

**CAROLINA CORREIA GONÇALVES DENTE**

**LOW-FIELD MRI IN HORSES DIAGNOSED WITH  
PALMAR FOOT PAIN**

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**LUSOFONA UNIVERSITY OF HUMANITIES AND TECHNOLOGIES**

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*It is only with the heart that one can see rightly. What is essential is  
invisible to the eye.*

Antoine de Saint-Exupery

To my mother, my father, my siblings

To my two stars in the sky

To those who supported me incondicionally

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## Resumo

É reconhecido, hoje em dia, que o que até então era agrupado na vaga categoria diagnóstica de síndrome podotroclear, pode ser o resultado de diferentes patologias em diferentes tecidos no casco, que poderão ocorrer concomitantemente. O desenvolvimento de técnicas imagiológicas mais sensíveis poderá proporcionar um melhor conhecimento acerca das causas de dor proveniente da região do casco.

Visto que as imagens de ressonância magnética se baseiam nas propriedades magnéticas de prótons, não são utilizadas radiações ionizantes como acontece em outras técnicas imagiológicas. A grande vantagem em comparação às outras modalidades imagiológicas é o potencial de detecção de lesões em tecidos moles, bem como lesões ao nível do osso e cartilagem.

O principal objectivo deste estudo foi avaliar a prevalência de lesões encontradas no casco, em cavalos de desporto com claudicação crónica em membros anteriores e submetidos a um exame de ressonância magnética. Secundariamente, foi avaliada a tendência para ocorrência das lesões encontradas, uni- ou bilateralmente. Ainda, das lesões encontradas, foi estudada a ocorrência de lesões em associação.

Neste estudo foram utilizados 95 cavalos de desporto de diferentes disciplinas. Lesões no osso navicular foram as mais frequentes (38%), seguido de lesões na articulação interfalângica distal (16%) e no tendão flexor digital profundo (15%). Diferentes combinações de lesões foram encontradas entre diferentes tecidos. Lesões no osso navicular apareceram de forma difusa (18%), com lesões que afetaram o bordo distal, superfície dorsal e flexora (12%), com lesões que afetaram o bordo distal e superfície flexora (9%) e com lesões que afetaram a superfície flexora e dorsal (1%). Na amostra estudada, não ocorreram lesões isoladas no bordo proximal e na superfície dorsal do osso navicular.

A Ressonância Magnética é uma excelente ferramenta de diagnóstico de problemas de casco quando comparada com as outras técnicas disponíveis. Devido aos elevados custos do exame, não deverá ser utilizada rotineiramente e só após um exame de claudicação rigoroso e quando não é possível chegar a um diagnóstico definitivo através de outras técnicas imagiológicas.

**Palavras-chave:** Ressonância magnética, cavalos, síndrome podotroclear, técnicas imagiológicas, osso navicular.

## **Abstract**

It is well recognised today, that the underlying pathology for the so called “palmar foot pain” or “navicular syndrome” can be a result of either single or multiple pathologies in different tissues in the hoof. The development of advanced diagnostic imaging modalities such as MRI, have taken the understanding of these conditions to a different level.

Since MRI is based on magnetic properties of protons, it uses no ionizing radiation unlike other imaging techniques, such as radiology and CT. The main advantage of MRI in comparison to the other techniques is its ability to highlight soft tissue lesions, as well as cartilage and bone.

The main objective of this study was to evaluate the prevalence of lesions in a population of sport horses presented with a chronic forelimb lameness that underwent an MRI examination. Also, was evaluated uni- or bilateral tendency of occurrence, of the lesions found and see if they occurred in association.

This study contemplated 95 sport horses from different disciplines. Navicular bone lesions were the most frequent (38%), followed by coffin-joint (16%) and DDFT (15%) lesions. Several of different combinations of lesions were seen among all the tissues. Lesions in the navicular bone appeared as a diffuse disease (18%), had lesions affecting the distal border, dorsal and flexor surface (12%), had lesions affecting the distal border and flexor surface (9%) and lesions affecting the flexor and dorsal surface (1%). Lesions of the proximal border and dorsal surface of the navicular bone did not occur without association to other areas of the navicular bone, in the population.

MRI proved to be an excellent tool to diagnose pathologies within the foot when compared to the other imaging techniques available. An accurate clinical lameness examination to include diagnostic analgesia is still crucial to confirm the localization to be within the foot. Due to the high cost of MRI, it should only be considered if other and less cost imaging techniques fail to provide an accurate diagnosis.

**Key words:** MRI, horses, palmar foot pain, navicular syndrome, diagnostic imaging modalities, navicular bone.

## **Resumo das secções em Português**

### **Introdução à Ressonância Magnética**

A ressonância magnética é uma técnica de diagnóstico de imagem que depende da distribuição e concentração de iões de hidrogénio nos tecidos biológicos, das suas propriedades e como cada um reage à presença de um campo magnético (Labruyère & Schwarz, 2013; Lauterbur, 1973). Os iões de hidrogénio são um dos mais sensíveis aos gradientes de campo e a sua elevada abundância nos tecidos biológicos tornam possível a criação de imagens sem a necessidade de adição e/ou exposição a outras substâncias (Armstrong & Stephen, 1991). Apesar de o sinal de ressonância magnética poder ser detetado em vários tipos de iões, são utilizados iões de hidrogénio devido aos benefícios já mencionados (Armstrong & Stephen, 1991; Murray, 2011).

A ressonância magnética cria imagens através da deteção de sinal dos iões de hidrogénio presentes na água e gordura dos tecidos biológicos (Armstrong & Stephen, 1991; Damadian, 1971; Lauterbur, 1973). A parte do corpo a ser examinada deverá, para isso, ser colocada sob influência de um campo magnético e sujeita a pulsos de radiofrequências. Os iões de hidrogénio irão ganhar energia e vão emitir um sinal de radiofrequência em retorno que é recolhido e utilizado para a formação da imagem (Armstrong & Stephen, 1991; Labruyère & Schwarz, 2013). A intensidade do sinal varia de tecido para tecido devido às diferenças de concentração e distribuição de iões de hidrogénio e ao estado dos mesmos, i.e. quimicamente livres ou ligados. Estas diferenças resultam em aparências diferentes dos tecidos na mesma imagem (Armstrong, 1991).

O caso a examinar é colocado num campo magnético e é posteriormente aplicada uma bobina de transmissão e deteção de sinal. Os pulsos de radiofrequência são transmitidos ao paciente pela bobina, absorvidos pelos iões de hidrogénio, que por sua vez ganham energia, e retransmitem um sinal de radiofrequência, que é recolhido pela mesma bobina (Armstrong & Stephen, 1991). O sinal de radiofrequência emitido pelos iões de hidrogénio vai depender da densidade de protões, i.e. do número de iões de hidrogénio presentes em cada tecido, e dos tempos de relaxamento T1 e T2 (Armstrong & Stephen, 1991; Murray, 2001).

Os tempos de relaxamento T1 e T2 refletem a taxa com que os íons de hidrogénio perdem a energia (Armstrong & Stephen, 1991). Todas as imagens de ressonância magnética contêm informação de ambos os tempos de relaxamento, contudo, através da manipulação dos parâmetros do sistema, a imagem poderá ser maioritariamente dependente de um ou de outro (Armstrong & Stephen, 1991). Várias combinações de pulsos e campos magnéticos podem ser usados para criar imagens com diferentes contrastes (Labruyère & Schwarz, 2013).

Quando o paciente é colocado sob influência do campo magnético, os núcleos dos íons de hidrogénio vão alinhar-se com a direção do mesmo (Armstrong & Stephen, 1991; Murray, 2011). Pulsos de radiofrequência que são emitidos pela bobina fazem com que algum dos núcleos fiquem desalinhados relativamente à direção do campo magnético. Quando a bobina é desligada e cessa a emissão de pulsos, os prótons tendem a regressar ao equilíbrio original, i.e. ao alinhamento com a direção do campo magnético. Este fenómeno é acompanhado por uma libertação de energia sob a forma de sinal de radiofrequência, que será captado novamente pela bobina (Labruyère & Schwarz, 2013).

O tempo de relaxamento T1 representa a velocidade em que os prótons excitados realinham com a direção do campo magnético.

O tempo de relaxamento T2 reflete a taxa de declínio do sinal devido ao desfaseamento dos prótons no seu “spin” (Armstrong & Stephen, 1991).

As imagens são produzidas dentro de uma escala de tons cinza com vários tipos de contraste, sendo o resultado da intensidade do sinal (Mair et al., 2005). A aparência do tecido na imagem é afetada pela sua natureza, pelo sistema, sequência de pulsos e pelos parâmetros de aquisição (Armstrong & Stephen, 1991; Labruyère & Schwarz, 2013). Quando existe uma lesão num tecido, alterações na sua estrutura, composição bioquímica e distribuição de água resultam em alterações na aparência da imagem de ressonância magnética (Murray, 2001).

O sinal provém maioritariamente dos íons de hidrogénio móveis presentes na gordura e água dos tecidos (Armstrong & Stephen, 1991) e por essa razão, estruturas com pouca quantidade de hidrogénio ou poucos íons móveis terão aparência negra (Mair et al., 2005; Murray, 2001).

O contraste é determinado pela quantidade de íons de hidrogénio, tempos de relaxamento T1 e T2 (Armstrong & Stephen, 1991) e pela manipulação da sequência de pulsos.

Por esta razão, o mesmo tecido terá aparências diferentes em imagens T1, T2 e PD (Labruyère & Schwarz, 2013; Murray, 2001).

Imagens referidas como T1 ou T1W o contraste depende do tempo de relaxamento T1, imagens referidas como T2 ou T2W o contraste depende do tempo de relaxamento T2 e imagens referidas como PD ou PDW o contraste depende do número de prótons de hidrogénio livre ou móvel (Murray, 2011).

O tempo de relaxamento T1 é longo para fluídos, mas muito curto para tecidos baseados em gordura. Em imagens T1W tecidos ricos em água irão ter uma aparência cinzenta clara, dependendo da sua quantidade do tecido. Neste caso, o aumento da quantidade de água irá tornar a imagem mais escura. Tecidos com um aumento do seu conteúdo de água devido a edema ou aumento da permeabilidade capilar, irão aparecer mais escuros rodeados por uma zona de tecido de “aparência normal”. Tecidos com composição elevada de gordura irão ter uma aparência mais clara (Murray, 2011). Imagens T1W providenciam o melhor detalhe anatómico e por isso são consideradas sequência “standart” para linha de base, num exame imagiológico (Mair et al., 2005).

Em imagens T2W, a água aparece a branco enquanto que tecidos baseados em água ou gordura terão sinal intermédio. Imagens T2W têm menos detalhe anatómico e menos resolução que T1W, mas são extremamente úteis para deteção de patologias onde existe um aumento da composição de água nos tecidos, tais como edema e inflamação. Neste casos, estas lesões irão aparecer como áreas com o aumento de intensidade de sinal, i.e. mais claras, rodeadas por tecido normal e mais escuro. Imagens T2W também são úteis para avaliação de estruturas sinoviais (Mair et al, 2005; Murray, 2001).

O aumento de conteúdo de água em tecidos ricos em gordura, por uma lesão, tal como a medula óssea, pode ser difícil de avaliar usando imagens T2W, devido ao sinal proveniente da gordura. Nestes casos, é usado uma sequência chamada STIR, em que o sinal da gordura é suprimido, sendo então possível a deteção do sinal de fluídos (Kleiter et al., 1999; Murray, 2011).

A qualidade da imagem em ressonância magnética é determinada pelo sinal, barulho, contraste e artefactos. O barulho é gerado pelo movimento térmico de eletrões e medidas deverão ser tomadas para prevenir quaisquer fontes de barulho provenientes do exterior, que possam ajudar a degradar a qualidade da imagem. Isto pode ser conseguido durante a instalação

da sala de ressonância magnética, blindando as paredes, teto, chão e portas com cobre impedindo ondas de radiofrequência provenientes do exterior. Devem ainda ser aplicadas proteções especiais em todos os equipamentos eletrônicos dentro da sala de ressonância magnética (Murray, 2011).

