lateromedial projections and each joint (DIP, PIP) was examined for flexion, extension or alignment.

The presence or absence of enthesophytes and osteophytes were recorded on the extensor process of the distal phalanx and dorsoproximal P2 and the distal phalanx was examined for dorsodistal mineralisation reactions. The dorsal hoof wall thickness and the palmar length of the distal phalanx were measured and the ratio between these two distances was calculated. The hoof capsule was examined for the presence or absence of dorsal hoof wall separation, capsular and phalangeal rotation, a depression immediately proximal to coronary band and the distance between the coronary band and extensor process of the distal phalanx was measured.

The ungular cartilages were examined for ossification and categorised accordingly (Grade 0 to 5). Fractures of the distal phalanx were categorised according to type (Type 0 to 6).

3.3.2 The metacarpophalangeal joint and proximal sesamoid bones

MCP radiographs were evaluated for the presence or absence of soft tissue swelling, changes consistent with MCP osteoarthritis (enthesophytes, osteophytes) and presence of fragments or subchondral bone cysts. The presence of proximal phalangeal bony fragments were categorised as either dorsal or palmar. Dorsal fragments were categorised as articular or non-articular based on their location relative to the MCP joint capsule insertion.

Changes to the dorsal distal MCIII (None, Notch, Lucency, Fragment/loose body, Flattening), palmar MCIII (None, Flat, Lucency, Sclerosis) and the distal sagittal ridge (None, Flat, Lucency) were examined and categorised accordingly. Palmar supracondylar lysis in distal MCIII was categorised as absent, slight or moderate and extreme.

The PSB were assessed for the presence or absence of elongation, surface irregularities, fractures (Type 0 to 5), osteophytes, lucencies (0 to 3) and the number of regular as well as irregular vascular channels.

3.4 DATA ANALYSIS

A survey containing a detailed categorised datasheet of radiographic changes (Appendix B) was completed by each observer for each series of radiographs once. Discrepancies were settled by consensus where possible. If no consensus could be reached the mathematical mode was recorded as the judgement.

The frequency of radiographic changes was obtained for each structure evaluated as listed above. From the frequency, the point prevalence of each variable was calculated. The questionnaire was set up in such a way to differentiate between medial and lateral and left and right for changes that could be bilateral or biaxial. Horses were classified as having a particular change if either limb was affected by the variable in question. Only descriptive data analysis was performed. Intra-rater repeatability was not assessed.

Inter-rater reliability was investigated by calculating Fleiss Kappa (adaptation of Cohen's kappa for 3 or more raters) for each variable after converting each variable into binominal categories. Cohen suggested the Kappa result be interpreted as follows (Table 8). The P-value for each Kappa was calculated (Appendix D) and variables where Fleiss Kappa had a P-value < 0.05 were interpreted as having no statistical significant agreement.

Table 8: Interpretation of Kappa values (McHugh, 2012).

Cohen's Kappa	**Interpretation**
≤0	No agreement
0.01-0.20	None to slight agreement
0.21-0.40	Fair agreement
0.41-0.60	Moderate agreement
0.61-0.80	Substantial agreement
0.81-1.00	Almost perfect agreement

3.5 ETHICAL CONSIDERATION

Key ethical considerations during the current study included radiographic safety and confidentiality of the radiographs taken from privately owned horses. Since producing radiographs of the distal limb is a common clinical procedure and experimental animals will be volunteered by the owners, no substantial ethical drawbacks were encountered.

Confidentiality was ensured and bias minimised by evaluating horses according to UV (Uithourit Vereeniging) number. The UV number (ERASA, 2019) is assigned to a horse when it is registered with ERASA. Confidentiality concerns have been obstacles to studies such as this one in the past, but Nagy et al. (2012) is of the opinion that participating parties in the future will recognise that the provision of anonymous data will lead to information that is useful for everyone involved, and can potentially improve the welfare of endurance racehorses. This was our experience during data collection.

This study protocol was approved by both the Animal Ethics Committee of the University of Pretoria and the Faculty of Veterinary Science Ethics Committee. See page III.

3.5.1 Experimental animals

Animals were volunteered by their owners to partake in the current study (n=100). Signed informed consent was obtained before a horse was radiographed (Appendix C). Horses were cared for and remained the responsibility of their owner throughout the exposure period. During radiographic examination, horses were handled by the owner or a suitable, consenting handler that had been made aware of the radiographic exposure risk. No adverse events occurred during data collection.

3.5.2 Staff, facilities, equipment and supplies

Staff were kept to a minimum and included the examiner, an assistant to position the cassette and a handler to control the horse. Study supervisor and co-supervisors were involved only in the radiographic analysis.

Radiographs were obtained using a DR system and recorded in DICOM format. Where available, radiographs were taken within a stable. Where no stable or barn was available, radiographs were taken in a designated, well-marked, access-controlled area.

Equipment used included the following:

1. DR system (Cassette, X-Ray generator and laptop/display screen, battery)
2. Protective clothing (Lead jackets, lead gloves, lead glasses, lead thyroid shields, dosimeters)
    a. Dosimeters supplied by University of Pretoria
    b. Protective clothing supplied by Tabitha Prior
3. Radiographic markers (RF, LF)
    a. Supplied by author
4. Positioning aids (cassette holder, two wooden blocks)
    a. Cassette holder lent from University of Pretoria, Onderstepoort campus
    b. Wooden blocks made specifically for the study by the author
5. Consent forms, pens
6. Clipboards, file to store consent forms
    a. Supplied by the author
7. Electrical extension lead
    a. Supplied by the authors

3.5.3 Records

Consent forms for each horse will be stored in a paper file kept for 5 years. Data was captured in Google Sheets® spreadsheets, which will be kept on the primary investigator's laptop. Data and digital radiographic images were also backed up in cloud storage (Google Drive®). Electronic copies of the data were made available to the co-supervisors and supervisor. The radiographic images will be kept by the primary investigator and if no longer in the employment of the University of Pretoria, they will be handed over to the Department of Companion Animal Clinical Studies (CACS).

Where owners requested a copy of the radiographs, they were sent to them via email in jpeg format. No radiographic report was supplied to owners.

3.5.4 Declaration of conflict of interest

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of this paper.

3.5.5 Biosecurity and safety

The radiographic examination was done in a separate clearly marked area, away from the main ride area, in an attempt to minimise irradiation of the public. All staff and handlers complied with the minimum safety standards according to the Code of Practice for Users of Medical X-ray Equipment (Department of Health Directorate, 2015). This included protective lead coats, thyroid shields and gloves where the cassette will be handheld. According to the ICRP (International Commission on Radiological Protection), the maximum whole-body radiation exposure limit is 20mSv per year. Each staff member wore a dosimeter to monitor exposure and readings returned below 20mSv after analysis.

CHAPTER 4: RESULT

4.1 STUDY POPULATION

The study population consisted of 100 endurance racehorses competing in the 2018-2019 endurance season. No horses needed to be twitched during data collection. The average age was 8.9 years old (5-17 years old) and consisted of 59 geldings (59%), 36 mares (36%) and 5 stallions (5%) (Figure 9). The majority of the population was Arab (46%) or Arab cross (48%) (Figure 10).

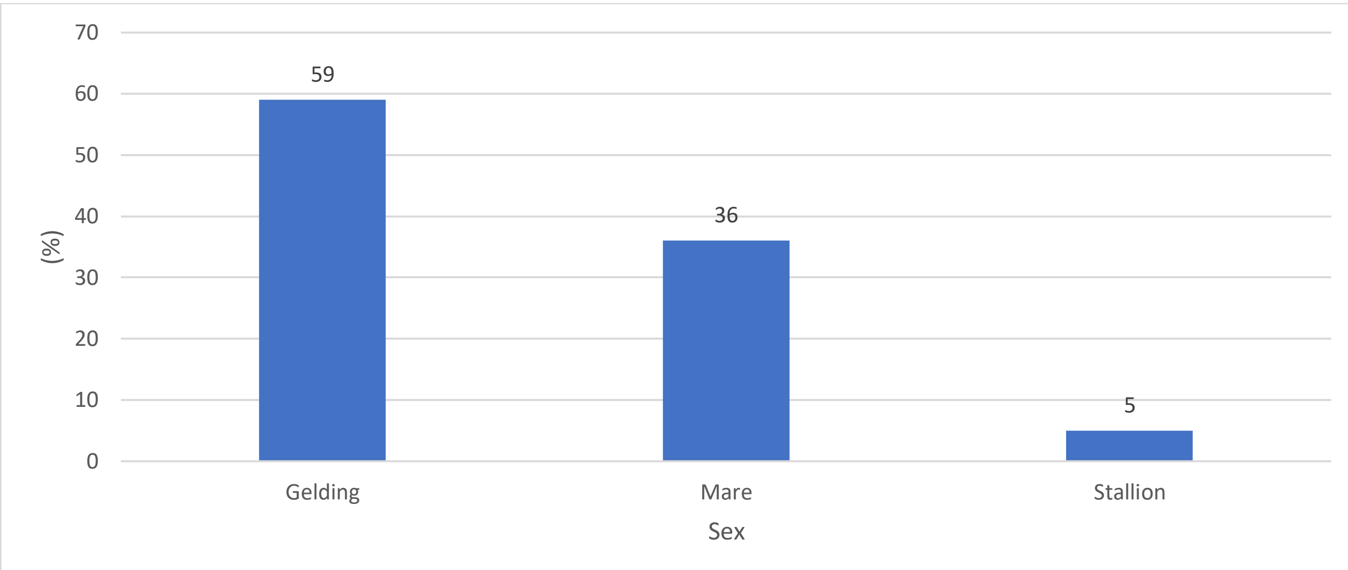

Figure 9: Study population sex distribution (South African endurance racehorses competing in the 2018-2019 endurance season, n=100).

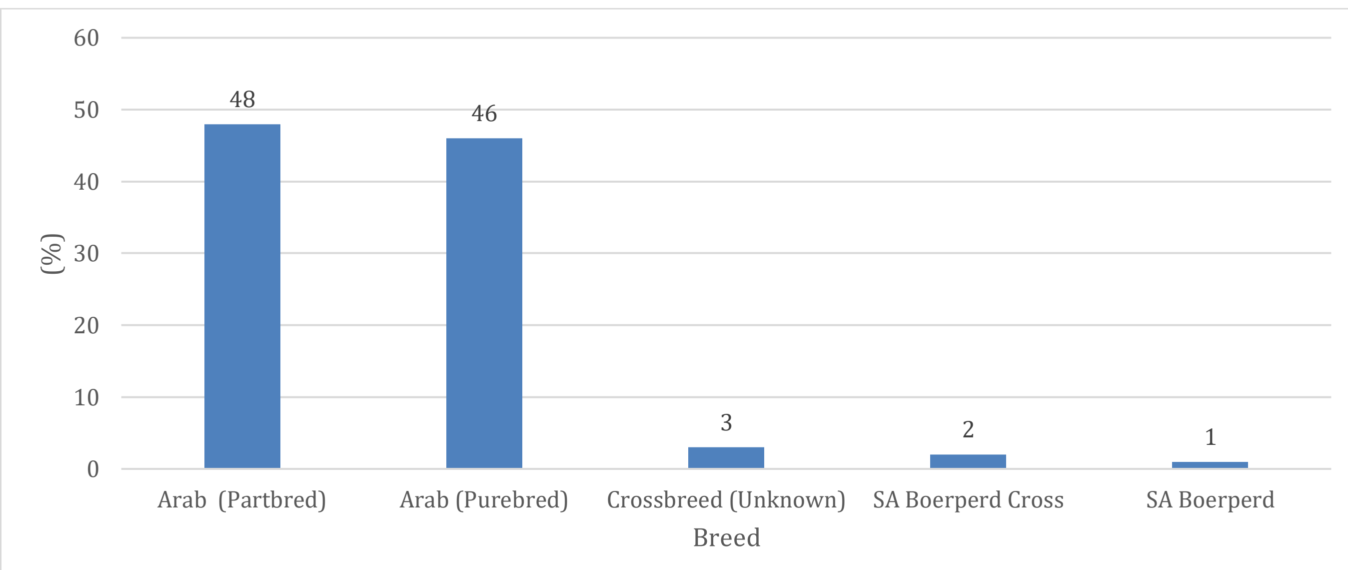

Figure 10: Study population breed distribution (South African endurance racehorses competing in the 2018-2019 endurance season, n=100).

4.2 DATA ACQUISITION

Radiographs were taken by the author, evaluated on site for diagnostic quality and retaken if of poor diagnostic quality.

4.3 DATA ANALYSIS

A total of 100 horses were evaluated during the current study. Due to non-diagnostic quality radiographs (i.e. poor quality, incorrect positioning, etc), only 93% (186/200 forelimbs) of foot radiographs could be evaluated for medial and lateral solar thickness. All other evaluations were made on all 200 forelimbs.

4.3.1 The digit

Forefeet radiographs were obtained from 100 horses. Due to poor quality radiographs, medial and lateral solar thickness could only be measured in 94% (94/100) of left feet and 92% (92/100) of right feet.

Solar thickness measurements are summarised in Table 9 and discussed below. The statistical significance of the difference between medial and lateral solar thickness was not assessed.

Table 9: Radiographic changes in the digit of endurance racehorses (n=100) - Mediolateral foot balance.

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Medial Solar Thickness								
0= <5mm	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
1= 5-9mm	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= 10-14mm	9	*9,6*	7	*7,6*	2	*2,0*	14	*15,2*
3= 15-19mm	44	*46,8*	41	*44,6*	32	*32,0*	53	*59,4*
4= >20mm	41	*43,6*	44	*47,8*	37	*37,0*	48	*54,4*
Lateral Solar Thickness								
0= <5mm	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
1= 5-9mm	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= 10-14mm	6	*6,4*	3	*3,3*	2	*2,0*	7	*7,6*
3= 15-19mm	37	*39,4*	28	*30,4*	23	*23,0*	42	*46,8*
4= >20mm	51	*54,3*	61	*66,3*	47	*47,0*	65	*73,6*

A solar angle less than 0º was measured in 6% (6/100) of left front feet and 5% (5/100) of right front feet, with a negative solar angle being present bilaterally in 3% (3/100) of horses with an overall prevalence of 8%. The solar angle was between 0 and 2º in 20% (20/100) of left front feet and 25% (25/100) of right front feet. This was observed bilaterally in 11% (11/100) of horses and had an overall prevalence of 34%. Normal solar angles between 3º and 10º were measured in 69% (69/100) of left front feet and 67% (67/100) of right front feet, with 53% (53/100) of horses having normal solar angles bilaterally. The overall prevalence was 83%. Solar angles larger than 10º was observed in 5% (5/100) of left front feet and 3% (3/100) of right front feet. This was present in only one horse bilaterally and had an overall prevalence of 7%. Solar angle measurements are summarised in Table 10 and distribution is indicated in Figure 11.

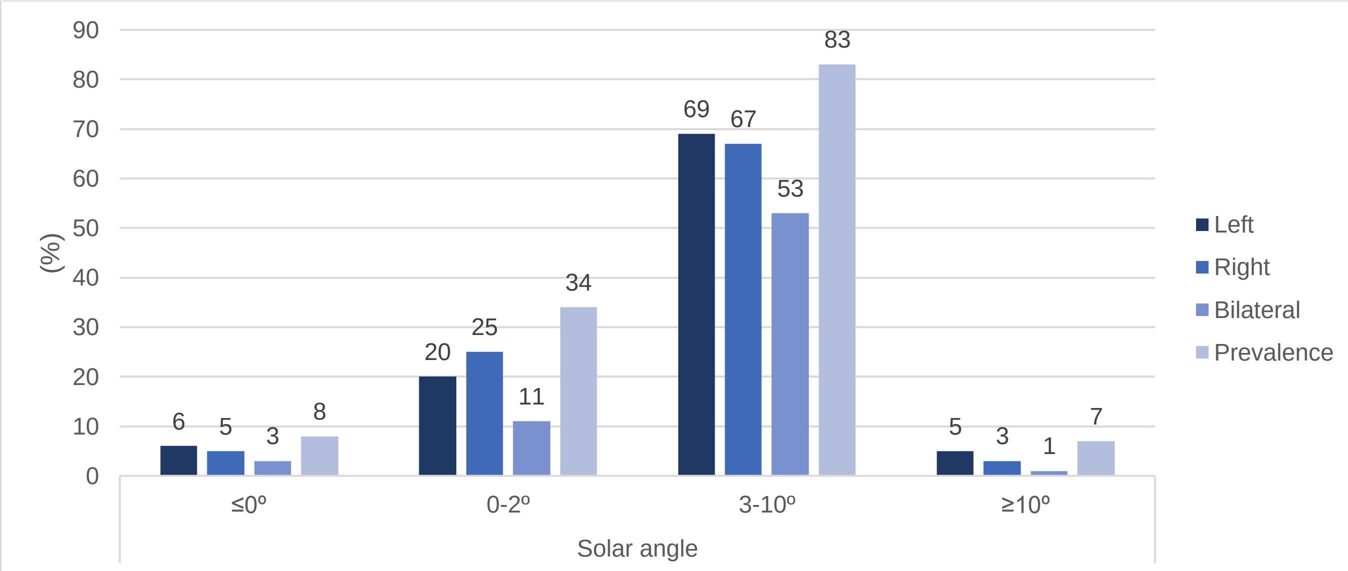

Figure 11: The distribution of solar angle of the distal phalanx (the angle between the solar surface of the distal phalanx and the horizontal) measured on lateromedial radiographs of the front feet of 100 endurance horses.

Only one horse had bilateral hoof length of less than 7.60cm. A hoof length of 7.6-8.9cm was measured in 28% (28/100) of left front feet and 40% (40/100) of right front feet. This was measured bilaterally in 26% (26/100) of horses and had a prevalence of 42%. A hoof length larger than 8.9cm was measured in 71% (71/100) of left front feet and 59% (59/100) of right front feet. A hoof length larger than 8.9cm was measured in 57% (57/100) of horses bilaterally and had a prevalence of 73%.

A vertical line from the centre of the condyles of P2 bisected the solar surface in 3% (3/100) of left front hooves and 3% (3/100) of right front hooves while it only occurred bilaterally in one horse and had a prevalence of 5%. The line was more palmar (Figure 12) in 97% (97/100) of left front hooves and 97% (97/100) of right front hooves. This was the case bilaterally in 95% (95/100) of horses and had a prevalence of 99%.

The angle of heel to the ground was equal to the angle of the dorsal hoof capsule to the ground in 30% (30/100) of left front feet and 42% (42/100) of right front feet. Equal angles were present in 20% (20/100) of horses bilaterally and equal angles had a prevalence of 52%. The angle of heel to the ground was smaller than the angle of the dorsal hoof capsule to the ground (Figure 13) in 68% (68/100) of left front feet and 55% (55/100) of right front feet. This was the case in 47% (47/100) of horses bilaterally with a prevalence of 76%. The angle of heel to the ground was larger than the angle of the dorsal hoof capsule to the ground in 2% (2/100) of left front feet and 3% (3/100) of right front feet. This was only observed bilaterally in one horse making the prevalence 4%.

Figure 12: Lateromedial radiograph revealing dorsopalmar hoof imbalance in a 13-year-old Arab gelding. The vertical line from the centre of the condyles of P2 does not bisect the solar surface but is more palmar. The heel and dorsal hoof wall angles are however still equal.

Figure 13: Lateromedial radiograph revealing dorsopalmar hoof imbalance in a 16-year-old Arab gelding. Note the heel and dorsal hoof wall angles are not equal, nor does the vertical line from the centre of the condyles of P2 bisected the solar surface. There is moderate ossification of one or both ungular cartilages.

Table 10: Radiographic changes in the digit of endurance racehorses (n=100) - Dorsopalmar foot balance.

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Solar angle								
0= ≤0º	6	*6,0*	5	*5,0*	3	*3,0*	8	*8,0*
1= 0-2º	20	*20,0*	25	*25,0*	11	*11,0*	34	*34,0*
2= 3-10º	69	*69,0*	67	*67,0*	53	*53,0*	83	*83,0*
3= ≥10º	5	*5,0*	3	*3,0*	1	*1,0*	7	*7,0*
Hoof length								
0= ≤7.6 cm	1	*1,0*	1	*1,0*	1	*1,0*	1	*1,0*
1= 7.6-8.9 cm	28	*28,0*	40	*40,0*	26	*26,0*	42	*42,0*
2= ≥8.9 cm	71	*71,0*	59	*59,0*	57	*57,0*	73	*73,0*
Dorso-palmar foot balance: proportions								
0= Bisects sole	3	*3,0*	3	*3,0*	1	*1,0*	5	*5,0*
1= More dorsal	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= More palmar	97	*97,0*	97	*97,0*	95	*95,0*	99	*99,0*
Dorso-palmar foot balance: angles								
0= Equal	30	*30,0*	42	*42,0*	20	*20,0*	52	*52,0*
1= Smaller	68	*68,0*	55	*55,0*	47	*47,0*	76	*76,0*
2= Larger	2	*2,0*	3	*3,0*	1	*1,0*	4	*4,0*

The digital axis was abnormal in 84% (84/100) of left front limbs and 80% (80/100) of right front limbs. 73% (73/100) of horses had abnormal digital axis bilaterally with a prevalence of 91%. This was caused by a hyperextended PIP joint (Figure 15) in 60% (60/100) of left front digits and 58% (58/100) of right front digits with this abnormality being present bilaterally in 51% (51/100) of horses. PIP flexion was also present in 1 right front digit.

The DIP joint was hyperextended in 8% (8/100) of left front digits and in 11% (11/100) of right front digits with this being present bilaterally in 4% (4/100) of horses. The DIP joint was flexed (Figure 14) in 11% (11/100) of left front digits and in 10% (10/100) of right front digits with this being present bilaterally in 5% (5/100) of horses (Table 11).

Figure 14: Lateromedial radiograph of the foot of a 9-year-old cross breed gelding. The hoof pastern axis is abnormal, the proximal interphalangeal joint is hyperextended while the distal interphalangeal joint is hyper-flexed. Note the metallic foreign body in the distal palmar pastern. There is also mild modelling on the dorsodistal tip of the distal phalanx. There is mild ossification of one or both ungular cartilages.

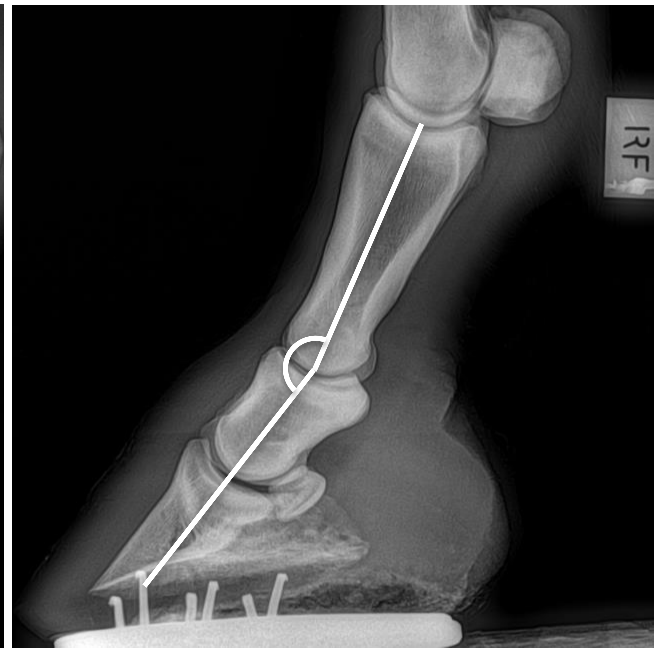

Figure 15: Lateromedial radiograph of the foot of a 9-year-old Arab gelding. The hoof pastern axis is abnormal as the proximal interphalangeal joint is hyperextended. There is mild ossification of one or both ungular cartilages.

Table 11: Radiographic changes in the digit of endurance racehorses (n=100) - Digital axis.

	Left		Right		Bilateral		Prevalence	
	n	***%***	**n**	***%***	**n**	***%***	**n**	***%***
Digital axis Normal								
1= yes	16	*16,0*	20	*20,0*	9	*9,0*	27	*27,0*
2= no	84	*84,0*	80	*80,0*	73	*73,0*	91	*91,0*
Digital axis: PIP joint hyperextended								
1= yes	60	*60,0*	58	*58,0*	51	*51,0*	67	*67,0*
2= no	40	*40,0*	42	*42,0*	33	*33,0*	49	*49,0*
Digital axis: PIP joint flexed								
1= yes	0	*0,0*	1	*1,0*	0	*0,0*	1	*1,0*
2= no	100	*100,0*	99	*99,0*	99	*99,0*	100	*100,0*
Digital axis: DIP joint hyperextended								
1= yes	8	*8,0*	11	*11,0*	4	*4,0*	15	*15,0*
2= no	92	*92,0*	89	*89,0*	85	*85,0*	96	*96,0*
Digital axis: DIP joint flexed								
1= yes	11	*11,0*	10	*10,0*	5	*5,0*	16	*16,0*
2= no	89	*89,0*	90	*90,0*	84	*84,0*	95	*95,0*

Enthesophytes or osteophytes were present on the extensor process of the distal phalanx (Table 12) in 4% (4/100) of left front feet and 3% (3/100) of right front feet with changes being present bilaterally in no horses and had a prevalence of 7%.