São chamados de artefactos todas as características numa imagem que não representem a realidade, e que podem levar a mal interpretações ou a diagnósticos incorretos. Ocorrem frequentemente e podem ser resultado de fatores relacionados com o paciente, com a natureza da ressonância magnética, técnica de aquisição das imagens e imperfeições do sistema. São classificados em artefactos de movimento, artefactos de campo magnético heterogéneo e artefactos digitais (Murray, 2011).

Artefactos de movimento, tal como o nome indica são causados pelo movimento involuntário ou voluntário durante a aquisição da imagem. São exemplos o movimento pulsátil de vasos sanguíneos, a respiração ou mesmo pequenos movimentos em cavalos que tenham recebido demasiada sedação. O resultado será uma imagem com manchas, borrões e arrastamento de estruturas que poderá levar a uma imagem sem poder diagnóstico. Artefactos de movimento podem ser minimizados pelo uso de scans MI, uma vez que eles permitem a aquisição da imagem pelo sistema apenas quando existem movimentos mínimos e por reposição das fatias quando movimento é detetado. Outra opção será encurtar o tempo de aquisição, através do uso de scans rápidos ou super-rápidos (Murray, 2001).

Artefactos de campo magnético heterogéneo são causados habitualmente por flutuações de temperatura ou objetos de metal. Artefactos causados por metal são observados como áreas sem sinal rodeados por uma halo fino hiper-intenso e com distorção das estruturas adjacentes. A temperatura e humidade deverão ser controladas dentro da sala de ressonância magnética, para minimizar a ocorrência destes artefactos, e a remoção de peças de metal na área de segurança do campo magnético. Botas de biqueira de aço deverão ser evitadas, ferraduras deverão ser removidas e o casco inspecionado para verificar a completa remoção dos pregos de casco.

Artefactos digitais contemplam: artefacto de desvio químico, ângulo mágico, e volume parcial. O desvio químico manifesta-se quando o sinal da água e da gordura se cancelam mutuamente. Por exemplo em áreas com o aumento de sinal em imagens T2 FSE, que aparecem mais escuras em T2 GRE. A presença real de fluído pode ser então avaliada usando imagens STIR. O ângulo mágico manifesta-se por um aumento de sinal em estruturas ricas em fibras de

colagénio que se encontram com uma orientação aproximada de 55° graus em relação ao campo magnético. Imagens T1W e PDW são mais suscetíveis á ocorrência deste artefacto. Estruturas comumente afetadas incluem os ligamentos colaterais da articulação interfalângica distal, ligamentos sesamóideos oblíquos, flexor digital profundo e ligamento anular distal. Deve dar-se preferência ao uso de scans em que este artefacto não ocorra, tais como T2W ou STIR, na avaliação destas estruturas (Murray, 2001). O artefacto de volume parcial ocorre em habitualmente em estruturas curvas ou irregulares, onde os limites de uma estrutura aparecem na mesma fatia em aposição ou parcialmente cruzadas. Este artefacto pode ser evitando diminuindo a espessura das fatias, através do uso de imagens de alta resolução (Murray, 2001).

### **Claudicação, Exame Físico e Técnicas Diagnósticas**

O exame deverá começar pela recolha dos dados da anamnese e história clínica, recolhendo informações essenciais como a idade, sexo, raça e uso do cavalo (Hinchcliff et al., 2004). Perguntas mais detalhadas acerca da história clínica do paciente são essenciais aquando a tentativa de descobrir a causa da claudicação ou falta de performance. Esta deverão incluir: a duração do problema, se melhora ou piora com exercício e se sim com quais, como se tem feito o manejo do problema até á data, história de problemas ortopédicos anteriores, alterações no manejo ou ferração, entre outros (Ross & Dyson, 2003).

Deverá ser seguido o exame físico do cavalo, começando por observar o cavalo á distancia, passando á palpação do pescoço, membros anteriores, tórax e coluna e por último os membros posteriores. Nesta fase deverão ser notadas alterações como inchaços e quaisquer assimetrias ou presença de dor á palpação.

De seguida é efectuado o exame dinâmico, observado o cavalo em andamento e em trote em linha recta e em círculo. Nesta fase a claudicação deverá ser identificada bem como os membros afectados.

Testes de flexão são efetuados na tentativa de exacerbar a claudicação, comparando sempre com o membro contra lateral. Após o exame físico e identificada a claudicação seguem-se os bloqueios anestésicos na tentativa de localizar a área do membro de onde provém a dor (Auer & Stick, 1999; Ross & Dyson, 2003).

Antes de efetuar qualquer bloqueio anestésico, deverá ser aplicada uma pinça de casco e verificar a existência de reação. Os bloqueios deverão ser aplicados da zona distal em direção proximal do membro (Moyer, 2010). Cavalos com síndrome navicular na grande maioria melhoram o grau de claudicação com bloqueio digital palmar ainda que muitas vezes a claudicação só consegue ser completamente eliminada com o bloqueio sesamóideo abaxial (Ross & Dyson, 2003). Muitos casos podem ainda responder a bloqueios intra-articulares da articulação interfalângica distal (Moyer, 2010).

Após localização do casco como fonte de claudicação, através do exame físico e bloqueios anestésicos, exames diagnóstico de imagem deverão ser efetuados. As ferraduras deverão ser removidas, os cascos limpos e um conjunto de radiografias deverão ser tiradas que incluem projeções lateromedial e dorsopalmar do casco em estação sobre um bloco, projeções dorsoproximal-palmarodistal e palmaroproximal-palmarodistal.

Infelizmente, o exame radiográfico permite apenas a visualização de alterações ao nível dos ossos e articulações (Rijkenhuisen, 2006; Kristoffersen & Thoenner, 2003; Butler et al., 2000) e os bloqueios anestésicos ajudam apenas no isolamento da área de interesse não indicando a distribuição nem a severidade do problema (Kristoffersen & Thoenner, 2003).

Ecografia é uma técnica de diagnóstico complementar á radiografia, usado rotineiramente na avaliação de tecidos moles (Busoni & J.-M. Denoix, 2001). O exame ecográfico ao aparelho podotrocLEAR inclui duas abordagens: suprasesamoidana, realizada na parte distal da quartela e infrasesamoidana, através da sola do casco (Jacquet & J.-M. Denoix, 2012; Busoni & Jean-Marie Denoix, 2001). Ambas as técnicas têm as suas limitações: na abordagem suprasesamoidana, apenas a parte proximal do aparelho podotrocLEAR é avaliado (Busoni & Jean-Marie Denoix, 2001) enquanto que na abordagem infrasesamoidana está limitada á conformação da ranilha do casco, em que se os sulcos forem muitos profundos impendem o acoplamento entre a sonda e a superfície da ranilha (Jacquet & J.-M. Denoix, 2012).

Na abordagem infrasesamoidana a preparação do casco e da ranilha é essencial para obtenção de imagens de qualidade. A ranilha deverá ser lavada com água quente e sabão e aparada com a ajuda de uma faca de cascos (Kristoffersen & Thoenner, 2003). Posteriormente deve ser aplicado um penso molhado de casco durante pelo menos 15 minutos para ajudar a suavizar a superfície da ranilha (Busoni & J.-M. Denoix, 2001). Em casos de falha de

diagnóstico após a realização de exames radiográficos e ecográficos, exame de ressonância magnética deverá ser visto como opção.

A ressonância magnética é a modalidade imagiológica com mais sensibilidade na detecção de lesões e não só é considerada uma excelente ferramenta por conseguir ultrapassar limitações de outras técnicas imagiológicas em avaliar as estruturas do casco, mas também porque ajuda a redirecionar o tratamento e reabilitação e a fornecer prognóstico (Murray, 2011; Barret et al., 2016 & Mair et al., 2005). Ajuda ainda na detecção de lesões subtis que normalmente não são detetáveis por outras técnicas imagiológicas e por essa razão é considerada técnica “standard” na detecção de lesões ao nível do casco. Também poderá ajudar a determinar se um caso é candidato para neurectomia digital palmar ou não (Murray, 2001).

Antes de começar o exame o sistema deverá ser calibrado consoante as instruções do fabricante. O cavalo é sedado e colocado em posição com o membro a ser examinado no centro do íman. Em exames com o cavalo em estação, os movimentos do íman deverão ser minimizados, para não assustar o cavalo, e por essa razão ele deve ser pré-colocado na posição e altura desejada (Mair et al., 2005). Colocação de ligaduras no membro contra lateral pode ser útil caso de o íman exerça pressão ou raspe em caso de necessidade de movimentação do mesmo (Murray, 2001).

As técnicas de pré-medicação e sedação variam entre hospitais, mas o objetivo será ter o cavalo relaxado, em posição de estação e evitar sobredosagem que poderá resultar em movimentos de inclinar e balançar (Murray, 2001). Comumente utilizam-se drogas como detomidina, romifidina, acepromazina e butorfanol. Após o posicionamento do cavalo é escolhida a bobina de radiofrequência mais pequena para maximizar a qualidade das imagens produzidas. São retiradas as imagens piloto para avaliar a posição e corrigir o posicionamento para as imagens seguintes do protocolo do exame de ressonância magnética (Murray, 2001; Mair et al., 2005).

## **Síndrome Navicular ou Podotroclear**

Síndrome navicular ou podotroclear é caracterizada por claudicação crónica no membro anterior associada a dor na área navicular ou estruturas adjacentes (Ross & Dyson, 2003; Dyson et al., 2011). Pode ser causado por lesões no osso navicular (Rijkenhuisen, 2006) mas também noutras estruturas adjacentes, tais como ligamentos colaterais da articulação interfalângica

distal ou do osso navicular, bursa navicular, tendão flexor digital profundo entre outras (Schneider, 2007; Schramme, 2011).

Devido á grande variedade de lesões possíveis, diferentes manifestações clínicas poderão ser observadas. Muito comum em Quarter Horses e Thoroughbreds, devido á sua conformação do casco (Ross & Dyson, 2003; Dyson et al., 2011). Causa exata para o desenvolvimento desta patologia ainda não foi encontrada e possíveis causas continuam especulação: etiologia vascular, que levem a isquémia do osso navicular, fatores biomecânicos, fraca conformação do casco, forma anatómica do osso navicular e envelhecimento que poderão resultar em alterações degenerativas.

Lesões no osso navicular podem ocorrer ou não em conjunto com lesões noutras estruturas tais como o tendão flexor digital profundo, o ligamento impar ou ligamentos colaterais do osso navicular, e podem afetar diferentes áreas do osso navicular. Diferentes lesões poderão afetar diferentes áreas que incluem o bordo distal, a área flexora, o bordo proximal e a superfície dorsal e consoante a sua localização, poderão relacionar-se com lesões em outras estruturas (Murray, 2001). Lesões frequentes incluem: fragmentos no bordo distal, aumento do tamanho das invaginações sinoviais no bordo distal, formação de entesiófitos, quistos e edema. Lesões que afetem a superfície flexora do osso navicular são frequentemente associadas a lesões no tendão flexor digital profundo enquanto que lesões no bordo distal, são frequentemente associadas a lesões no ligamento impar (Mair et al., 2005).

Lesões do ligamento impar são caracterizadas, em imagens de ressonância magnética, pelo alargamento do diâmetro do ligamento associada a áreas de diminuição de sinal em imagens T1W e aumento de sinal em imagens T2W e STIR, em lesões agudas. Por vezes podem existir lesões associadas na sua origem no osso navicular ou na inserção distal, na falange distal (Murray, 2001). Lesões no ligamento impar aparecem frequentemente associadas com lesões no osso navicular, em que se verifica um aumento de sinal em imagens STIR na sua origem (Murray, 2001).