Enthesophytes or osteophytes were present on the dorsoproximal P2 in 11% (11/100) of left front digits and 11% (11/100) of right front digits with changes being present bilaterally in 6% (6/100) of horses and had a prevalence of 16%.

No dorsal mineralisation reactions were observed during the current study.

Modelling of the dorsodistal margin of the distal phalanx was seen in 10% (10/100) of left front digits and 8% (18/100) of right front digits with changes being present bilaterally in 4% (4/100) of horses with a prevalence of 14%.

Table 12: Radiographic changes in the digit of endurance racehorses (n=100) - Middle and distal phalanx modelling.

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Enthesophytes/osteophytes - Extensor process of P3								
1= yes	4	*4,0*	3	*3,0*	0	*0,0*	7	*7,0*
2= no	96	*96,0*	97	*97,0*	93	*93,0*	100	*100,0*
Enthesophytes / osteophytes - Dorsal proximal P2								
1= yes	11	*11,0*	11	*11,0*	6	*6,0*	16	*16,0*
2= no	89	*89,0*	89	*89,0*	84	*84,0*	94	*94,0*
P3 dorsal mineralisation reactions								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
Dorsodistal P3 modelling								
1= yes	10	*10,0*	8	*8,0*	4	*4,0*	14	*14,0*
2= no	90	*90,0*	92	*92,0*	86	*86,0*	96	*96,0*

The ratio of the dorsal hoof wall to palmar cortical length of P3 was ≤25% in 24% (24/100) of left front digits and 18% (18/100) of right front digits. This ratio was ≤25% bilaterally in 14% (14/100) of horses with a prevalence of 28% (Figure 16). The ratio was >25% in in one or both feet (Figures 17 and 18) in 86% of horses.

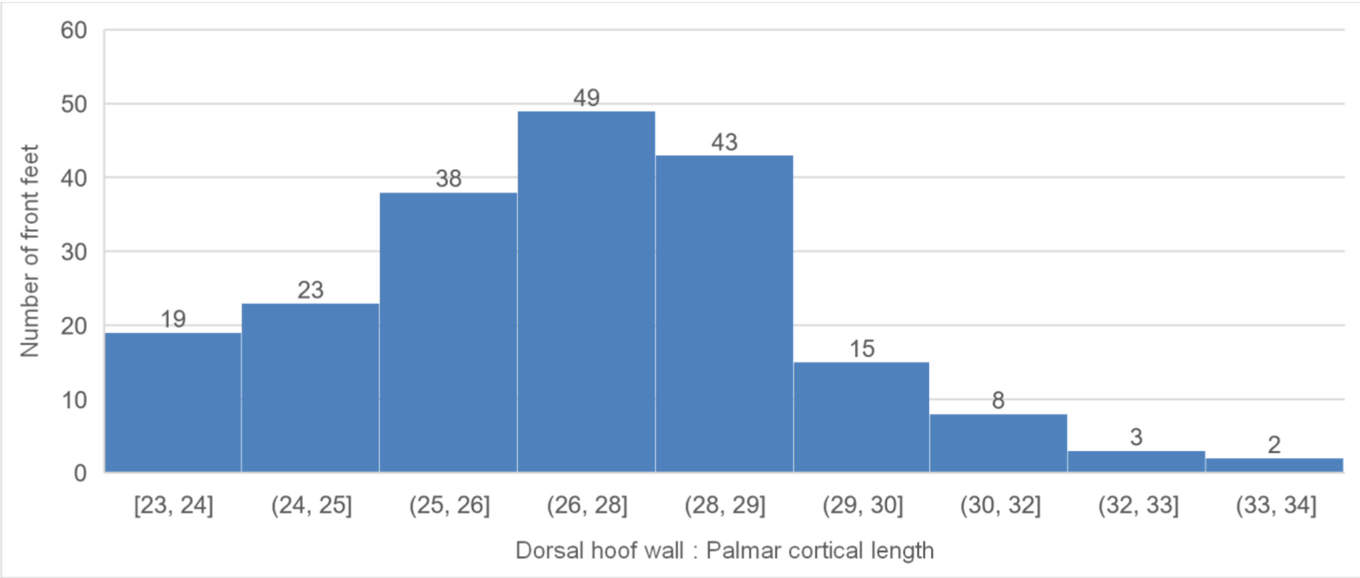

Figure 16: The distribution of the dorsal hoof wall to palmar cortical length of the distal phalanx ratio (%) measured on lateromedial radiographs of the front feet of 100 endurance horses.

No dorsal hoof wall separation, phalangeal or capsular rotation was observed during the current study. No depression immediately proximal to the coronary band was recorded during the current study (Table 13).

Figure 17: Lateromedial radiograph of a sound 8-year-old Arab mare revealing an increased dorsal hoof wall to palmar P3 length ratio.

Figure 18: Lateromedial radiograph of a sound 14-year-old Arab gelding revealing an increased dorsal hoof wall to palmar P3 length ratio.

The vertical distance between the coronary band and the extensor process was measured and ranged from 5.0mm to 17.0mm. The median was 11.0mm, the mean was 10.7mm with a standard deviation of 1.8mm (Figure 19).

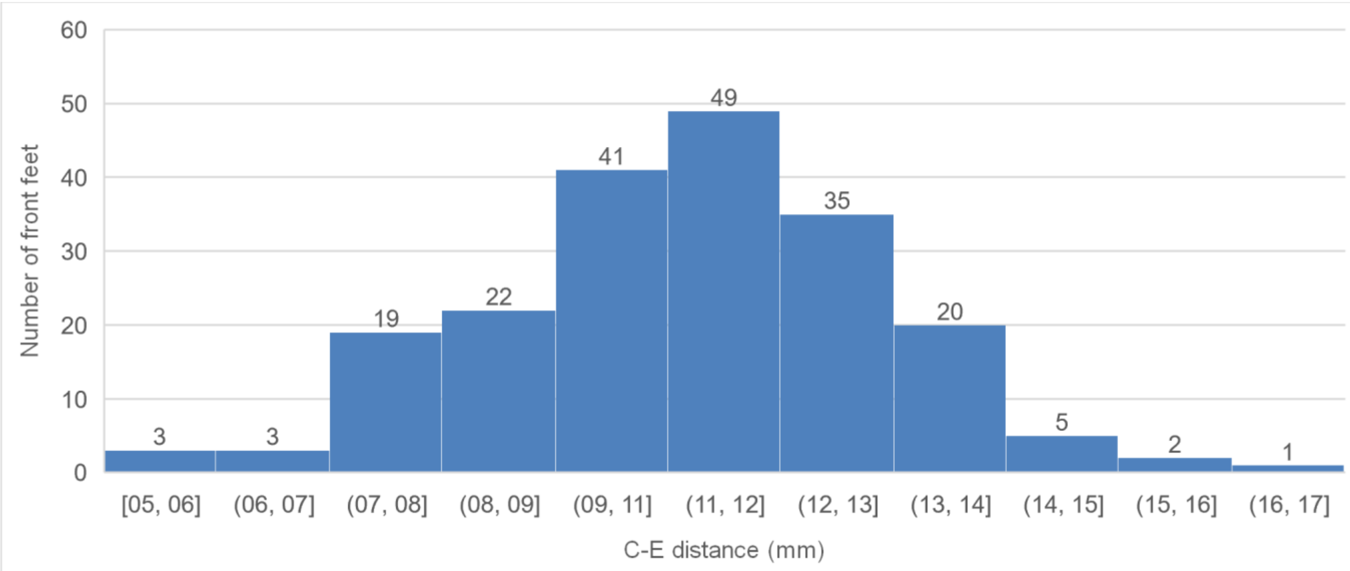

Figure 19: The distribution of the coronary band extensor process (C-E) distance measured on lateromedial radiographs of the front feet of 100 endurance horses.

Table 13: Radiographic changes in the digit of endurance racehorses (n=100) - Indicators of chronic laminitis.

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Ratio: hoof distal phalanx distance to palmar length of distal phalanx (%)								
0= ≤25%	24	*24,0*	18	*18,0*	14	*14,0*	28	*28,0*
1= >25%	76	*76,0*	82	*82,0*	72	*72,0*	86	*86,0*
Dorsal hoof wall separation								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
Phalangeal rotation								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
Capsular rotation								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
Sinking of P3- Depression immediately proximal to coronary band								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*

No fractures of P3 were observed during the current study. A metallic foreign body was seen on the palmar aspect of P2 in one horse. Ungular cartilage ossification measurements are summarised in Table 14 and distribution is indicated in Figure 22.

No ungular cartilage ossification (Grade 0) was observed in 41% (41/100) of left front digits and 41% (41/100) of right front digits with 31% (31/100) of horses having no evidence of ossification in either limb. The prevalence of grade 1 to 5 ossification was 59%. Grade 1 ungular cartilage ossification had a prevalence of 35.6% and was present in 23% (23/100) of left front digits and 24% (24/100) of right front digits with 12% (12/100) of horses having bilateral grade 1 ungular cartilage ossification. Grade 2 ungular cartilage ossification had a prevalence of 24% and was present in 14% (14/100) of left front digits and 15% (15/100) of right front digits with 5% (5/100) of horses having bilateral grade 2 ungular cartilage ossification. Grade 3 ungular cartilage ossification had a prevalence of 21% and was present in 17% (17/100) of left front digits (Figure 21) and 16% (16/100) of right front digits with 12% (12/100) of horses having bilateral grade 3 ungular cartilage ossification. Grade 4 ungular cartilage ossification had a prevalence of 5% and was present in 5% (5/100) of left front digits and 3% (3/100) of right front digits with 3% (3/100) of horses having bilateral grade 4 ungular cartilage ossification. Grade 5 ungular cartilage ossification had a prevalence of 1% and was present in no left front digits and 1% (1/100) of right front digits (Figure 20).

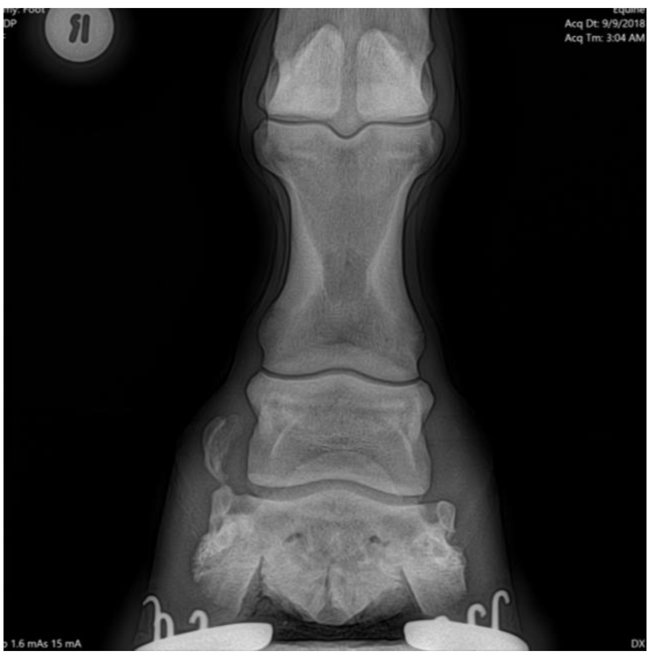

Figure 20: Dorsopalmar radiograph of the RF limb of a 7-year-old Anglo Arab gelding with grade 5 lateral ungular cartilage ossification.

Figure 21: Dorsopalmar radiograph of the LF limb of a 9-year-old cross breed gelding with grade 2 lateral ungular cartilage ossification and grade 3 medial ungular cartilage ossification. Note the metallic foreign body superimposed over the PIP joint (incidental finding) (Same horse as Figure 14).

Table 14: Radiographic changes in the digit of endurance racehorses (n=100) - Ungular cartilage ossification and P3 fractures.