Lesões dos ligamentos colaterais do osso navicular terão a mesma aparência das lesões do ligamento impar e raramente ocorrem de forma isolada. O aparecimento de um aumento de sinal de forma linear desde a inserção distal dos ligamentos colaterais até à origem do ligamento impar é indicativo de patologia em ambos os ligamentos. Lesões crónicas aparecem normalmente com formação de entesiófitos no bordo proximal do osso navicular e uma perda

na separação com o tendão flexor digital profundo, devido á formação de adesões (Murray, 2001).

Lesões no tendão flexor digital profundo é uma importante causa de claudicação que pode ocorrer de forma isolada, mas muitas vezes aparece associada a lesões noutras estruturas do casco (Murray, 2001). Lesões primárias podem ocorrer como resultado de sobrecarga ou alterações degenerativas resultantes do envelhecimento. Estas lesões podem manifestar-se como lesões difusas, abrasões na margem dorsal, “tearing”, “splits” e “core lesions” podendo originar-se a qualquer nível do tendão (Barret et al., 2016). Abrasões na margem dorsal, “splits” e “core lesions” ocorrem frequentemente ao nível no osso navicular e ligamentos colaterais do osso navicular. Em casos em que existe lesões no osso navicular e tendão flexor digital profundo, existem múltiplas lesões com envolvimento de ambos os lóbulos do tendão associado a um defeito na superfície flexora do osso navicular e adesões com a bursa navicular (Murray, 2011). “Core lesions” associadas a inchaço do lobo afetado, resultam na perda da simetria mediolateral normal. Neurectomia está contraindicada em casos de lesão do tendão flexor digital profundo, devido à continuação de forças de sobrecarga do tendão comprometido, mas dessensibilizado, podendo levar ao agravamento ou mesmo rutura do tendão (Barret et al., 2016).

Distensão ou efusão da articulação interfalângica distal com ou sem proliferação da membrana sinovial é um achado comum em cavalos com claudicação, mas não significa necessariamente que esta seja a causa principal (Murray, 2001). Normalmente as lesões aparecem com diminuição do sinal em imagens T1W ou com superfície irregular da cartilagem, com a diminuição do espaço articular acompanhado por alteração no osso subcondral, detetadas como diminuição de sinal em imagens T1W associadas a um aumento de sinal em imagens T2W e STIR (Murray, 2001).

Lesões agudas nos ligamentos colaterais da articulação interfalângica distal são caracterizadas por um aumento da intensidade de sinal em todas as sequências de imagens, associadas a um inchaço de um dos ligamentos, ou ambos, com efusão na articulação interfalângica distal. Imagens em plano transversal são mais sensíveis na deteção de lesões ainda que planos frontais possam ser bastante úteis (Murray, 2001). As lesões podem estar restringidas a uma porção do ligamento ou estendidas a todo o seu comprimento e muitas vezes são acompanhadas por reações no perióstio e formação de entesiófitos na sua origem ou inserção distal (Murray, 2001). Imagens T2W e STIR são preferíveis para evitar o artefacto de

ângulo mágico. A existência de lesão requer a presença de inchaço em um dos ligamentos e/ou tecidos periligamentares, aumento de sinal em imagens T2W e STIR ou completa rotura do ligamento com perda da arquitetura normal associada a alterações ósseas ou não (Murray, 2001).

As lesões mais comuns nas falanges média e distal incluem edema, quistos, fraturas e defeitos no processo palmar da falange distal. Edema pode aparecer focalmente ou de forma difusa e caracteriza-se por uma diminuição do sinal em imagens T1W e T2W associado a um aumento de sinal em imagens STIR, ocorrendo frequentemente no especto dorsal da falange média. Quistos aparecem normalmente no osso subcondral tanto da falange média como da falange distal, podendo ou não envolver a articulação interfalângica distal e caracterizam-se pelo aumento do sinal em imagens STIR. Fraturas aparecem normalmente como um aumento de sinal em forma linear em imagens STIR, com diminuição da intensidade do sinal em imagens T1W e T2W nas áreas adjacentes á fratura (Murray, 2001).

## **Materiais e Métodos**

Foram usados 95 cavalos no presente estudo, trazidos como referência ou examinados na clínica no período compreendido entre Setembro de 2015 e 2016. Exames de acompanhamento foram efetuados num período máximo de 2 meses após o exame inicial.

Os cavalos utilizados neste estudo apresentaram claudicação aguda ou crónica em pelo menos um membro anterior. A claudicação foi eliminada através do bloqueio digital palmar ou bloqueio sesamoideu abaxial, e os resultados de outras técnicas imagiológicas foram insuficientes ou inconclusivos na tentativa de explicar a causa da claudicação. Consoante o caso, ambos ou apenas um membro foi objeto de estudo num exame de ressonância magnética, incluindo o casco e a quartela.

Lesões no osso navicular foram separadas em áreas: bordo proximal, superfície dorsal, bordo distal e superfície flexora. As lesões foram apenas classificadas em presente ou ausente e não consoante a sua severidade.

As imagens de ressonância magnética, neste estudo, foram adquiridas usando o sistema 0,27 T Hallmarq. As sequências foram obtidas em três planos: sagital, frontal e transversal e incluíram as seguintes sequências: T1 3D GRE, T1 SE, STIR FSE, T1 GRE HR e T2 FSE. Em

alguns casos foram usadas sequências extra incluindo T2 GRE, STIR GRE e PDW SE. Imagens em plano transversal foram orientadas perpendicularmente à superfície flexora do osso navicular. Imagens em plano sagital foram orientadas perpendicularmente à inserção distal no tendão flexor digital profundo. Imagens em plano frontal foram orientadas paralelamente à superfície flexora do osso navicular ou perpendicularmente à inserção distal do tendão flexor digital profundo.

Descrição estatística foi efetuada para todos os dados para estabelecer a frequência de ocorrência dos vários tipos de lesões no aparelho podotrochlear e incluíram lesões ao nível do osso navicular, ligamento impar, ligamentos colaterais do osso navicular, tendão flexor digital profundo, articulação interfalângica distal, ligamentos colaterais da articulação interfalângica distal e falange média e distal. Foram apenas consideradas lesões se se verificasse repetição da mesma em diferentes planos e em mais de uma sequência diferente. Artefactos e variações anatómicas não foram classificados como lesões.

As correlações estatísticas entre o resultado e as variáveis de tratamento foram analisadas utilizando um teste de qui-quadrado. Todas as análises foram realizadas com o software de análise estatística, SPSS, com um nível de significância de 0,05.

## **Resultados**

67,4% dos cavalos do estudo apresentaram claudicação unilateral e foram sujeitos a exame de ressonância magnética em apenas um membro, ao passo que os restantes 32,6% apresentaram claudicação bilateral e foram sujeitos a um exame em ambos os membros.

Os cavalos da população estudada são cavalos de desporto, cuja disciplina não foi tida em conta, com o maior número de casos em cavalos da raça Hannoveraner (16%), seguidos de cavalos da raça Westfalen (14%), Holsteiner (13%) e American Quarter Horse (12%).

Foram consideradas lesões todos os achados no exame que pudessem contribuir para a claudicação ainda que alguns achados possam não ser a sua principal causa.

Lesões no osso navicular tiveram uma prevalência de 38% na amostra, sendo a lesão mais comum, com maior incidência de lesões no bordo distal seguido de lesões na superfície flexora, superfície dorsal e por último, lesões no bordo proximal.

Lesões na articulação interfalângica distal foram as lesões mais frequentes, seguidas á lesões do osso navicular encontradas com uma prevalência de 16,4%. Estas foram seguidas de lesões do tendão flexor digital profundo com uma prevalência de 15,3% e lesões no ligamento impar com uma prevalência de 8,6%. Lesões com menor prevalência no estudo incluem lesões na falange distal, lesões na bursa navicular, lesões na falange média e lesões nos ligamentos colaterais do osso navicular.

Foram encontradas relações estatísticas entre o tipo de claudicação, i.e. uni- ou bilateral, e lesões no ligamento impar, tendão flexor digital profundo e articulação interfalângica distal, sendo que a presença destas lesões mostraram tendência para a bilateralidade.

Foi também estudada a possibilidade de associação de lesões no aparelho podotrocLEAR, dos quais várias relações estatísticas relevantes foram encontradas.

As relações estatísticas mais fortes foram encontradas entre as diferentes áreas do osso navicular. A associação entre a presença de lesões na superfície dorsal e flexora tiveram a relação estatística mais forte ( $p\text{-value}<0,001$ ; phi-coefficient: 0,729), seguidos da associação entre a presença de lesões no bordo proximal e superfície dorsal ( $p\text{-value}<0,01$ , phi-coefficient: 0,704). Associação entre presença de lesões no bordo distal e bordo proximal foi a associação com menor relação estatística entre todas as áreas do osso navicular, ainda assim com uma forte e positiva relação estatística ( $p\text{-value}<0,001$ ; phi-coefficient: 0,434). Os resultados parecem sugerir que normalmente não existe apenas uma área afetada no osso navicular e que uma lesão difusa deverá ser expectável. Outra explicação será a possibilidade de detecção de patologias no osso navicular em estados mais preeliminares da doença ser difícil, devido á ausência de sinais clínicos óbvios ou por adiamento por parte proprietários em vir a consulta.

38% dos cavalos da amostra não apresentaram qualquer lesão no osso navicular. Nenhum cavalo apresentou lesões no bordo proximal ou superfície dorsal sem associação a outras lesões noutras áreas do osso navicular. 18% dos cavalos no estudo apresentaram lesões difusas, afetando todas as áreas do osso navicular, 12% dos cavalos apresentaram lesões que afetaram o bordo distal, dorsal e superfície flexora, 9% dos cavalos apresentaram lesões no bordo distal e superfície flexora e uma minoria de 1% com lesões na superfície flexora e dorsal.

Associações entre lesões presentes no tendão flexor digital profundo e ligamentos colaterais na articulação interfalângica distal ou falange distal, bordo distal do osso navicular e

ligamentos colaterais da articulação interfalângica distal, ligamento impar ou ligamentos colaterais da articulação interfalângica distal, tiveram uma relação estatística negativa.

## **Discussão**

O principal objetivo foi estudar a prevalência de cada lesão associada com o aparelho podotroclear em cavalos de desporto, que foram submetidos a um exame de ressonância magnética. O segundo objetivo era estudar possíveis associações entre as lesões encontradas.

Os resultados suportam o facto de que dor ao nível do casco poderá ser o resultado de alterações numa variedade de estruturas e que diferentes lesões em diferentes estruturas podem ocorrer simultaneamente, provavelmente como resultado da próxima relação anatómica entre as estruturas do casco (Dyson & Murray, 2007; Murray et al., 2006).

Lesões no osso navicular, articulação interfalângica distal, tendão flexor profundo e ligamento impar predominaram na amostra. Associação de lesões ao nível do osso navicular, tendão flexor digital profundo e ligamento impar são bem conhecidas (Wright et al., 1998).

O elevado número de lesões encontradas na articulação interfalângica distal, mas a falta de associações com outras lesões nesta amostra, sugere que a mesma ocorre como um processo separado e independente das outras estruturas (Murray et al., 2006). Outros estudos sugerem que a relação anatómica próxima entre a articulação interfalângica distal e o osso navicular poderá levar, potencialmente, a associação de lesões (Dyson & Murray, 2007) através da pressão causada durante a locomoção e outras microlesões no ligamento impar ou no tendão flexor digital profundo (Kimberly et al., 1997).

A sobrecarga mecânica desencadeia uma cascata de eventos moleculares que podem levar à doença em indivíduos suscetíveis ao aumentar a produção e libertação de radicais livres, citoquinas, catabolitos de ácidos gordos, neuropeptídeos e enzimas degradantes da matriz. Essas moléculas podem estar envolvidas na remodelação articular e subcondral se exceder a capacidade adaptativa da articulação, nos quais os biomarcadores serão detetáveis (Rijkenhuisen, 2006). Mudanças em marcadores bioquímicos na articulação interfalângica distal e bursa navicular foram observadas em cavalos com "doença navicular" clínica. Os marcadores bioquímicos são uma expressão de um processo ativo e podem não refletir os danos

acumulados ao longo do tempo (van den Boom et al., 2004) e sua confiabilidade para indicar patologia em qualquer articulação dada ainda não foi confirmada (McIlwraith, 2005).

Neste estudo, lesões na articulação interfalângica distal tiveram uma relação estatística positiva com lesões na falange distal refletindo a extensão das lesões para a zona subcondral. Houve também uma relação estatística positiva entre lesões desta articulação e lesões na cartilagem articular e bursa navicular.

Lesões no ligamento impar não tiveram relação estatística com lesões no tendão flexor digital profundo, osso navicular, ligamentos colaterais do osso navicular ou bursa navicular como descrito em estudos prévios (Dyson & Murray, 2007; Murray et al., 2006). Uma relação estatística negativa foi observada entre lesões do ligamento impar e ligamentos colaterais da articulação interfalângica distal, indo contra estudos previamente publicados, podendo ser o resultado da seleção de casos para o estudo.

Lesões no tendão flexor digital profundo foram comuns. Houve uma relação estatística positiva entre estas lesões e lesões na bursa navicular. Associação de lesões entre o tendão flexor digital profundo e a falange distal ou ligamentos colaterais da articulação interfalângica distal tiveram uma relação estatística negativa. Estudos prévios demonstraram a associação positiva entre lesões do tendão flexor digital profundo e lesões do ligamento impar ou ligamentos colaterais do osso navicular (Dyson & Murray, 2007), não tendo isso sido observado neste estudo. Associações de lesões no tendão flexor digital profundo e a bursa navicular podem ser expectáveis devido à próxima relação anatómica entre ambas as estruturas, particularmente em casos de lesões do bordo dorsal do tendão flexor digital profundo ou bursite navicular (Schramme, 2011). Lesões no tendão flexor digital profundo são mais frequentemente observáveis ao nível dos ligamentos colaterais do osso navicular e ao nível do osso navicular, seguidos do ligamento impar e inserção distal (Dyson & Murray, 2007). Os resultados sugerem que com o aumento de lesões no tendão flexor digital profundo existe uma diminuição no número de lesões no processo palmar da falange distal e ligamentos colaterais na articulação interfalângica distal, ainda que por lógica pensemos ao contrário devido á próxima relação anatómica destas estruturas, podendo também refletir o resultado da seleção de casos da amostra.

Uma relação estatística positiva foi observável entre lesões na bursa navicular e o bordo distal do osso navicular, descritas previamente noutros estudos (Dyson et al., 2003; Dyson and Murray, 2007).

Foi encontrada também uma relação estatística positiva entre lesões nos ligamentos colaterais da articulação interfalângica distal e lesões na falange distal. Tem sido sugerido que movimentos rotacionais e lateromediais da articulação poderão resultar em lesões dos ligamentos colaterais que poderão ocorrer ao nível da origem, do corpo ou inserções distais do ligamento na falange distal (Zubrod et al., 2005). Embora neste estudo não tenha sido observada qualquer relação estatística entre lesões dos ligamentos colaterais e articulação interfalângica distal, estudos prévios obtiveram os mesmos resultados (Murray et al., 2006).

Foi encontrada uma relação estatística negativa entre lesões dos ligamentos colaterais da articulação interfalângica distal, bordo distal do osso navicular e tendão flexor digital profundo, não suportada ainda por outros estudos.

## **Conclusão**

“Síndrome navicular ou podotroclear continua a ser uma causa comum de claudicação no cavalo, podendo ser o resultado de várias condições clínicas. Este estudo sustenta que várias combinações de problemas podem contribuir para a claudicação.

A grande variedade de possíveis tecidos lesionados dentro do casco torna o diagnóstico um desafio para os veterinários. É essencial uma investigação prévia e precisa da através de um exame de claudicação antes de proceder a um exame de ressonância magnética. Bloqueios anestésicos diagnósticos, deverão ser realizados para assegurar que o casco é a fonte de dor e outras modalidades de diagnóstico de imagem aplicados, como radiologia e ultrassonografia, para excluir ou confirmar diagnósticos diferenciais, quando possível.

Os exames de ressonância magnética são dispendiosos e, por esse motivo, só devem ser realizados quando outras técnicas de imagem falham na obtenção do diagnóstico final, ou quando é necessária mais informação sobre a natureza das lesões e distribuição. A ressonância magnética é uma ferramenta útil, não apenas no diagnóstico específico do que anteriormente foi agrupado num diagnóstico vago de síndrome podotroclear, mas também no fornecimento de prognóstico e ajuda a direcionar o tratamento e a reabilitação.

A quantidade de lesões encontradas neste estudo, e as suas possíveis associações é tão vasta que tornam impossível categorizar todas as possibilidades de associações de lesões. Por isso, cada caso deverá ser avaliado como situação singular.

O aumento do conhecimento acerca dos processos biológicos, anatomia, possíveis patologias e as suas respostas a tratamento médico ou cirúrgico e reabilitação ajudam a conceber possíveis desfechos e evolução da própria patologia.

Patologias do osso navicular continuam a provar ser uma importante causa de claudicação no membro anterior, mas, lesões noutras estruturas devem ser sempre consideradas, uma vez que estruturas anatomicamente relacionadas são comumente acometidas.

## Abbreviations and Symbols

1. MRI: Magnetic resonance imaging;
2. MR: Magnetic resonance;
3. DDFT: Deep digital flexor tendon;
4. DIPJ: Distal interphalangeal joint;
5. FSE: Fast spin echo;
6. SE: Spin echo;
7. GRE: Gradient echo;
8. RF: Radio-frequency;
9. DSIL: Distal sesamoidean impar ligament;
10. CSL: Collateral sesamoidean ligament;
11. P3: Distal phalanx;
12. T2W: T2-weighted;
13. T1W: T1-weighted;
14. SNR: Signal to noise ratio;
15. MI: Motion Insensitive;
16. STIR: Short Tau ( $\tau$ ) Inversion Recovery;
17. PD: Proton Density;
18. PDW: Proton Density –weighted;
19. PTA: Podotrochlear apparatus;
20. HR: High-resolution;
21. P2: Middle phalanx;
22. TE: Echo-Time.

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## **I- EXTERNSHIP**

My final curricular externship to obtain the Master Degree in Veterinary Medicine from FMV-ULHT, was made in the Pferdeklinik Leichlingen GmbH, in Germany, under supervision of Dr. Klaus-Peter Neuberg and Dra. Juliane Veh.

The externship was carried between the 28 September 2015 and 1<sup>st</sup> April 2016, approximately 6 months of duration. In the first 2 months, I had a rotative schedule within the hospital which included daily routine practice as well as nightshifts. In this initial 2 months period I developed a strong interest in sports horse medicine, orthopedics and diagnostic imaging. To further deepen my interest in these subjects, I was given the opportunity to work with and support Dr. Neuberg in the Orthopedic department for the rest of my Externship. I was assisting during the daily routine in a busy hospital with a high orthopedic caseload. Orthopedic work included normal day orthopedic referral appointments, lameness examinations and pre-purchase examinations, weekend-shifts and stable visits as well lameness investigation in hospitalized horses and x-ray duty.

Every Thursday we had a Journal Club in which we discussed a special clinical case, scientific articles or a chapter of the Equine Surgery Book. All of the procedures were carried under supervision of a board certified veterinary surgeon.

### **1. Pferdeklinik Leichlingen**

The Pferdeklinik Leichlingen was founded in 2011 by Dr. Björn Nolting, Dr. Matthias Krebs and Dr. Guido von Plato, and is located between Düsseldorf and Cologne, in Germany. The hospital provides referral and first opinion service and covers all aspects of modern equine medicine such as Orthopedics, Sports Medicine and Diagnostic Imaging, Internal Medicine, intensive Care and Emergencies as well Surgery.

The hospital is divided into different sections. The main building contains the reception desk and waiting room, pharmacy and administrative offices and is connected to the emergency room. In the emergency room where receive all the emergencies, despite cases suspicions of infectious disease, is equipped with a stock 1 ultrasound machine and a portable x-ray machine. The laboratory is directly connected to the surgery room. Just next door to the emergency room is close is the intensive care stable that houses 16 boxes, with 2 foal boxes and 2 stallion boxes.

The orthopedic building has 5 examination rooms, 3 ultrasound machines, 1 x-ray room with a non-portable x-ray machine, and 1 MRI room. Outside there are two trot up strips, a circle with firm sand for lunging on hard ground as well as a sand school outdoor arena, used for ridding and lameness or pre-purchase examinations.

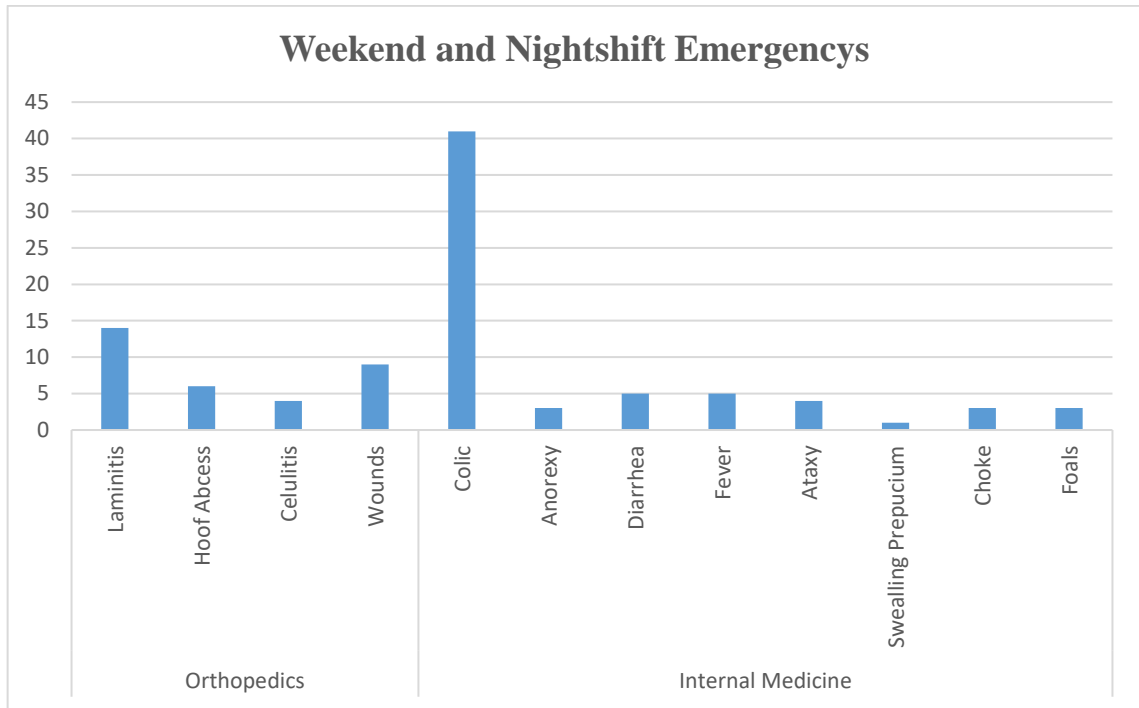
The Internal medicine building has 2 big rooms in which one has one stock used for endoscopy and standing surgeries and the other normally is reserved for dentistry.

The hospital still has 2 more stables each one with 16 boxes, a isolation unit with 6 boxes and a nuclear scintigraphy building with 8 boxes and an outside grazing area for hospitalized horses, and another barn. The barn there is a indoor lunging circle with soft sand and another 8 boxes.