	Left		Right		Bilateral		Prevalence	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Ossification of ungulate cartilages								
0= Grade 0	41	*41,0*	41	*41,0*	31	*31,0*	51	*51,0*
1= Grade 1	23	*23,0*	24	*24,0*	12	*12,0*	35	*35,0*
2= Grade 2	14	*14,0*	15	*15,0*	5	*5,0*	24	*24,0*
3= Grade 3	17	*17,0*	16	*16,0*	12	*12,0*	21	*21,0*
4= Grade 4	5	*5,0*	3	*3,0*	3	*3,0*	5	*5,0*
5= Grade 5	0	*0,0*	1	*1,0*	0	*0,0*	1	*1,0*

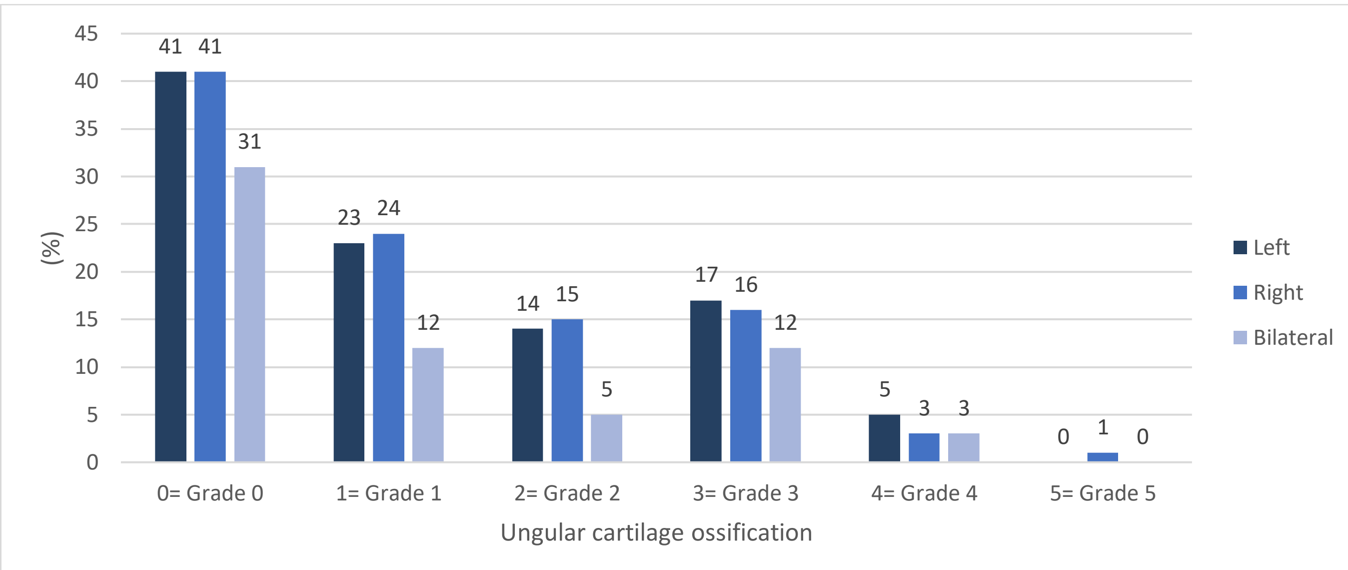

Figure 22: The distribution of ungular cartilage ossification measured on dorsopalmar radiographs of the front feet of 100 endurance horses.

4.3.2 The metacarpophalangeal joint

Metacarpophalangeal soft tissue swelling was observed in 17% (17/100) of left front limbs and 13% (13/100) of right front limbs with 8% (8/100) of horses having bilateral MCP soft tissue swelling making the overall prevalence 22%.

Metacarpophalangeal osteophytes were observed in 22% (22/100) of left front limbs and 16% (16/100) of right front limbs with 10% (10/100) of horses having bilateral MCP osteophytes making the overall prevalence 28%.

Metacarpophalangeal enthesophytes were observed in 2% (2/100) of left front limbs and no right front limbs. The prevalence of MCP enthesophytes was 2%.

Articular fragments on the dorsoproximal aspect of the proximal phalanx were observed in 13% (13/100) of left front limbs and 13% (13/100) of right front limbs with 3% (3/100) of horses having bilateral articular proximal phalanx fragments with an overall prevalence 3% (Figures 25 and 26). No extra-articular fragments on the dorsoproximal aspect of the proximal phalanx were observed during the current study.

No cysts were observed in the dorsodistal MCIII or the proximal aspect of the proximal phalanx during the current study.

A notch in the dorsodistal aspect of MCIII was observed in 17% (17/100) of left front limbs and 13% (13/100) of right front limbs with 7% (7/100) of horses having bilateral MCIII notches making the prevalence 23%. A lucency in the dorsodistal aspect of MCIII was observed in 1% (1/100) of right front limbs. A fragment of the dorsodistal aspect of MCIII was observed in 2% (2/100) of left front limbs and 1% (1/100) of right front limbs with no horses having bilateral MCIII fragments making the prevalence 3%. No flattening of the dorsodistal aspect of MCIII was observed in the current study.

No flattening of the distal sagittal ridge of MCIII was observed in the current study. Lucency of the distal sagittal ridge was observed in 1% (1/100) of left front limbs and no right front limbs.

Flattening of the distal palmar MCIII condyles was observed in 2% (2/100) of left front limbs and 3% (3/100) of right front limbs with no horses having bilateral flattening. No lucency of the distal palmar MCIII condyles were observed in the current study. No sclerosis of the distal palmar MCIII condyles was observed.

Palmar supracondylar lysis was observed in the distal MCIII and was rated as slight in 34% (34/100) of left front limbs and 34% (34/100) of right front limbs with 24% (24/100) of horses having slight lysis bilaterally making the prevalence 44%. The lysis was rated as extreme in 5% (5/100) of left front limbs and 5% (5/100) of right front limbs with 3% (3/100) of horses having extreme lysis bilaterally making the prevalence 7% (Figures 23 and 24).

Metacarpophalangeal changes are recorded in Tables 15 and 16.

Figure 23: Flexed lateromedial radiograph of a RF fetlock in a 14-year-old Anglo Arab gelding with palmar and dorsal supracondylar lysis. There is also modelling of the dorsodistal aspect of the proximal sesamoid bones.

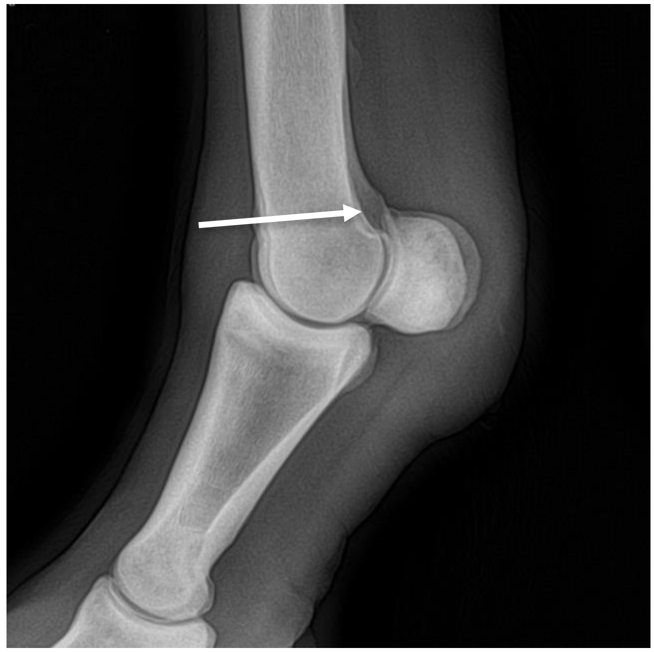

Figure 24: Lateromedial radiograph of a RF fetlock in a 9-year-old Arab gelding with mild palmar supracondylar lysis.

Table 15: Radiographic changes in the MCP joint of endurance racehorses (n=100).

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	***%***	**n**	***%***	**n**	***%***	**n**	***%***
MCP Soft tissue swelling								
1= yes	17	*17,0*	13	*13,0*	8	*8,0*	22	*22,0*
2= no	83	*83,0*	87	*87,0*	78	*78,0*	92	*92,0*
MCP Osteophytes								
1= yes	22	*22,0*	16	*16,0*	10	*10,0*	28	*28,0*
2= no	78	*78,0*	84	*84,0*	72	*72,0*	90	*90,0*
MCP Enthesopytes								
1= yes	2	*2,0*	0	*0,0*	0	*0,0*	2	*2,0*
2= no	98	*98,0*	100	*100,0*	98	*98,0*	100	*100,0*
Fragment dorsoproximal proximal phalanx								
0= None	87	*87,0*	87	*87,0*	77	*77,0*	97	*97,0*
1= Articular	13	*13,0*	13	*13,0*	3	*3,0*	23	*23,0*
2= Non-articular	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*

Table 16: Radiographic changes in the MCP joint of endurance racehorses (n=100) – continued.

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	***%***	**n**	***%***	**n**	***%***	**n**	***%***
Cyst distal MC3 or proximal proximal phalanx								
1= yes	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= no	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
Changes dorsodistal aspect MC3								
0= None	81	*81,0*	85	*85,0*	75	*75,0*	91	*91,0*
1= Notch	17	*17,0*	13	*13,0*	7	*7,0*	23	*23,0*
2= Lucency	0	*0,0*	1	*1,0*	0	*0,0*	1	*1,0*
3= Loose fragment	2	*2,0*	1	*1,0*	0	*0,0*	3	*3,0*
4= Flattening	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
Change distal sagittal ridge of MC3								
0= None	99	*99,0*	100	*100,0*	99	*99,0*	100	*100,0*
1= Flat	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= Lucency	1	*1,0*	0	*0,0*	0	*0,0*	1	*1,0*
Change distal palmar MC3 condyles								
0= None	98	*98,0*	97	*97,0*	95	*95,0*	100	*100,0*
1= Flat	2	*2,0*	3	*3,0*	0	*0,0*	5	*5,0*
2= Lucency	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
3= Sclerosis	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
Palmar supracondylar lysis MC3								
0= None	61	*61,0*	61	*61,0*	53	*53,0*	69	*69,0*
1= Slight	34	*34,0*	34	*34,0*	24	*24,0*	44	*44,0*
2= Mod/extreme	5	*5,0*	5	*5,0*	3	*3,0*	7	*7,0*

Figure 25: DLPMO radiograph of a 12yo Arab stallion. Note the articular fragment at the dorsoproximal aspect of the proximal phalanx.

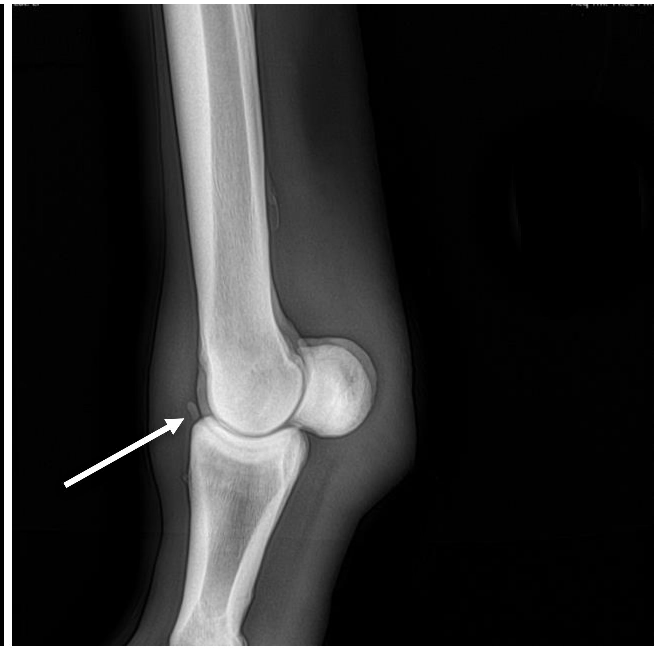

Figure 26: Lateromedial radiograph of a 13-year-old Arab gelding with an articular fragment on the dorsoproximal aspect of the proximal phalanx.

Radiographic changes of the PSB are recorded in Table 17 and 18.

Proximal sesamoid bone elongation was observed in 1% (1/100) of left front limbs but in no right front limbs. The PSB had an irregular border in 22% (22/100) of left front limbs and 20% (20/100) of right front limbs with 12% (12/100) of horses having irregular sesamoid borders bilaterally. The prevalence was 30%. No proximal sesamoid bone fractures were observed during the current study.

Osteophytes of the PSB were observed 14% (14/100) of left front limbs and 8% (8/100) of right front limbs with 5% (5/100) of horses having osteophytes bilaterally. The prevalence was 17%.

One circular proximal sesamoid lucency were observed 1% (1/100) of left front limbs and no right front limbs. Two circular proximal sesamoid lucencies were observed 2% (2/100) of left front limbs and 6% (6/100) of right front limbs with 1% (1/100) of horses having two lucencies bilaterally making the prevalence 7%. Three circular proximal sesamoid lucencies were observed 1% (1/100) of left front limbs and 1% (1/100) of right front limbs but no horses were observed to have three or more lucencies bilaterally making the prevalence 2%.

One vascular channel was observed in the PSB in 19% (19/100) of left front limbs and 28% (28/100) of right front limbs with 7% (7/100) of horses having only one vascular channel bilaterally making the prevalence 40%. Two vascular channels were observed in the PSB in 28% (28/100) of left front limbs and 23% (23/100) of right front limbs with 11% (11/100) of horses having two vascular channels bilaterally making the prevalence 40%. Three vascular channels were observed in the PSB in 16% (16/100) of left front limbs and 15% (15/100) of right front limbs with 6% (6/100) of horses having three vascular channels bilaterally making the prevalence 25%. More than three vascular channels were observed in the PSB in 12% (12/100) of left front limbs and 8% (8/100) of right front limbs with 5% (5/100) of horses having more than three vascular channels bilaterally making the prevalence 15%. One irregular vascular channel was observed in one limb left front limb.