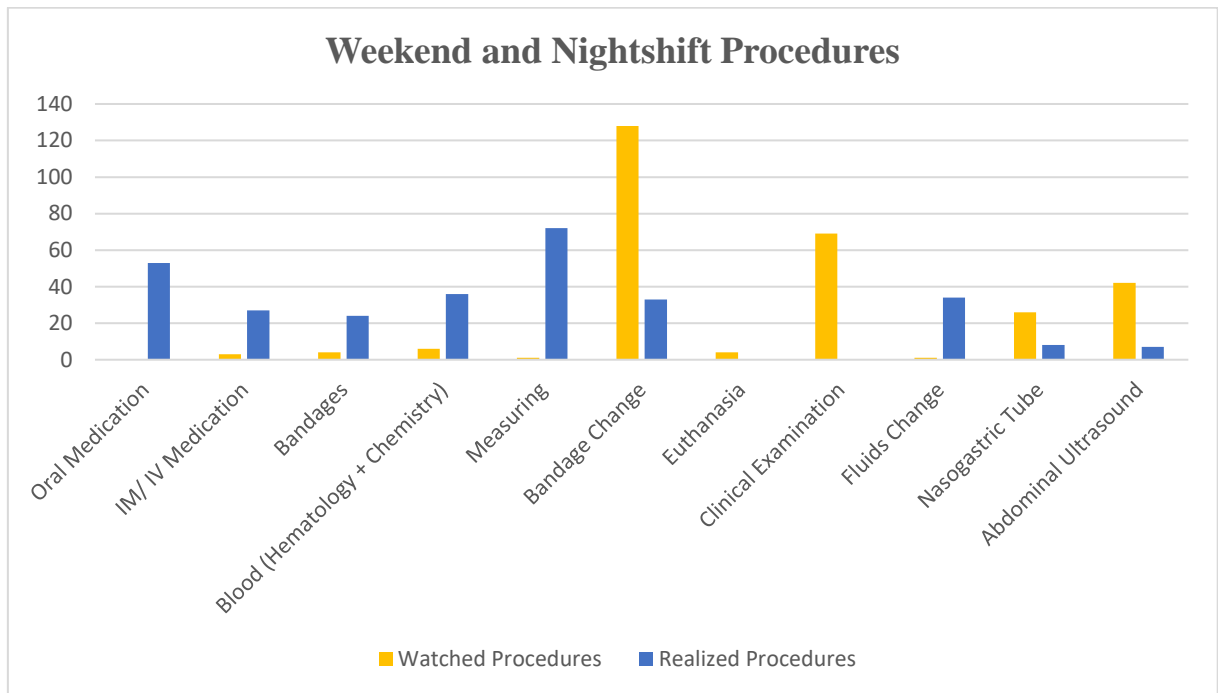
## **2. Casuistry of Externship**

Everyday morning started at 8am with the rounds, where all the vets were going through the stables, box by box, reviewing the clinical history of the patient, current treatments and current state of the patient. After the rounds all the externs were distributed into either orthopedics or internal medicine, surgery, stables and emergency duty, the last one also on nightshift emergency call.

The stable work started in the morning by doing a follow-up examination on the critical patients, normally emergencies admitted in the previous night or during the weekendshift (see figure 1 and 2). After taking care of the inpatients, was time to help the stables nurses finishing bandage change and oral medication or IV/IM medication. Further responsibilities of the students was to take the temperatures, heart and respiratory rate, checking the color of the mucous membranes, auscultation of the and checking gastric reflux with the nasogastric tube. Once this was finished, the student would follow the vet on call to help with the emergencies. In the spare time the student would stay and provide help wherever needed.



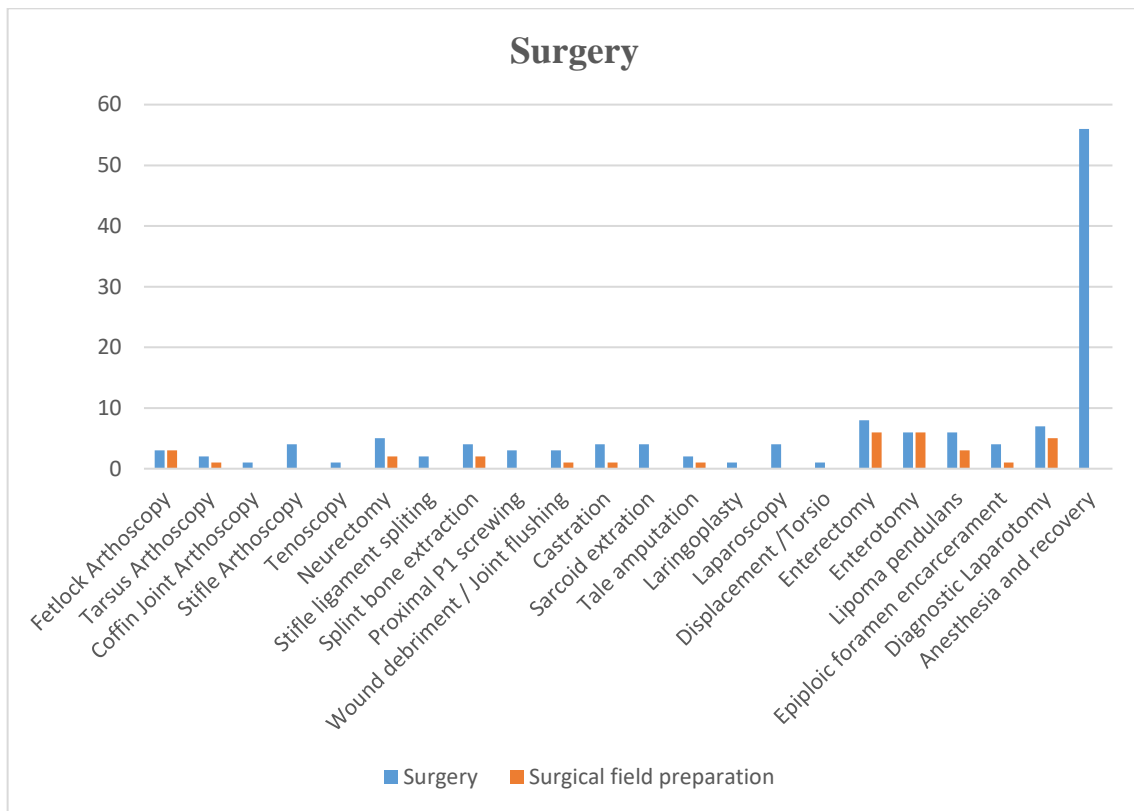
**Figure 1** Emergencies cases during weekend and nightshift duty



**Figure 2** Total of procedures observed vs. done during weekend and nightshift duty.

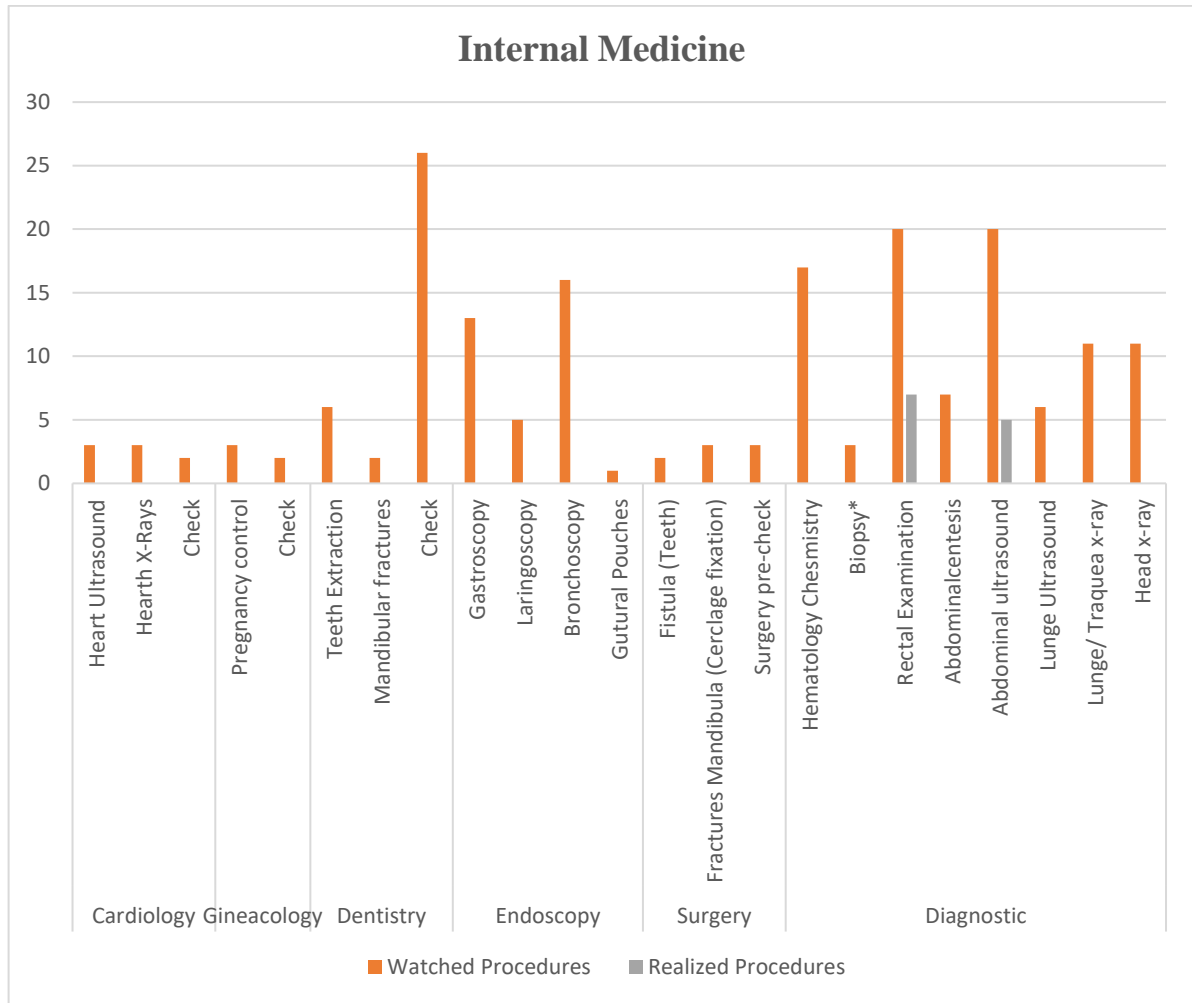
While on surgery duty (see figure 3), we started in the morning with a brief clinical examination of all surgical candidates for the day. Before going into the knock-down-box the horses were prepared by flushing the mouth with water, putting the stables bandages in all four

legs and in colic patients a nasogastric tube was placed. In the knock-down-box there as usually four people to anesthetize the horse. When the horse is oin the floor, the anesthetist puts the endotraqueal tube in and the horse is lifted with a crain on to the surgery table. Depending on the type of surgery the horse can be positioned right or left lateral recumbency or dorsal recumbency. After its properly positioned, the surgical field is prepared and the nurses start scrubbing with chlorhexidine solution followed by 70% alcohol. During the surgery it self, the student would either watch the surgeon, assisting the surgeon if necessary or help with the anesthesia. Afterwards the student would help to recover the horse, while the anesthetist would knock the next horse out and keep going. On a routine day the hospital would operate and average from 5 to 7 horses.