Table 17: Radiographic changes in the PSB of endurance racehorses (n=100).

	Left		**Right**		**Bilateral**		**Prevalence**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Sesamoid elongation								
1= yes	1	*1,0*	0	*0,0*	0	*0,0*	1	*1,0*
2= no	99	*99,0*	100	*100,0*	99	*99,0*	100	*100,0*
Irregular shape / border								
1= yes	22	*22,0*	20	*20,0*	12	*12,0*	30	*30,0*
2= no	78	*78,0*	80	*80,0*	70	*70,0*	88	*88,0*
Sesamoid fracture								
0= None	100	*100,0*	100	*100,0*	100	*100,0*	100	*100,0*
1= Apical	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
2= Abaxial	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
3= Basal	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
4= Midbody	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
5= Comminuted	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
Osteophytes								
1= yes	14	*14,0*	8	*8,0*	5	*5,0*	17	*17,0*
2= no	86	*86,0*	92	*92,0*	83	*83,0*	95	*95,0*

Table 18: Radiographic changes in the PSB of endurance racehorses (n=100) – continued.

	Left		Right		Bilateral		Prevalence	
	n	***%***	**n**	***%***	**n**	***%***	**n**	***%***
Sesamoid circular lucencies								
0= 0 Lucencies	96	*96,0*	93	*93,0*	90	*90,0*	99	*99,0*
1= 1 Lucencies	1	*1,0*	0	*0,0*	0	*0,0*	1	*1,0*
2= 2 Lucencies	2	*2,0*	6	*6,0*	1	*1,0*	7	*7,0*
3= 3 Lucencies	1	*1,0*	1	*1,0*	0	*0,0*	2	*2,0*
Sesamoid total vascular channels								
0= None	22	*22,0*	25	*25,0*	11	*11,0*	36	*36,0*
1= 1	19	*19,0*	28	*28,0*	7	*7,0*	40	*40,0*
2= 2	28	*28,0*	23	*23,0*	11	*11,0*	40	*40,0*
3= 3	16	*16,0*	15	*15,0*	6	*6,0*	25	*25,0*
4= >3	15	*15,0*	9	*9,0*	5	*5,0*	19	*19,0*
Sesamoid regular vascular channels								
0= None	27	*27,0*	27	*27,0*	13	*13,0*	41	*41,0*
1= 1	20	*20,0*	28	*28,0*	7	*7,0*	41	*41,0*
2= 2	27	*27,0*	23	*23,0*	10	*10,0*	40	*40,0*
3= 3	14	*14,0*	14	*14,0*	5	*5,0*	23	*23,0*
4= >3	12	*12,0*	8	*8,0*	5	*5,0*	15	*15,0*
Sesamoid irregular vascular channels								
0= None	99	*99,0*	100	*100,0*	99	*99,0*	100	*100,0*
1= 1	1	*1,0*	0	*0,0*	0	*0,0*	1	*1,0*
2= 2	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
3= 3	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*
4= >3	0	*0,0*	0	*0,0*	0	*0,0*	0	*0,0*

4.4 INTER-RATER RELIABILITY

Inter-rater reliability was investigated by calculating Fleiss Kappa for each variable after converting each variable into binominal categories. Kappa values and their P-values are listed in appendix D.

Raters (YS, CR, MR) agreed on dorsopalmar foot balance, and most measurements of digital axis normality although they did not agree on digital axis normality itself. They also agreed on the presence of enthesophytes or osteophytes on the extensor process of P3 and the dorsoproximal aspect of P2 as well as modelling on the dorsodistal aspect of P3. No statistically significant agreement was calculated for toe and heel angle measurements, digital axis normality or dorsal mineralisation reactions on P3.

No agreement existed for indications of laminitis (dorsal hoof wall separation, phalangeal rotation and capsular rotation), the presence of MCP cysts or changes to the distal palmar MC3 (flattening, lucency or sclerosis). Raters reached better agreement for changes to the distal dorsal aspect of MC3 (notch and fragmentation). Agreement was calculated for ungular cartilage ossification when absent and moderate, but no agreement existed for grade one ossification.

Raters agreed on MCP soft tissue swelling, osteophytes and enthesophytes (left) as well as the absence of a dorsoproximal proximal phalangeal fragment. They also agreed on the severity of palmar supracondylar lysis and irregularities on the sesamoid bones. No agreement existed for sesamoid elongation, changes to the distal palmar MC3 condyles (flattening, lucency, sclerosis) and circular sesamoid lucencies. Sesamoid vascular channels were difficult to assess according to the raters and very little agreement was recorded (Appendix D).

Due to the low prevalence of certain variables Kappa and thus agreement could not be calculated for phalangeal rotation (left), sinking of P3, P3 fractures, sclerosis of the distal palmar MC3 (right) and sesamoid fractures (left).

CHAPTER 5: DISCUSSION

The current study population consisted of 100 endurance racehorses competing in the 2018-2019 endurance season and was similar to international endurance populations with regard to breed and sex distribution (Nagy et al., 2017). The majority of the sample population was Arab (46%). This is in agreement with previously published population distributions where the majority of horses were also Arab (48.9%) (Nagy et al., 2017). In the same study by Nagy et al. (2017), the median age of competitive endurance racehorses was 12 years old. This is higher than the current study with a median age of 8 years old (5-17 years old).

No studies exist describing radiographic changes in endurance racehorses, thus findings in the current study are mostly compared to studies describing radiographic changes in Thoroughbred racehorses. It must be noted that horses in such studies are significantly younger when compared to horses in the current study (Contino et al., 2012; Furniss et al., 2011; Kane et al., 2003; Smit, 2014). Further, one should keep in mind that horses entered into an endurance race (as in the current study) are generally free from apparent lameness or overt clinical signs of orthopaedic disease. The prevalence of radiographic changes recorded in the current study may thus not be a true reflection of the larger endurance racehorse population.

5.1 The digit

No horse had a medial or lateral solar thickness less than 10mm. The prevalence of thin soles (10-14mm solar thickness) was higher on the medial aspect (15.2%) when compared to the lateral aspect (7.6%). In a study comparing digital radiography to magnetic resonance imaging (MRI) measurements in a mixed population of horses (Grundmann et al., 2015), the mean lateral solar thickness when measured on digital radiographs was 20.7mm (σ=4.4) while the mean medial solar thickness was 18.7mm (σ=4.7). The lateral aspect of the sole was thus significantly thicker than the medial aspect owing to different thicknesses of the strata externum and medium; this disparity was noted on DR and MRI measurements (Grundmann et al., 2015). In the current study medial solar thickness was most prevalent in the 15-19mm category (59.4%) while lateral solar thickness was most prevalent in the ≥20mm category (73.6%). Lateral solar length thus appears to be longer than medial solar length in the majority of horses in the current study. This could be due to uneven weight distribution. According to O'Grady (2014) decreased hoof growth is one of the three consequences of increased load on a specific area of the hoof capsule. Abnormal forces or weight distribution on a specific proportion of the foot will over time cause hoof capsule distortion which is related to lameness in the front limb (O'Grady, 2014) as it is associated with conditions like sheared heels, distorted hoof walls and hoof cracks (O'Grady and Poupard, 2003). The uneven weight distribution is also supported by increased radiopharmaceutical uptake on scintigraphy and lower signal intensity in MR images in the medial than in the lateral palmar process of the distal phalanx (Nagy et al., 2008).

The prevalence of pedal inversion (solar angle <0º) was 8% and is similar to findings by Smit (2014) describing a prevalence of 8.7% in Thoroughbred yearlings (n=566). The prevalence of horses with a solar angle ≤2º but above horizontal was 34%. Flat feet (≤2º) and pedal inversion has been associated with more proximal sites of pain (i.e. proximal suspensory desmitis) causing lameness (Dyson and Ross, 2003). According to Eggleston (2012) even minimal flattening of the solar angle is related to lameness. Normal solar angles between 3º and 10º (Butler et al., 2017) had a prevalence of 83%, with 53% of horses having normal solar angles bilaterally. A study of 255 Thoroughbred yearlings by Furniss et al. (2011) found the average solar angle to be 2.4° and 2.8° of the RF (right front) and LF (left front) feet respectively. This variation could be due to breed conformation. Solar angles larger than 10º had a prevalence of 7%.

The majority of horses in the current study had evidence of "long toe low heel" syndrome as defined by O'Grady and Poupard (2003). A vertical line drawn distally from the condyle of P2 bisected the solar surface more palmar bilaterally in 95% of horses. Further, the angle of heel to the ground was smaller than the angle of the dorsal hoof capsule to the ground in 47% of horses bilaterally and 57% of horses had bilateral dorsal hoof wall length larger than that expected for their size. This could be due to breed conformation, general poor hoof care and farriery or the belief that horses with longer toes also have thicker soles and are thus less likely to concussion injuries and solar bruising. Foot conformation is also believed to change between shoeings (Eggleston, 2012) with decreases in hoof angles, increases in toe length and more palmar centre of pressure being recorded by Wilson et al. (2016). Poor dorsopalmar balance contributes remarkably to the long toe/underrun heel conformation and the altered biomechanics that it causes. Long toes delay break over causing an excessive pull on the DDFT and associated structures and is associated with lameness (O'Grady and Poupard, 2003).

The digital axis of the majority of horses (91%) in the current study was abnormal with 73% of horses having abnormal digital axis bilaterally. Hyperextension of the PIP joint was the most common abnormality (67%) occurring in 60% of left front digits, 58% of right front digits and bilaterally in 51% of horses. This is higher than in a study looking at Thoroughbred yearlings (n=240) were hyperextension of the PIP joint was found in 15.1% and 18.9% of left and right front digits respectively (Furniss et al., 2011) (Figure 27). Again, this could be due to breed conformation or poor farriery but warrants further investigation.

During the current study the DIP joint was hyperextended in 8% of left front digits, 11% of right front digits and 4% of horses bilaterally. This is similar previous findings by Furniss et al. (2011) who reported 7.6% and 9.7% in left and right DIP joints respectively.

The DIP joint was flexed in 11% of left front digits, 10% of right front digits and bilaterally in 5% of horses in the current study while Furniss et al. (2011) reported a lower prevalence of DIP flexion both left (0.4%) and right (0.8%).

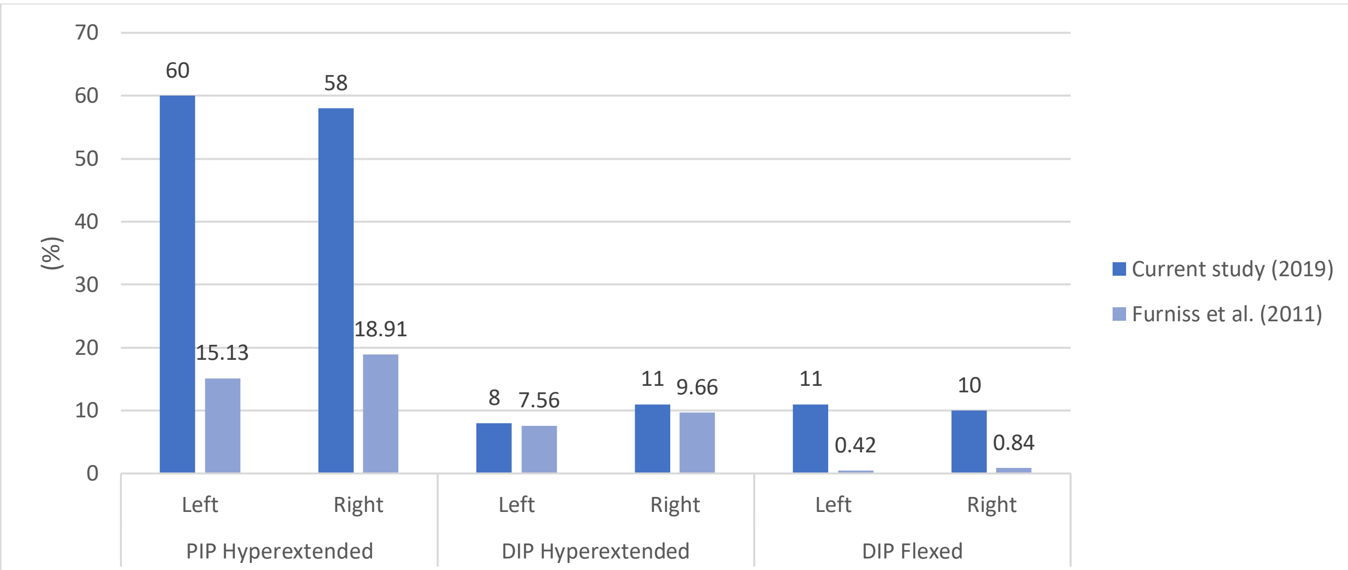

Figure 27: The prevalence of digital axis abnormalities when comparing authors.