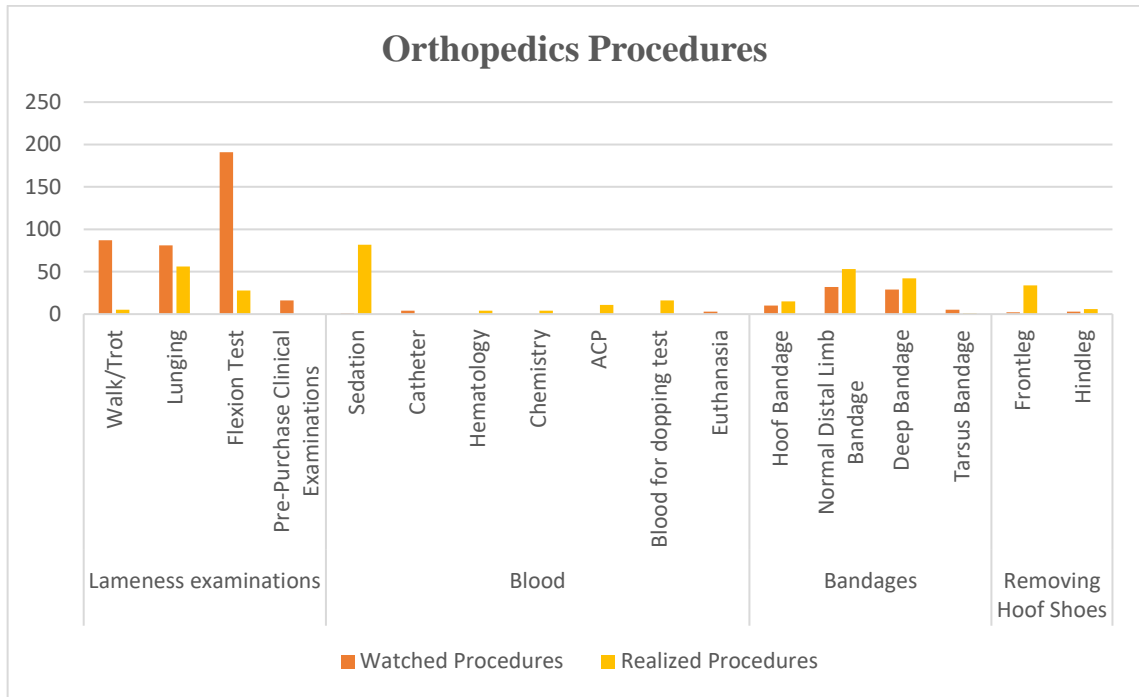
**Figure 3** Total of surgeries and surgical field preparations during surgery duty.

While on the Internal Medicine department (see figure 4), the day also started by making a “to do” list of all the in patients, and normally included endoscopy as well as helping the stables vet with emergencies and also laboratory work. Normally the first appiotments would start before lunchtime.

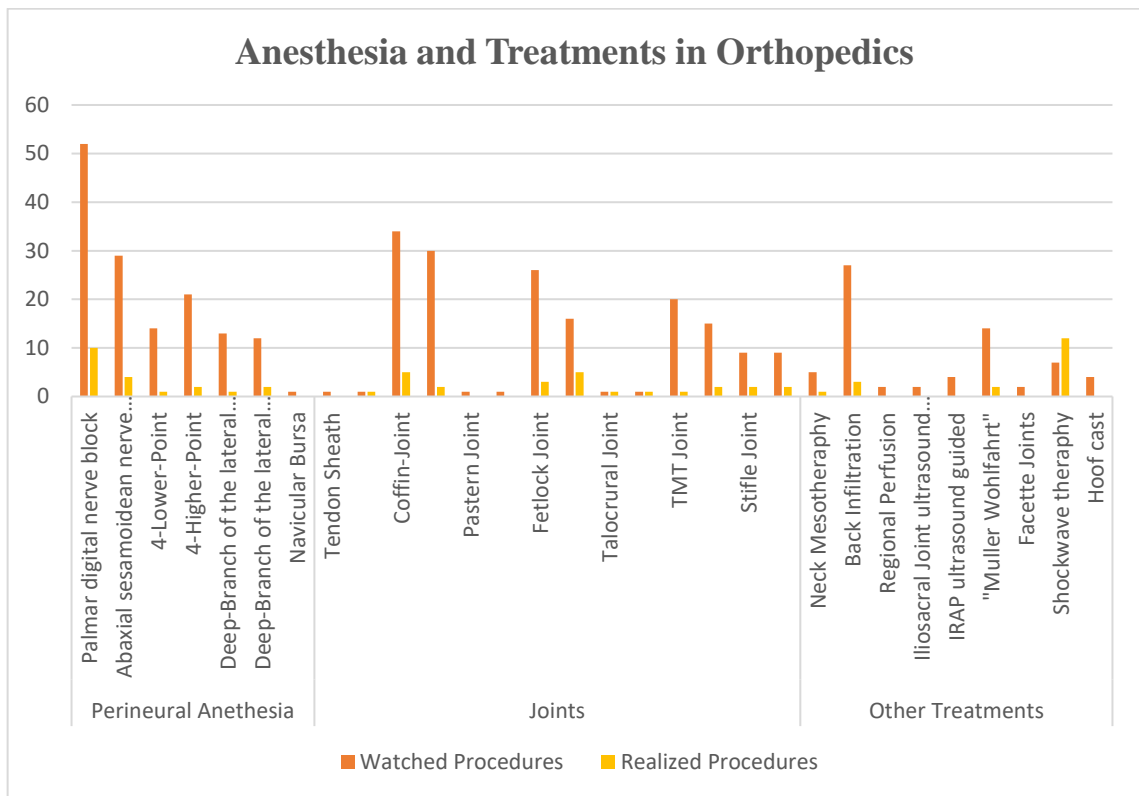


**Figure 4** Total of cases and procedures during internal medicine duty. \*Liver and lung biopsy.

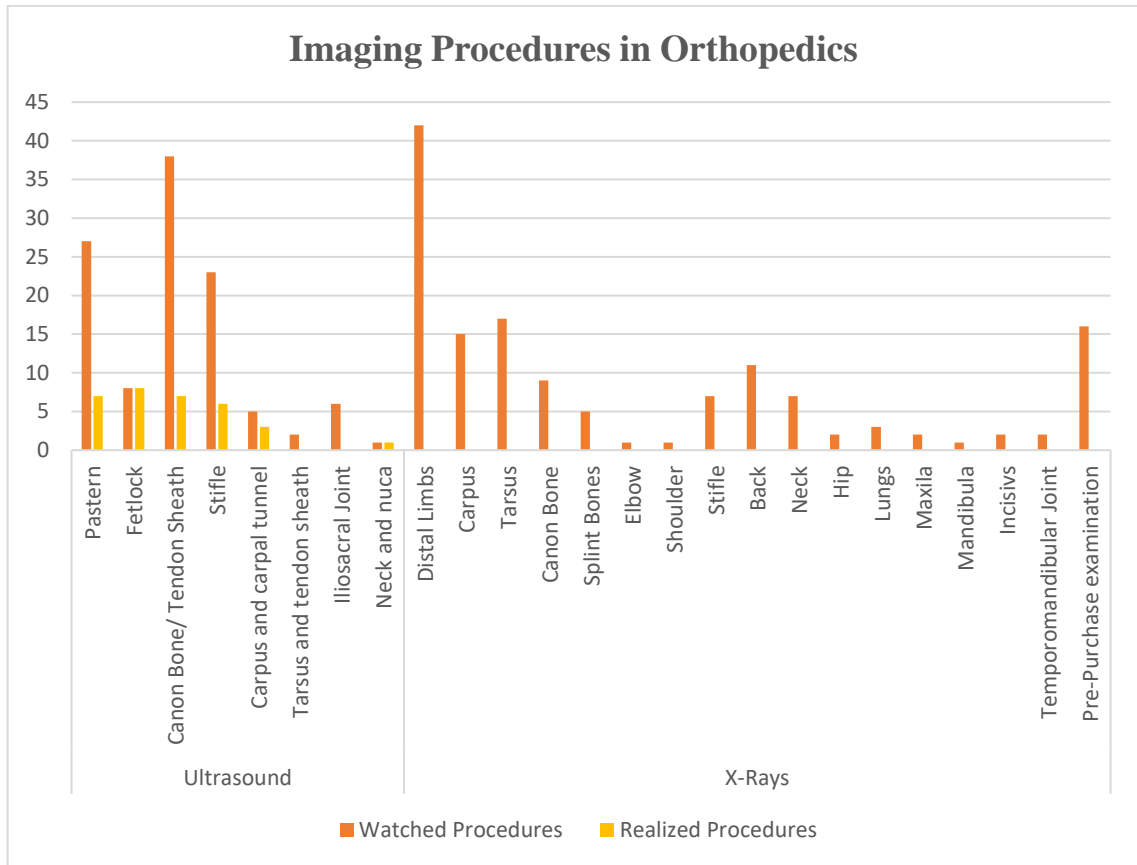
As mentioned before, I spent almost 3 months in Orthopedics where I was mostly assisting Dr. Neuber and occasionally other vets. After the rounds, the student would start the day by checking the list of all the appointments throughout the day and out to fit the inpatients in between them. Depending on how busy the day was going to be, the day was started with appointments or with inpatients. The student responsibility was to constantly assist the vet throughout the day and discussing every case. In the early stages of the externship in orthopedics the student started by assisting in basic things such as to trot the horses up and lounging them, scrubbing for nerve blocks and sterile joint injections, preparing ultrasounds and process blood samples in the laboratory. As time went on, the student was allowed to do all types of medical procedures, like perineural anesthesia, joint injections and ultrasounds, always under supervision of Dr. Neuberger (see figure 6 and 7). In Orthopedics, there was a chance to see the most variety of cases and choice of treatments or procedures and specially to see follow up examinations and the course of recovery in every case (see figure 5).



**Figure 5** Total observed vs. done procedures during orthopaedic duty.



**Figure 6** Anaesthesia and treatments observed and realized during orthopaedic duty. Notice that in joint injections the column of the left is regarded on anaesthesia and the right on treatment.



**Figure 7** Imaging procedures watched and realized during orthopaedic duty.

## **II- LOW-FIELD MRI IN PODOTROCHLEOSIS**

### **1. Introduction**

MRI is a diagnostic imaging modality that depends on the distribution and concentration of hydrogen nuclei in biological tissue, its properties and how each nuclei reacts and resonates in the presence of a magnetic field (Labruyère & Schwarz, 2013; Lauterbur, 1973). Hydrogen is among the most sensitive nuclei to a magnetic field gradient and it is a nuclei with natural abundance in biological tissue, making possible the creation of images with no need to expose or add any other substance (Armstrong & Stephen, 1991).

When a magnetic field is applied to hydrogen protons, the MRI can create an image by detecting the signal of these protons in the water and fat of biological tissues (Armstrong & Stephen, 1991; Damadian, 1971; Lauterbur, 1973).

This is accomplished by placing the part of the limb to be imaged within a magnetic field and to subject it to perturbing radiofrequency pulses (Armstrong & Stephen, 1991; Labruyère & Schwarz, 2013). Magnetic resonance signal intensity vary widely in different musculoskeletal tissues, due to differences in proton density and status of the chemically free versus bound hydrogen nuclei, and for that reason, different tissues will appear differently in the same image or scan (Armstrong, 1991). Applying a linear magnetic field i.e. a magnetic field stronger on one side, the position of the nuclei can be determined by measuring the resonance frequency. Because they are in different position in the field gradient, they resonate in different frequencies (Armstrong & Stephen, 1991; Lauterbur, 1973).

Magnetic resonance signal can be detected from a wide range of nuclei, but as explained above, only hydrogen nuclei are used because of their unique benefits, and the term “nuclear” was dropped and the abbreviation MRI was used ever since (Armstrong & Stephen, 1991; Murray, 2011).

#### **1.1. Basics of MRI**

Magnetic resonance images depend on the absorption of radio-waves (radiofrequency pulses) by hydrogen nuclei. The radiofrequency (RF) pulses are transmitted to the patient by a RF transmitter coil and absorbed by hydrogen nuclei. The nuclei gain energy and reemit this energy through RF signal wich is detected by a RF receiver coil (Armstrong & Stephen, 1991).

The size of the RF signal will depend on proton density i.e. the number of hydrogen nuclei in the tissue, T1 and T2 relaxation times (Armstrong & Stephen, 1991; Murray, 2001). T1 and T2 relaxation times reflect the rate at which excited protons lose their energy (Armstrong & Stephen, 1991). Every MR image contains both T1 and T2 information, but by choosing the appropriate timing and length of the RF pulses, the images can depend mainly on one or the other (Armstrong & Stephen, 1991). Different combinations of RF pulses and magnetic fields can be used to create sequences of images with different contrasts (Labruyère & Schwarz, 2013).

The body part of interest has to be placed into a magnetic field. The stronger the magnetic field, the greater the proportion of nuclei that will line up in the direction of the field, and the stronger the signal will be received (Armstrong & Stephen, 1991; Murray, 2001). In low-field, standing MRI, usually, it is used a 0,27T field strength. Since the spatial origin of the signals can be localised, an image can be created (Armstrong & Stephen, 1991; Lauterbur, 1973).