The prevalence of enthesophytes or osteophytes on the extensor process of P3 was 7% (left (4%) and right (3%)) with no horses being affected bilaterally. Furniss et al. (2011) reported similar findings (3% and 3.8% in left and right feet respectively). According to Smit (2014), enthesophytes in this area may be a source of pain and lameness.

The prevalence of enthesophytes or osteophytes on the dorsoproximal P2 was 11% in left front digits, 11% in right front digits and 6% of horses bilaterally. This is four times higher than findings reported in young horses (Figure 28). A prevalence of 1.2% and 2.5% in left and right digits respectively were reported in two-year-old quarter horses (n=162) (Contino et al., 2012) and a prevalence of 2.1% and 2.5% in left and right digits respectively in Thoroughbred yearlings (n=240) (Furniss et al., 2011). Caution should be applied when comparing young horses such as in the studies by Contino et al. (2012) and Furniss et al. (2012) with older horses as in the current study. Older horses have most likely undergone more training and riding and are thus more likely to show radiographic evidence of degenerative changes associated with athletic wear. The clinical significance of these changes warrants further investigation. According to Smit (2014), osteophytes often occur in the presence of articular cartilage disease and is thus of clinical significance. Entheseous new bone however does not imply osteoarthritis, but often occurs when osteoarthritis is present and must thus be interpreted with caution (Dyson and Ross, 2003).

No dorsal mineralisation reactions were reported during the current study. Furniss et al. (2011) also reported a low prevalence of 0.8% and 0.4% in left and right digits respectively.

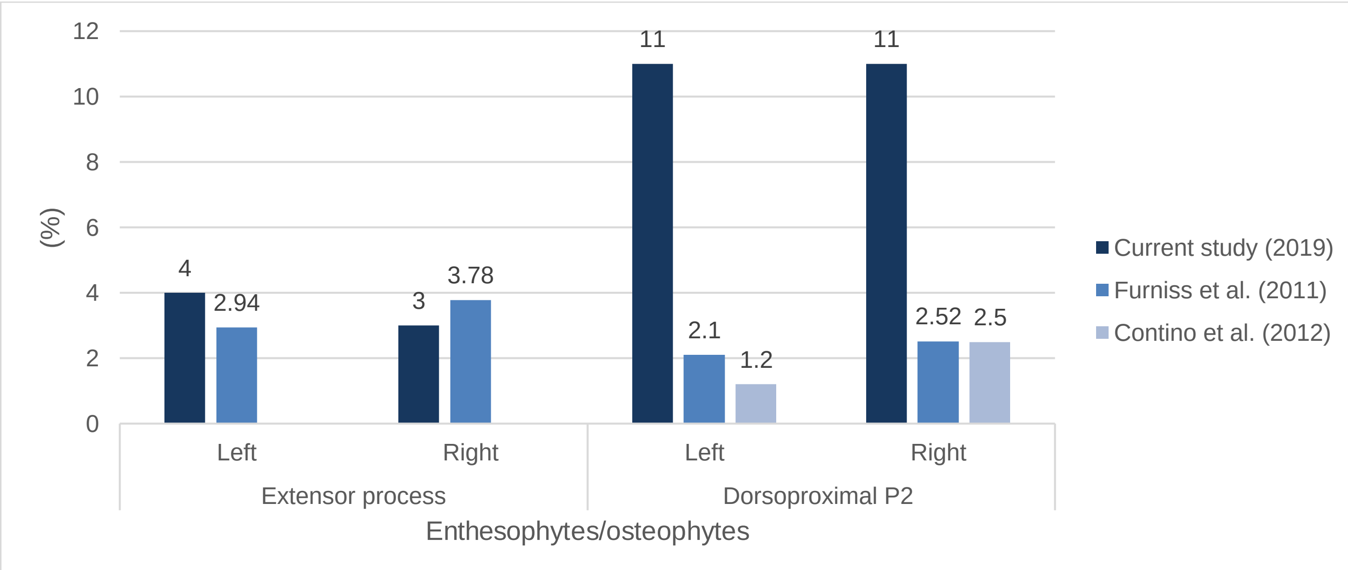

Figure 28: The prevalence of enthesophytes and osteophytes on the extensor process of P3 and the dorsoproximal aspect of P2 when comparing authors.

Dorsal hoof width as a percentage of the palmar cortical length of P3 was calculated as a ratio. Authors advocate that this ratio should be <25% ±3% (Butler et al., 2017). In their opinion a ratio >25% could be indicative of chronic laminitis. During the current study the ratio ranged from 22.6% to 33.3% and had a mean of 27.1% (σ=2.1). The prevalence of a ratio >25% was 86%.

The prevalence of other indicators of chronic laminitis was low. Modelling of the dorsodistal margin of P3 had a prevalence of 14%. No dorsal hoof wall separation, phalangeal or capsular rotation or a depression immediately proximal to the coronary band was observed during the current study. This raises the question on the reliability and accuracy of the dorsal hoof wall to palmar cortical length ratio when evaluating this population for laminitis. When a cut-off ratio of 28% is used as an indicator for chronic laminitis, 32% of feet (64/200) would still be classified as having chronic laminitis. When 30% is used 7% of front feet (14/200) would be classified as laminitic. It is possible that other radiographic signs of laminitis could have been under reported in the current study. The possibility exists that dorsal hoof wall thickening has an alternative aetiology in endurance horses and that laminitis is not the only cause of an increased dorsal hoof wall to palmar cortical length ratio in this population. A full musculoskeletal evaluation would be needed to make conclusions regarding the clinical significance of this finding.

The vertical distance between the coronary band and the extensor process was measured and ranged from 5.0mm to 17.0mm. The median was 11.0mm, the mean was 10.7mm with a standard deviation of 1.8mm. This is in line with an article on radiographic assessment of laminitis (Sherlock and Parks, 2013) that state normal CE distance in the front feet of sound horses to be -2 to 15mm. It is however, higher than previously published means of 3.3-6.9mm in various breeds (Belknap and Geor, 2016; Grundmann et al., 2015). Care must be taken in interpretation of these values as there is marked individual (breed and size) variability.

The prevalence of ungular cartilage ossification (grade 1-5) was 69% and although the clinical significance thereof remains controversial it is generally reported that extensive (grade 4 and 5) ossification or severe lateromedial asymmetrical ossification may be predisposing factors for fracture, contribute to foot-related pain and is thus of clinical significance (Butler et al., 2017; Jones and Dyson, 2015). The prevalence of grade 4 and 5 ungular cartilage ossification was 5% and 1% respectively. Asymmetrical ungular cartilage ossification was not assessed in the current study.

No fractures of P3 were observed during the current study. This is most likely due to the fact that horses presented to endurance rides are generally free from obvious lameness. According to Ross (1998) fractures are not single-event injuries and horses typically show some degree of lameness prior to fracture. The prevalence of this radiographic finding would thus be under reported in the general population of endurance horses.

5.2 THE METACARPOPHALANGEAL JOINT

The prevalence of MCP osteophytes was 28% with 10% of horses having bilateral MCP osteophytes. MCP joint osteophytes on the medial and lateral articular margins of the proximal phalanx indicate degenerative joint disease and may be associated with lameness (Butler et al., 2017). The prevalence of MCP entheseophytes was 2% with no horses having bilateral MCP entheseophytes. Enthseophytes do not necessarily indicate degenerative joint disease but is often seen in conjunction with it (Butler et al., 2017). This raises the question whether these horses suffered previous lameness episodes or have undiagnosed subclinical osteoarthritis.

The prevalence of articular dorsoproximal fragments of the proximal phalanx was 23%. Articular fragments were present in 13% in left front limbs, 13% in right front limbs and 3% of horses had bilateral dorsoproximal articular proximal phalangeal fragments. This is higher than articular fragments reported by previous authors (0.3%, 0.3% and 0% respectively in 566 Thoroughbred yearlings (Smit, 2014) and 0.4%, 1.6% and 0% respectively in 255 in Thoroughbred yearlings (Furniss et al., 2011)(Figure 29)). According to Butler et al. (2017), small well-rounded fragments on the medial dorsoproximal proximal phalanx a common finding and not necessarily associated with clinical findings. The exact aetiology of these fragments are unknown but they may be a manifestation of developmental orthopaedic disease (Butler et al., 2017; Declercq et al., 2008). Although they are only sometimes associated with joint effusion, the majority of horses show arthroscopic evidence of synovitis and cartilage fibrillation (Butler et al., 2017). The presence of more than one fragment or fragments in horses older than seven years of age (such as in the current study) were risk factors associated with lameness (Declercq et al., 2008). The lower prevalence in young Thoroughbreds may be explained by pre-sale arthroscopic removal of fragments.

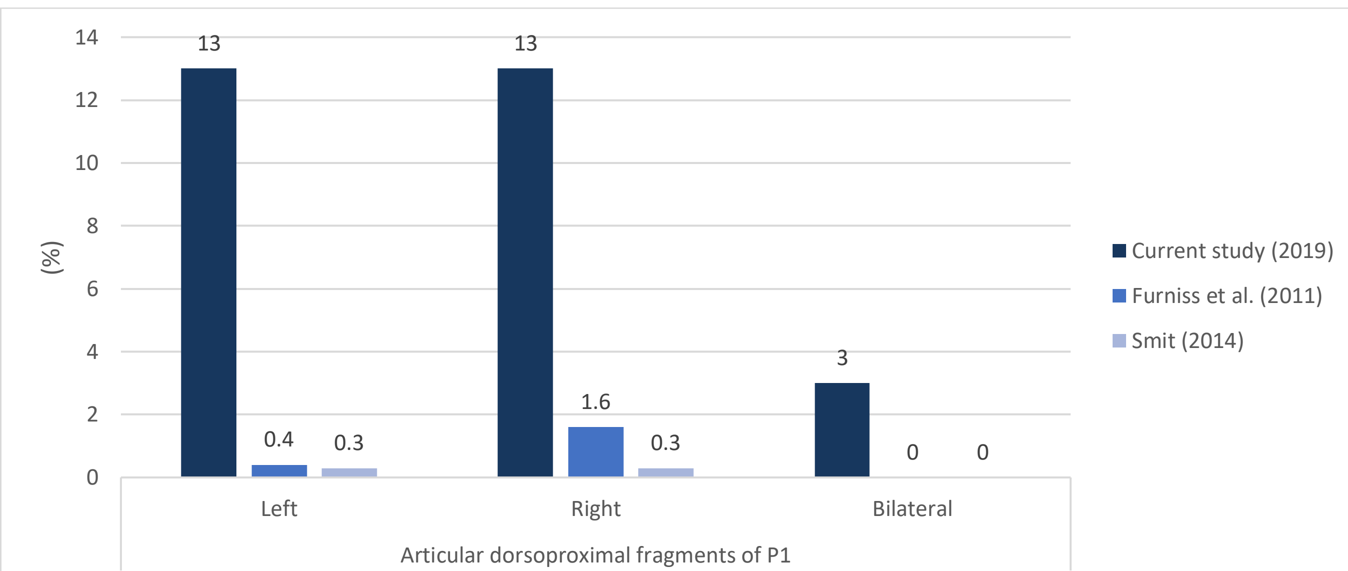

Figure 29: Articular dorsoproximal proximal phalangeal fragments (%) when comparing authors.

No non-articular fragments on the dorsoproximal proximal phalanx were observed during the current study. This is similar to the prevalence in thoroughbreds reported to be 0% (Furniss et al., 2011) and 0.3% (Smit, 2014) in recent years.

No cysts were observed in the dorsodistal MCIII or proximal phalanx during the current study. This is similar to findings by Contino et al. (2012) who reported a prevalence of less than 1.0% in both one-year-old (n=199) and two-year-old (n=162) quarter horses destined for cutting, (Miyakoshi et al., 2017) who reported 0.4% prevalence in Japanese 2-year-old Thoroughbreds (n=850) as well as Smit (Smit, 2014) who reported the prevalence in Thoroughbred yearlings to be 0.4%. According to Dyson (2003), SCL occur on the weight bearing surface of the MCP joint (mostly on the medial MCIII condyle) and horses usually show obvious lameness exacerbated by distal limb flexion. Horses presenting to and competing in endurance races are generally sound. This may explain the low prevalence of lesions recorded during the current study. These lesions carry a poor prognosis (Butler et al., 2017).

Changes to the dorsodistal aspect of MCIII was present in 25% of horses (Table 19). A notch was the most common change with a prevalence of 23%, followed by the presence of a fragment (3%), lucency (1%) and flattening (0%). A higher prevalence of lucency and flattening and a lower prevalence of notches and loose fragments were reported in Thoroughbred yearlings (Smit, 2014). A lower prevalence of notches and loose fragments but a higher prevalence of flattening was reported in young quarter horses (Contino et al., 2012)(Figure 30). Again, this could be explained by pre-sale arthroscopic removal of fragments.