In terms of physics, the nucleus of each atom is electrically positive due to the presence of charge carrying-protons (Murray, 2001). Besides these properties, neutrons and protons have another physical property called spin, that gives rise to the phenomenon of nuclear magnetic resonance (NMR). (Armstrong & Stephen, 1991; Murray, 2011).

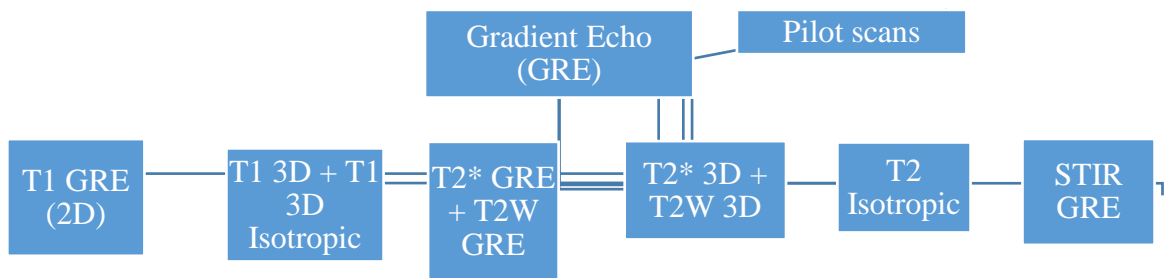
When the patient is placed into the magnet, the nuclei in the biological tissue will line up with the direction of the field (Armstrong & Stephen, 1991; Murray, 2011). RF pulses transmitted cause some protons to alter their alignment relative to the field. Once the RF coil is turned off the protons return to their original equilibrium, accompanied by a release of energy in the form of a RF signal, which will be captured by a receiver coil (Labruyère & Schwarz, 2013).

T1 relaxation time represents the rate at which the excited protons realign with the field, after the transmitter RF coil is turned off (Armstrong & Stephen, 1991; Labruyère & Schwarz, 2013). In MRI, the RF pulses excite the protons to a higher energy state but also put them in to phase. When the pulse is turned off, the protons start to dephase. T2 is a relaxation time, that reflects the rate of signal decay due to dephasing of the spinning protons (Armstrong & Stephen, 1991).

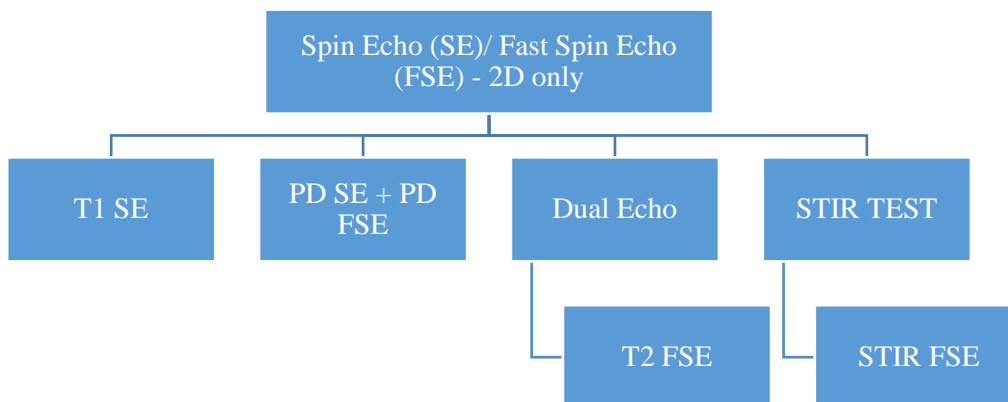
In biological tissue, T1 is faster in fat and slower in fluid/water and this can be used to distinguish both of them on images. By applying pulses in quick succession, the water nuclei never get a chance to recover, contrary to the fat nuclei that do so repeatedly and generate a strong signal. (Damadian, 1971; Damadian et al, 1974; Murray, 2011)

T2 relaxation is sensitive to the degree of mobility of a substance, being much longer in fluids and shorter in solid material and also being extremely sensitive to the external environment (Murray, 2011).

As mentioned above, pulse sequences can be defined to create images with different contrasts (Labruière & Schwarz, 2013). A pulse sequence are usually repeated many times during a scan, whereareas the time interval between pulses and the amplitude and the shape of the gradient waveforms will control the signal reception and affect the characteristics of the MR images. Computer programs that control all hardware aspects of the MRI measurement process drive pulse sequences. Gradient-Echo (GRE) and Spin-Echo (SE) are the two different types, that are used most frequently (MR- Technology Information Portal, 2003; Murray, 2001).



**Figure 8** GRE Pulse sequence Family Tree (Adapted from Hallmarq Veterinary Imaging, 2011)



**Figure 9** SE and FSE Pulse Sequence Family Tree (Adapted from Hallmarq Veterinary Imaging, 2011).

The signal to noise ratio (SNR) is used in MRI to describe the relative contributions of a detected signal to the true signal and to random superimposed signals ('background noise') - a criteria for image quality (MR- Technology Information Portal, 2003; Murray, 2001).

GRE sequences have a higher signal to noise ratio and lower T2W contrast when compared to SE that have higher T2W contrast and lower signal to noise ratio. For that reason, SE sequences can have poorer image quality, when compared to GRE sequences, and necessitate reduced spatial resolution and increased slice thickness. GRE sequences are more susceptible to some artifacts and are more useful to obtain high anatomic resolution images and T1W images of bone (Murray, 2001).

<b>GRE</b>	<b>SE/ FSE</b>
Fast imaging sequences	Slower sequences
Less sensitive to patient motion	More sensitive to patient motion
High relative SNR	Lower relative SNR
Less image contrast	Greater image contrast
Sensitive to magnetic field distortions – signal “drop out”	Relatively insensitive to magnetic field distortions
Fat/water cancellation artefacts can occur	Less susceptible to image artifacts
Mix of T1W and T2*W contrast	Image contrast is easier to understand
2D or 3D scans	2D scans only

**Table 1** Differences between GRE and SE/FSE (Adapted from Hallmarq Veterinary Imaging, 2011).

## **1.2. MRI Safety, Equipment and Facilities**

Although MRI practice does not carry hazards like some other modalities in imaging such as radiology and scintigraphy (Labruyère & Schwarz, 2013; Mair et al., 2005), there are still some health and safety issues that should be avoided and minimised. Warning signs should be positioned both on the front MRI door and inside. The MRI room should have restricted access, and should be entered through a lockable door only (MR- Technology Information Portal, 2003; Murray, 2001). All ferromagnetic objects including medical equipment such as scalpels/blades and clippers, will be attracted to the magnet, this may cause issues for the technicians or the horse and, if used too close can cause a magnetic field disruption, resulting in image artifacts (Hartwig et al., 2009; Murray, 2011). To scan the hoof region, the hoof-shoes

have be removed before hands, and a dorsoproximal-palmarodistal x-ray picture should be taken prior to the scan, to make sure there are no nail pieces left, that may cause artifacts (Murray, 2001). It is essential that no metallic object are allowed to enter the MRI room, this includes personal objects of the technicians like watches, mobile phones, coins and jewelry. The same is applied to all magnetic material implanted into the horse or patient such as pacemakers or other metallic implants that can have their function disrupted (Hartwig et al., 2009; MR- Technology Information Portal, 2003; Murray, 2011).

### **1.3. Image Interpretation**

The MR images are produced in a grey scale with a varying range of contrasts that are a result of the level of signal intensity (Mair et al., 2005). The appearance of a tissue on the image is affected by its nature, by the system, pulse sequence and acquisition parameters (Armstrong & Stephen, 1991; Labruyère & Schwarz, 2013). When a tissue is injured, changes in the tissue structure, biochemical composition or water distribution result in alterations in the MR images appearance (Murray, 2011).

The signal comes mainly from the mobile hydrogen protons present in fat and water (Armstrong & Stephen, 1991) and that is why structures that have just a few or no free hydrogen protons appear black (Mair et al., 2005; Murray, 2001). The contrast in the images can be determined by Proton Density (PD), T1 and T2 properties (Armstrong & Stephen, 1991) and by manipulating the pulse sequences, and for that reason a tissue has different appearances on T1, T2 and PD images (Labruyère & Schwarz, 2013; Murray, 2001). For images referred as T1 or T1-weighted, contrast is dependent mainly on T1 relaxation properties, for T2 or T2-weighted, the contrast is dependent on T2 relaxation properties and PD or PD-weighted the contrast is dependent on the proton density i.e. the number of free and mobile hydrogen nuclei in the tissue (Murray, 2011).

Fluids have long T1 relaxation time but it is very short in fat-based tissues. On T1W images water based tissues will appear in a mid-grey scale, depending on the water content as with more water on the tissue the image becomes darker. Tissue with higher water content due to edema or increased capillary content will appear darker than the surrounding normal tissue. Fat based tissues, on T1W images will appear brighter (Murray, 2011). T1W provides the best anatomical detail and for this reason is considered the standard accepted sequence for baseline information of the musculoskeletal system (Mair et al., 2005).

On T2W images, the fluid appears bright while water-based and fat-based tissues have intermediate signal intensity. T2W images have less anatomical detail and less resolution when compared to T1 and so, they have a grainier appearance. They are very useful to detect based-fluid pathology like edema and inflammation as they appear as areas of increased and high signal intensity against the darker normal tissue and for the evaluation of synovial structures. (Mair et al, 2005; Murray, 2001) However, if there is increased fluid content in a fat-based tissue like medullary bone, it might be difficult to assess the increased signal using T2W images, due to the signal coming from the fat. Sequence parameters can be adjusted to improve detection of fluid in fat-based tissues and therefore it is useful to suppress the fat signal, using fat suppressed images i.e. Short tau Inversion Recovery (STIR), allowing to differentiate high signal from fluids within the tissues or fat. (Kleiter et al., 1999; Murray, 2011)

		<b>T1W</b>	<b>T2W</b>	<b>PDW</b>	<b>STIR</b>
<b>Bone</b>	<b>Cortical and subchondral bone</b>	Black- zero signal intensity			
	<b>Trabecular bone</b>	Heterogeneous: Trabecular with minimal signal surrounded with high signal intensity from fat: Influenced by fat content and bone mineral density and distribution.			
<b>Tendons</b>		Black			
<b>Ligaments</b>		Dark grey- low signal intensity			Black
<b>Articular Cartilage</b>		Light grey- Intermediate to high signal intensity	Dark grey- Intermediate to low signal intensity	Light grey- Intermediate to high signal intensity	Black
<b>Synovia</b>		Dark grey/Black- Low signal intensity	White- High signal intensity	-	White- High signal intensity
<b>Vessels</b>		-	-	-	-

**Table 2** Biological tissue appearance in the MRI scans (Adapted from Murray, 2001).

As described above, STIR scans are a form of fat suppression that allows any underlying fluid signal to be seen by suppressing the fat signal (Mair et al., 2005; Murray, 2001). STIR scans can be both GRE or FSE (Hallmarq, 2011).

## **1.4. Image Quality and Artifacts**

Image quality is determined by signal, noise, contrast and artefacts, but signal, and noise are often considered together as the signal to noise ratio (SNR) (Murray, 2011).

### **1.4.1. Signal**

The MR signal comes from the hydrogen nuclei within the biological tissue. Increased field strength and increased amounts of material, give more signal but this is sharply reduced as the image resolution increases (Murray; 2011).

### **1.4.2. Noise**

Electrical noise is generated by thermal motion of electrons in the sample, coil and amplifiers and care should be taken not to allow any external sources of noise to further degrade the image quality (Murray, 2011).

### **1.4.3. Contrast**

If images were with no contrast at all and all tissues of the same grey intensity, they wouldn't have any diagnostic value. The contrast of the images comes from the different amount of signal (proton density) within the different tissues but for diagnostic interpretation a greater contrast is obtained at lower signal strengths. So normally, GRE images have more signal but less contrast and on the other hand, SE images have more contrast but less signal (Murray, 2011).