Table 19: Changes to dorsal aspect of distal MCIII study result comparison.

	Current study (2019) n=100 5- to 17-year-old Mixed population	**Smit (2014)** n=566 one-year-old Thoroughbreds	**Contino *et al.* (2012)** n=199 one-year-old Quarter horses	**Contino *et al.* (2012)** n=162 two-year-old Quarter horses
1=Notch	23.0%	20.3%	4.0%	3.7%
2=Lucency	1.0%	8.5%	NA	NA
3=Loose fragment	3.0%	0.2%	1.5%	0%
4=Flattening	0.0%	0.9%	12.6	7.4%

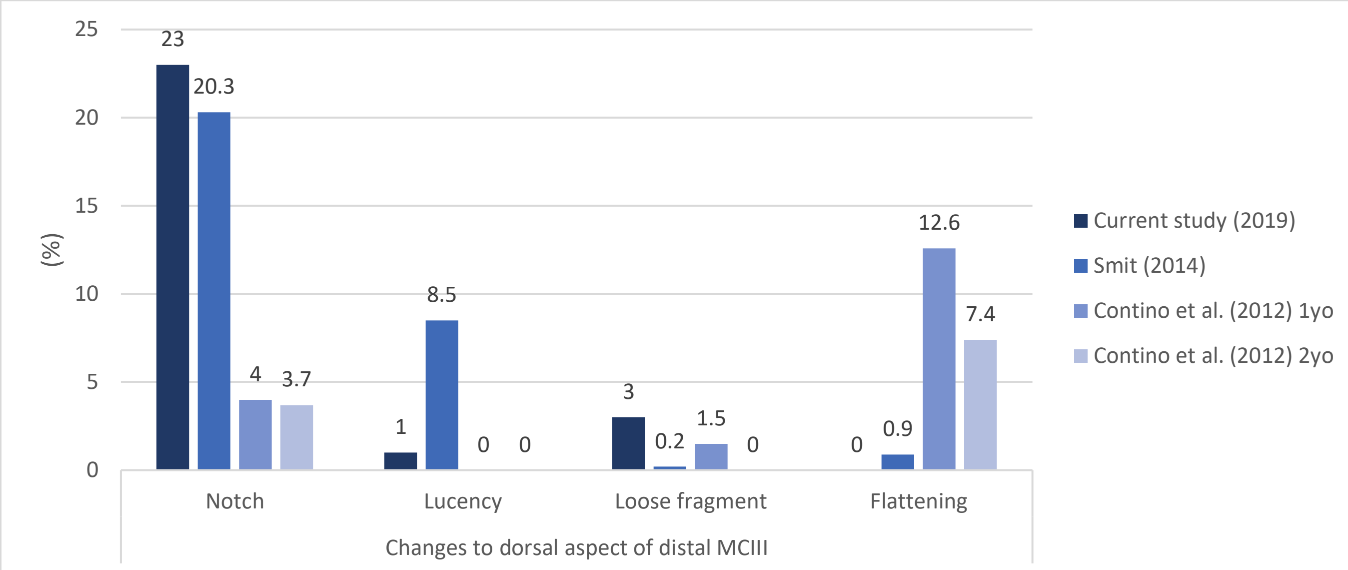

Figure 30: Changes to distal MCIII (%) study result comparison.

No flattening of the distal sagittal ridge of MCIII was observed in the current study population contrary to findings in Thoroughbred yearlings (Smit, 2014) where the prevalence was 13.6%. The prevalence of distal sagittal ridge lucency was 1% while 19.4% was reported in Thoroughbred yearlings (Smit, 2014). Osteochondral abnormalities present after eight months of age are regarded as permanent (Dik et al., 1999; Mccoy, 2013). It is possible that this population of horses show less osteochondral abnormalities due to the fact that they are generally not fed high energy diets during the fast-growing period and start ridden work at a much later stage when compared to most Thoroughbreds. This may also be due to breed difference.

The prevalence of flattening of the distal palmar MCIII condyles was 5% similar to that reported in Thoroughbred yearlings (6.0%) (Smit, 2014). No lucency or sclerosis of the distal palmar MCIII condyles was observed which is consistent with findings in Thoroughbred yearlings (Smit, 2014). These changes did not relate to poor racing performance in Thoroughbred yearlings (Kane et al., 2003).

The presence of palmar supracondylar lysis was graded subjectively, and the overall prevalence was 47%. It is associated with the fibrous proliferation of the synovial membrane which occurs during degenerative joint disease (Butler et al., 2017).

The prevalence of mild supracondylar lysis was 34% in both left and right front limbs while 24% of horses had mild lysis bilaterally. This is significantly higher than findings by Contino et al. (2012) who reported a prevalence of mild supracondylar lysis in one-year-old (n=199) quarter horses to be 10.1% in the left MCIII and 4.5% in the right. He reported a prevalence of 7.4% and 4.5% respectively in two-year-old quarter horses (n=162). It is also higher than findings in Thoroughbred yearlings (Smit, 2014) where the prevalence of mild supracondylar lysis was reported to be 19.3% in the left MCIII and 19.1% in the right.

Moderate to extreme lyses had a prevalence of 5% in both left and right front limbs and 3% horses had extreme lysis bilaterally in the current study. This again in higher than prevalence reported by Contino et al. (2012) were prevalence of extreme supracondylar lysis in one-year-old (n=199) quarter horses was 1.5% in the left MCIII and 1.0% in the right. He reported a prevalence of 2.4% and 1.9% respectively in two-year-old quarter horses (n=162). A higher prevalence of moderate to extreme supracondylar lysis was reported in Thoroughbred yearlings (Smit, 2014) with 10.5% of left legs and 10.8% of right MCIII fell into this category (Table 20).

Overall mild supracondylar lysis is more prevalent in the current study (Figure 31) of endurance racehorses when compared to younger horses while moderate to severe palmar supracondylar lysis is most prevalent in young Thoroughbreds. This is most likely due to the repetitive and speed-related trauma young Thoroughbreds are subjected to, while horses in the current study are subjected to a larger amount of lower-speed exercise. When one considers that the prevalence of other indicators of osteoarthritis, such as MCP osteophytes, is also high in the current study; mild supracondylar lysis could be another indication of subclinical or early osteoarthritis in this population. This could also be due to the higher mean horse age of the sample population, the higher amount of kilometres these horses have completed both in competition and training, the higher weight of endurance riders when compared to flat racing jockeys or, the nature of the discipline itself or the terrain these horses are expected to compete on. The possibility does exist that supracondylar lysis is not caused by synovial effusion due to osteoarthritis but has a different aetiology in endurance horses. Endurance horses may for example undergo adaptive synovial thickening due to the repetitive nature and intensity of exercise these horses are subjected to. This change may be adaptive or protective and not necessarily pathological.

Table 20: Supracondylar lysis study result comparison.

	Current study (2019) n=100 5 to 17-year-old Mixed population			**Smit (2014)** n=566 one-year-old Thoroughbreds			**Contino *et al.* (2012)** n=199 one-year-olds Quarter horses			**Contino *et al.* (2012)** n=162 two-year-olds Quarter horses		
	L	R	Pr	L	R	Pr	L	R	Pr	L	R	Pr
Mild / Slight (%)	36.9	37.5	46.9	19.3	19.1	19.3	10.1	4.5	11.1	7.4	4.3	8.6
Moderate / Severe (%)	5.6	5.6	6.9	10.5	10.8	10.2	1.5	1.0	2.5	2.4	1.9	3.7

L = Left; R = Right; Pr = Prevalence

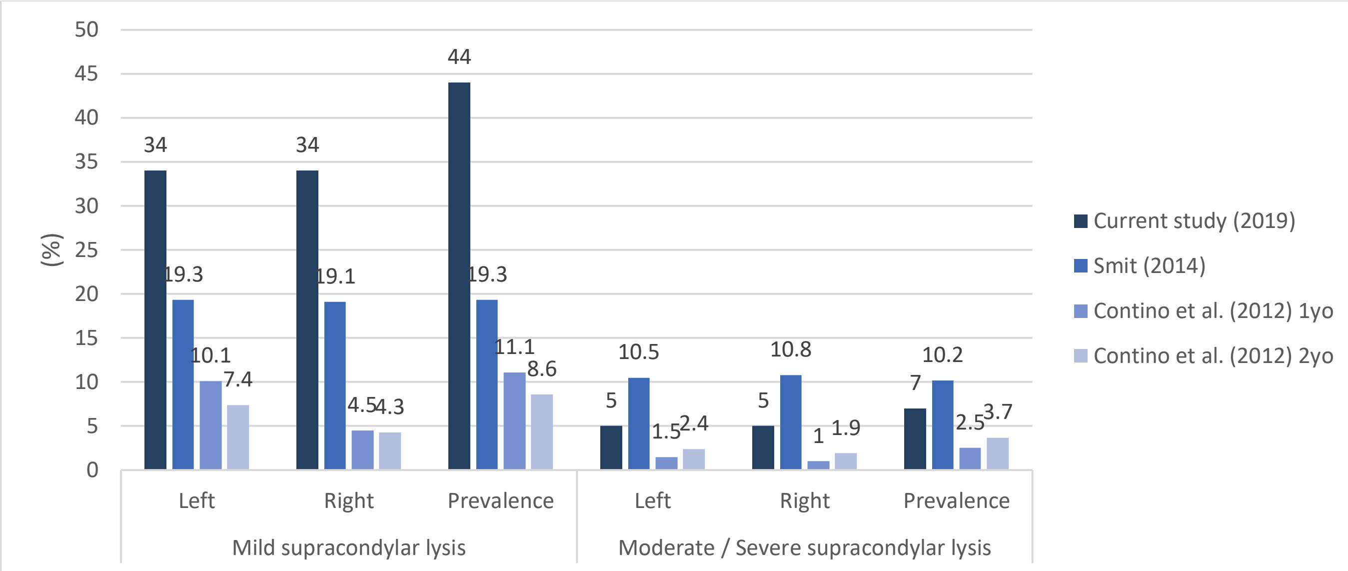

Figure 31: Palmar supracondylar lysis (%) study result comparison.

Proximal sesamoid bone elongation was observed in 1% of left front limbs but in no right front limbs. Contino et al. (2012) reported a prevalence of 0% in young quarter horses (n=277), while the prevalence in yearling Thoroughbreds (n=566) was reported to be higher (1.9%) (Smit, 2014).

The prevalence of PSB with an abnormal shape or irregular border was 30%. This is three times that reported in Thoroughbred yearlings (10.8%) by Smit (2014). Contino et al. (2012) reported no PSB with an abnormal shape in young quarter horses.

No proximal sesamoid bone fractures were observed in the current study. This is similar to the low prevalence in previous studies (1.9% (Contino et al., 2012), 0.4% (Miyakoshi et al., 2017), 1.1% (Smit, 2014)). The clinical significance of PSB fractures depends on their position and the degree of associated soft-tissue injury (Nixon, 2012).

Osteophytes of the PSB were observed in 14% of left front limbs and 8% of right front limbs with 5% of horses having osteophytes bilaterally. The prevalence of PSB osteophytes was 17% in the current study. Contino et al. (2012) reported lower incidence (0.5%, 1% and 0% respectively) in one-year-old quarter horses with prevalence being 1.5%. The prevalence by the same authors in two-year-old quarter horses was 3.7%. Smit (2014) reports an even lower prevalence (0.4%) in Thoroughbred yearlings.

The prevalence of circular PSB lucencies was 10%. This is similar to 8.6% reported by Smit (2014) in Thoroughbred yearlings. According to Spike-Pierce and Bramlage (2010), abnormally shaped or wide lucencies are likely to be are likely to be associated with clinical lameness.

Only one irregular vascular channel was reported in the current study. Smit (2014) however reported many more vascular channels (both total, regular and irregular) in Thoroughbred yearlings. Kane et al. (2003), reported that Thoroughbreds with two or more irregular vascular channels had decreased performance when compared to horses with normal vascular channels and Spike-Pierce and Bramlage (2010) states that the greater the number of irregular vascular channels, the more likely there is to be poor performance and lameness. Sesamoids demonstrating any number of regular vascular channels (<2mm wide with parallel borders) did not negatively affect racing performance (Spike-Pierce and Bramlage, 2010).

LIMITATIONS

A major limiting factor of the current study was the poor inter-rater reliability and the lack of evaluation of intra-rater repeatability (Appendix D). The statistical significance of the difference in prevalence between medial and lateral solar thickness was not calculated.

A further limiting factor one must keep in mind is the small radius (250km) in which data was collected when compared to the country as a whole. The sample population consisted of 100 horses (1.7%) out of 5922 registered horses (ERASA, 2019).

Further, no radiopaque marker was placed on the coronary band which made measurements difficult.

CONCLUSION

This is the first study to describe radiographic findings in the distal aspect of the limb in competing endurance horses. The clinical relevance of these radiographic changes warrants further investigation as the current study makes no correlations with factors such as horse age, conformation, lameness, kilometres competed, breed, distance, terrain, speed, rider weight or training regimes.

Comparisons to earlier studies on the prevalence of radiographic changes in horse should be done with caution. The majority of previous studies have been performed on yearling Thoroughbreds intended for flat racing and yearling quarter horses intended for cutting. The median age was 8 years old (5-17 years old). The majority of the population was Arab (48%) or Arab cross (46%). The difference in prevalence of changes compared with previous studies could thus be due to age, breed, or differences between disciplines and the injuries associated with them.

This information about prevalence and distribution of radiographic changes will enable equine veterinarians and riders to better manage horses showing these changes with regard to shoeing and training. It may also serve as comparison for future similar studies in the endurance discipline in South Africa and possibly internationally.

A limiting factor of the current study was the poor inter-rater reliability and the lack of evaluation of intra-rater repeatability. A further limiting factor is the small radius in which data was collected and the relatively small sample size (1.7%) out of 5922 registered horses (ERASA, 2019). The prevalence of lesions may be biased due to the relatively small sample population evaluated and the very specific geographical location, and thus limited terrain changes. This might warrant future investigation and comparison to other regions in South Africa.

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APPENDICES

APPENDIX A: ENDURANCE RIDES WHERE RADIOGRAPHS WERE TAKEN

Date	Ride	Club	Number of Horses
11/08/2018	Pretoria Military club ride	Pretoria Military Equestrian club	15 horses
18/08/2018	Dullstroom	Platorand endurance club	25 horses
08/09/2018	Arkab stud	Private	41 horses
08/09/2018	Bronkhorstspruit	Private	13 horses
09/09/2018	Bronkhorstspruit	Private	6 horses

APPENDIX B: RADIOGRAPHIC CHANGES DATASHEET

Variable	Categories
UV Number	Unique per horse
Side	1= L 2= R
Medial Solar Thickness	0= <5mm 1= 5-9mm 2= 10-14mm 3= 15-19mm 4= >20mm
Lateral Solar Thickness	0= <5mm 1= 5-9mm 2= 10-14mm 3= 15-19mm 4= >20mm
Solar angle	0= ≤0º 1= 0-2º 2= 3-10º 3= ≥10º
Hoof length	0= ≤7.6 cm 1= 7.6-8.9 cm 2= ≥8.9 cm
Dorsopalmar foot balance: proportions	0= Bisects solar surface 1= More dorsal 2= More palmar
Dorsopalmar foot balance: angles	0= Equal 1= Smaller 2= Larger
Digital axis Normal	1= yes 2= no
Digital axis: PIP joint hyperextended	1= yes 2= no
Digital axis: PIP joint flexed	1= yes 2= no
Digital axis: DIP joint hyperextended	1= yes 2= no
Digital axis: DIP joint flexed	1= yes 2= no
Enthesophytes/ osteophytes - Extensor process of P3	1= yes 2= no
Enthesophytes/ osteophytes - Dorsoproximal P2	1= yes 2= no
P3 dorsal mineralisation reactions	1= yes 2= no
Dorsodistal P3 modelling	1= yes 2= no
Hoof-P3 distance	mm
Palmar length of P3	mm
Ratio: hoof P3 distance to palmar length of P3 (%)	%
Ratio: hoof P3 distance to palmar length of P3 (%)	0= ≤25% 1= >25%
Dorsal hoof wall separation	1= yes 2= no
Phalangeal rotation	1= yes 2= no

Capsular rotation	1= yes 2= no
Sinking of P3 - Depression immediately proximal to coronary band	1= yes 2= no
Sinking of P3 - Founder distance	mm
Ossification of ungular cartilages	0= Grade 0 1= Grade 1 2= Grade 2 3= Grade 3 4= Grade 4 5= Grade 5
P3 fracture	0= None 1= Type 1 2= Type 2 3= Type 3 4= Type 4 5= Type 5 6= Type 6
MCP Soft tissue swelling	1= yes 2= no
MCP Osteophytes	1= yes 2= no
MCP Enthesopytes	1= yes 2= no
Fragment dorsoproximal proximal phalanx	0= None 1= Articular 2= Non-articular
Cyst distal MC3 or proximal P1	1= yes 2= no
Changes dorsal aspect distal MC3	0= None 1= Notch 2= Lucency 3= Fragment/loose body 4= Flattening
Change distal sagittal ridge of MC3	0= None 1= Flat 2= Lucency
Change distal palmar MC3 condyles	0= None 1= Flat 2= Lucency 3= Sclerosis
Palmar supracondylar lysis MC3	0= None 1= Slight 2= Mod/extreme
Sesamoid elongation	1= yes 2= no
Irregular border	1= yes 2= no
Sesamoid fracture	0= None 1= Apical 2= Abaxial 3= Basal 4= Midbody 5= Comminuted
Osteophytes	1= yes 2= no

Sesamoid circular lucencies	0= 0 Lucencies 1= 1 Lucencies 2= 2 Lucencies 3= 3 Lucencies
Sesamoid total vascular channels	0= None 1= 1 2= 2 3= 3 4= >3
Sesamoid regular vascular channels	0= None 1= 1 2= 2 3= 3 4= >3
Sesamoid irregular vascular channels	0= None 1= 1 2= 2 3= 3 4= >3

APPENDIX C: OWNER CONSENT FORM AND BRIEF QUESTIONNAIRE

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

I ___________________________________ hereby give consent for the above mentioned horse to be radiographed as part of the study titled "Prevalence of Radiographic Changes in South African Endurance Racehorses Part I and I". 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 D: KAPPA VALUES

Variable	Side	L Kappa	L P-value	Agreement	Side	R Kappa	R P-value	Agreement
FOOTProportions(equal)	L	0,1964	0,0007	Slight	R	0,1964	0,0007	Slight
FOOTProportions(dorsal)	L	-0,0067	0,9075	None	R	-0,0067	0,9075	None
FOOTProportions(palmar)	L	0,2152	0,0002	Fair	R	0,1661	0,0040	Slight
FOOTAngles(equal)	L	-0,1786	0,0020	None	R	-0,1333	0,0209	None
FOOTAngles(smaller)	L	-0,1871	0,0012	None	R	-0,1335	0,0207	None
FOOTAngles(larger)	L	0,0271	0,6383	None	R	0,1959	0,0007	Slight
DAnormal	L	0,0173	0,7649	None	R	0,1014	0,0790	None
PIPext	L	0,1855	0,0013	Slight	R	0,2737	0,0000	Fair
PIPflex	L	-0,0101	0,8611	None	R	0,2399	0,0000	Fair
DIPext	L	0,2941	0,0000	Fair	R	0,3203	0,0000	Fair
DIPflex	L	0,5896	0,0000	Moderate	R	0,5148	0,0000	Moderate
OsteophytesEPP3	L	0,1726	0,0028	Slight	R	0,3257	0,0000	Fair
OsteophytesDPrP2	L	0,4178	0,0000	Moderate	R	0,2337	0,0001	Fair
P3mineralisation	L	-0,0067	0,9075	None	R	-0,0135	0,8149	None
P3modeling	L	0,2500	0,0000	Fair	R	0,2010	0,0005	Fair
HOOFseperation	L	-0,0101	0,8611	None	R	-0,0135	0,8149	None
RotationPHAL	L	NA	NA	Prevalence too low to calculate Kappa	R	-0,0033	0,9538	None
RotationCAP	L	-0,0067	0,9075	None	R	-0,0169	0,7691	None
P3sinkDEPRESSION	L	NA	NA	Prevalence too low to calculate Kappa	R	NA	NA	Prevalence too low to calculate Kappa
UCossification0	L	0,1940	0,0008	Slight	R	0,2500	0,0000	Fair
UCossification1	L	-0,1199	0,0378	None	R	-0,0703	0,2231	None
UCossification2	L	0,1360	0,0185	Slight	R	0,0604	0,2953	None
UCossification3	L	0,4463	0,0000	Moderate	R	0,4740	0,0000	Moderate
UCossification4	L	0,5504	0,0000	Moderate	R	0,4792	0,0000	Moderate
UCossification5	L	-0,0067	0,9075	None	R	0,7466	0,0000	Substantial
P3fracture	L	NA	NA	Prevalence too low to calculate Kappa	R	NA	NA	Prevalence too low to calculate Kappa
MCPswelling	L	0,1769	0,0022	Slight	R	0,1159	0,0446	Slight
MCPosteophytes	L	0,4172	0,0000	Moderate	R	0,4033	0,0000	Moderate
MCPenthesopytes	L	0,1724	0,0028	Slight	R	-0,0417	0,4705	None
P1fragment	L	0,8062	0,0000	Near perfect	R	0,6340	0,0000	Substantial
Cyst	L	-0,0067	0,9075	None	R	-0,0135	0,8149	None
MC3changesDIDO(none)	L	0,2281	0,0001	Fair	R	0,2313	0,0001	Fair
MC3changesDIDO(notch)	L	0,2774	0,0000	Fair	R	0,3125	0,0000	Fair
MC3changesDIDO(lucency)	L	-0,0101	0,8611	None	R	-0,0067	0,9075	None
MC3changesDIDO(fragment)	L	1,0000	0,0000	Near perfect	R	0,3266	0,0000	Fair
MC3changesDIDO(flattening)	L	-0,0381	0,5097	None	R	-0,0309	0,5922	None
SAGITTALRchanges(none)	L	0,4149	0,0000	Moderate	R	-0,0204	0,7237	None
SAGITTALRchanges(flat)	L	-0,0101	0,8611	None	R	-0,0169	0,7691	None
SAGITTALRchanges(lucency)	L	0,7466	0,0000	Substantial	R	-0,0033	0,9538	None
MC3changesDIPA(none)	L	-0,1969	0,0006	None	R	-0,1815	0,0017	None
MC3changesDIPA(flat)	L	-0,1912	0,0009	None	R	-0,1815	0,0017	None

MC3changesDIPA(lucent)	L	-0,0101	0,8611	None	R	-0,0067	0,9075	None
MC3changesDIPA(sclerosis)	L	-0,0033	0,9538	None	R	NA	NA	Prevalence too low to calculate Kappa
MC3lysisPA(none)	L	0,3236	0,0000	Fair	R	0,1379	0,0169	Slight
MC3lysisPA(mild)	L	0,1830	0,0015	Slight	R	0,0850	0,1410	None
MC3lysisPA(mod/severe)	L	0,0741	0,1995	None	R	0,1157	0,0451	Slight
SESelong	L	-0,1503	0,0092	None	R	-0,1858	0,0013	None
SESirregular	L	0,5387	0,0000	Moderate	R	0,5379	0,0000	Moderate
SESfracture	L	NA	NA	Prevalence too low to calculate Kappa	R	-0,0033	0,9538	None
SESosteophytes	L	0,290	0,000	Fair	R	0,0757	0,1900	None
SESlucencies0	L	-0,3791	0,0000	None	R	-0,2664	0,0000	None
SESlucencies1	L	-0,0714	0,2160	None	R	-0,0563	0,3292	None
SESlucencies2	L	-0,1605	0,0054	None	R	-0,1161	0,0444	None
SESlucencies3	L	-0,0895	0,1209	None	R	-0,0997	0,0841	None
SESchannelsTOT0	L	0,0851	0,1403	None	R	0,0034	0,9533	None
SESchannelsTOT1	L	0,2680	0,0000	Fair	R	0,2096	0,0003	Fair
SESchannelsTOT2	L	0,0672	0,2444	None	R	0,0069	0,9051	None
SESchannelsTOT3	L	0,0327	0,5707	None	R	-0,0083	0,8853	None
SESchannelsTOT3+	L	0,1350	0,0194	Slight	R	-0,0169	0,7702	None
SESchannelsREG0	L	0,1945	0,0008	Slight	R	0,0079	0,8907	None
SESchannelsREG1	L	0,2808	0,0000	Fair	R	0,2071	0,0003	Fair
SESchannelsREG2	L	0,0484	0,4018	None	R	0,0757	0,1895	None
SESchannelsREG3	L	0,0575	0,3190	None	R	0,0078	0,8926	None
SESchannelsREG3+	L	0,2040	0,0004	Fair	R	0,0192	0,7391	None
SESchannelsIRR0	L	-0,0555	0,3364	None	R	0,0190	0,7425	None
SESchannelsIRR1	L	-0,0526	0,3620	None	R	-0,0239	0,6790	None
SESchannelsIRR2	L	-0,0309	0,5922	None	R	-0,0274	0,6351	None
SESchannelsIRR3	L	-0,0135	0,8149	None	R	-0,0067	0,9075	None
SESchannelsIRR3+	L	-0,0169	0,7691	None	R	-0,0169	0,7691	None