### **1.4.4. Artefacts**

Artefacts is the term for everything in an image, that does not truly represent what is being imaged. The dilemma of an artifact is that it can be interpreted as a pathologic finding and, therefore, can lead to a false diagnosis. Artefacts do occur commonly. They can be caused by patient related factors, acquisition technique, nature of the MRI and also due to imperfections in the system. They are classified into motion artifacts, magnetic field inhomogeneity and digital imaging artifacts (Murray, 2011). The artifacts are:

- 1. Motion artifacts:** Are caused by movement during scans acquisition, including involuntary movements such as breathing, pulsatile movement in the vessels and blood

flow, or small movements in over sedated horses. This results in a smearing or blurring and ghosting of the scans. Continuous movement of the area to be scanned can lead to a non-diagnostic scan. This can be minimised by using motion insensitive (MI) scans, as these allow the system to acquire the data only when the horse is stationary by repositioning of the slices when motion is detected and acquisition of segments in real time, but this lead to longer scans acquisition time. Other option is to use fast or super-fast scans (Murray, 2011).

- 2. Magnetic field inhomogeneity artifacts:** It is mandatory to have a homogeneous magnetic field, in order to obtain a good quality in MR images. A heterogeneous field often leads to artifacts and is normally caused by temperature fluctuations and metal. Metal artifacts are seen as an area of zero signal within a high intensity rim and distortion in adjacent tissues. Metal artifacts are more severe in GRE scans than in SE. In order to minimise these artifacts, temperature and humidity should be controlled inside the MRI room, and it is also important that all the metal is removed within the magnet area, shoes and nails included. It is advised to take a dorsoproximal-palmarodistal x-ray view prior to the scan, to look for any nail fragments after shoe removal as they can produce severe metal artifacts. Steel toecap boots should also be avoided in the area near the magnet. Hemosiderin artifact will appear as a black region on the image that can be useful to determine the extension of a penetrating injury (Murray, 2011).
- 3. Fat/Water Cancellation:** The resonant frequency of fat and water are different, at the time the echo is collected. On T2\* and T2W, both expected to show increased brightness associated with increased fluid water content. This is the basis for their diagnostic use in detecting edema and inflammation. Sometimes, the areas that appear bright in T2W FSE, can appear dark in T2\*W GRE, and this is due to the signal from fat and water cancelling each other out. This phenomenon occurs in injured bone, where fluid and fat can both occupy the trabecular spaces. The true presence of water can be determined by using STIR sequence, but care must be taken not to misdiagnose the lesion as sclerosis. (Hallmarq Veterinary imaging, 2007) If true sclerosis is seen, it should appear as a low signal in all the sequences and on the other way fluid should appear with low signal on T1 GRE but with high signal in STIR, Proton Density (PD) and T2 FSE. (Murray, 2011) The T2\*GRE may be also helpful in detecting fluid as fat/water cancellation does not happen when the amount of fluid is bigger than the fat. (Murray, 2011).

**4. Magic angle effect:** When collagen fibers of tendons and ligaments are aligned at the particular angle of  $54.7^\circ$  ( $\pm 10^\circ$ ) to the main magnetic field, the T2 relaxation increases. Normally the T2 relaxation of normal tendon tissue is so fast, that the signal is gone before it is collected and it is for that reason, that it appears dark. When the tendon is aligned at the “magic angle”, the signal duration is increased and the tissue will have an artefactual increased signal and will appear grey, which can be mistaken as pathology. The magic angle effect is reduced as TE increases, so T2W FSE images are less susceptible while T1W and PDW are more susceptible because of their short TE. In the low field standing MRI, it is often seen in the collateral ligaments of the DIPJ, oblique sesamoidean ligaments, abaxial aspect of DDFT and in the distal annular ligament. It is more likely to occur in the lateral collateral ligament, lateral lobe of the DDFT and medial oblique sesamoidean ligament in the standing horse with the limb slightly abducted, which is the most common position while scanning. It is recommended for this reason, that the horse stands as squarely as possible in order to minimise magic angle effect. Limb repositioning in the magnetic field should also be taken as an option (Murray, 2011);

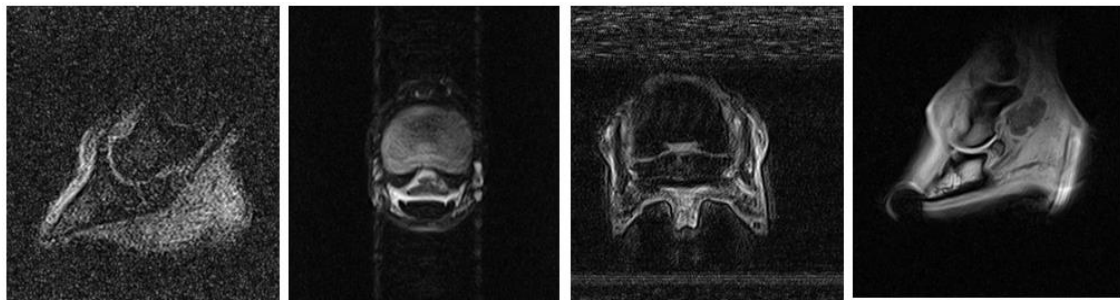
	<b>T1 GRE</b>	<b>PDW</b>	<b>T2*W GRE</b>	<b>T2W FSE</b>	<b>STIR</b>
<b>Sclerosis</b>	Low signal	Low Signal	Low signal	Low signal	Low signal
<b>Fluid (edema)</b>	Low signal	Intermediate to high signal	Intermediate to high signal	Intermediate to high signal	Intermediate to high signal
<b>Phase Cancellation (Water = Fat)</b>	-	-	Low signal	High signal	High signal

**Table 3** Appearance of phase cancellation artefact in the different pulse sequences and its difference to bone edema and sclerosis appearance (Murray, 2001)

**5. Partial volume effect:** This occurs when a mixture of different tissue types is in the same voxel, causing misleading pixel intensities in the images. When curved or irregular

shaped surfaces or edges are scanned and parts of more than one structure appear in the same slice in apposition, or even when they are partially cross, cut between or separated into two different slices, the margins tend to appear less clearly defined and small structures may be missed completely. By reducing the slice thickness, the effect is also reduced but as the SNR is reduced, the imaging time increases. Using a combination of sequences, including HR scans over the area of interest, might also be beneficial. For curved articular surfaces, it is useful to acquire the images perpendicular to the articular surface in several points across the joint (Murray, 2011);

- 6. Temperature effects:** System parameters and image appearance can be affected by the temperature of the magnet but also by the temperature of the tissues. This has more impact when STIR sequences are being used because the optimal inversion time for fat suppression or fluid attenuation is affected by the temperature. It is advised to take a STIR test to find the optimal inversion time (Murray, 2011).



**Figure 10** MRI Artefacts. From the left to the right the first picture represents the “noise” caused by a heterogeneous magnetic field due to temperature floatation. The second picture represents a motion artefact from the blood vessels. The third and fourth pictures a heterogeneous magnetic field due to radiofrequency interference and a piece of metal from a nail, respectively.

## 1.5. Clinical Approach to the Lamé Horse

### 1.5.1. Anamnesis

Clinical history, should be taken to obtain basic information such as age of the horse, sex, breed and use, and additional information with questions tailored to the specific patient (Ross & Dyson, 2003). An accurate history is an essential step in attempting to identify the cause of a poor athletic performance or lameness (Hinchcliff et al., 2004).

Many pathologies are age-related and some problems also can get worse with advancing age (Ross & Dyson, 2003). There are however situations, when attempting to acquire an accurate history is a true challenge (Moyer, 2010). It is very important to directly ask the

owner about the duration and nature of the problem, if it gets better or worse with exercise and how the problem was managed or treated so far (Moyer, 2010; Ross & Dyson, 2003).

Asking questions in a nonthreatening fashion and avoiding a condescending or sarcastic manner is essential.

<b>Anamnesis: Basic and specific information</b>	
<b>Signalment</b>	Age
	Sex
	Breed
	Use: Competitive activities such as Jumping or Dressage have a subset of predictable/common injuries. Level of competition
<b>Current Lameness What is the problem?</b>	History of trauma
	Duration of lameness
	Deterioration or improvement of lameness and its circumstances
	Exercise effect on the lameness
	Past lameness problems
<b>Management Changes</b>	Changes in shoeing
	Changes in training or performance intensity
	Changes in surface
	Changes in diet and health
	Changes in housing
	Current medication and response
<b>Specific information</b>	Type of sporting activity and level of competition
	Others: <ul style="list-style-type: none"> <li>– Videotapes</li> <li>– Images</li> <li>– Records</li> <li>– Clinical records from other clinic/hospital</li> <li>– Discussions with others</li> </ul>

**Table 4** Information to be included in the anamnesis (Ross & Dyson, 2003).

The role of the veterinarian is to collect as many information as possible, particularly whether the problem is complex or not apparent (Hinchcliff et al., 2004).

Navicular disease is recognised in horses with a wide variety of hoof shapes like the Quarter Horse with narrow and boxy upright feet, Thoroughbreds with flat hoofs and low and collapsed heels and European Warmbloods (Dyson et al., 2010; Waguespack & Hanson, 2010). In case of poor hoof conformation, it is worthwhile improving the trimming and shoeing and re-assessing the lameness after several weeks and if the lameness has markedly improved, it is unlikely to be a navicular problem. (Ross & Dyson, 2003)

### **1.5.2. Physical Examination**

The lameness examination should always begin with the observation of the horse, standing in a square position. (Ross & Dyson, 2003) It is very important at this stage to check from the distance, if there is any muscle asymmetry, areas of swelling and to look for the symmetry of the limbs, as well for limb conformation and hoof configuration (Auer & Stick, 1999; Hinchcliff et al., 2004). Palpation of the vertebra begins at the poll, continues down the length of the cervical spine and ends with palpation of the withers. Limb palpation begins in the front limbs at the level of the scapula and continues down until the hoof. The entire length of the limb is palpated to include the weight-bearing surface of the foot and the shoe (Moyer, 2010). The degree of digital pressure might vary, but with the initial palpation we try to appreciate differences like atrophy, swelling or heat. This is followed by applying increased digital pressure to detect the presence or absence of pain (Auer & Stick, 1999; Ross & Dyson, 2003). The veterinarian should palpate, feel and manipulate every possible anatomical structure, like soft tissue, i.e. muscles, tendons, ligaments and joints. If any finding or doubt, it should be compared with the contralateral limb, always bearing in mind that both sides might be affected (Moyer, 2010). In normal horses, digital pulse may be difficult to detect, especially in cold weather, and so if it is with increased strength, it can be a sign of inflammatory conditions like hoof abscess or laminitis. (Ross & Dyson, 2003)

Examination of the hoof is accomplished by cleaning the sole and the frog with a hoof pick or with a hoof knife. Removal of the shoe is indicated, when a sub-solar abscess is suspected (Moyer, 2010; Ross & Dyson, 2003). When the hoof is prepared, it should be carefully examined with hoof testers. The veterinary should hold the hoof between the legs and must be able to feel the horses reactions to subtle pressure.

Examination is continued to evaluate the length of the back beginning at the withers and ending with the tail head. The initial assessment is followed by more aggressive digital

pressure to appreciate presence or absence of pain, muscle atrophy and symmetry (Ross & Dyson, 2003). The pelvis and pelvic musculature is then palpated with the horse standing as squarely as possible (Moyer, 2010). All the bony protuberances should be palpated, including tubera coxae, tubera sacrale and tubera ischia, by standing behind the horse and palpating both sides simultaneously (Ross & Dyson, 2003). After that the hip and thigh region is palpated and manipulated followed by palpation of the stifle. Distal limb palpation mirrors the technique utilized with the forelimbs (Moyer, 2010; Ross & Dyson, 2003).

### **1.5.3. Examination in Motion**

After examination of horse at rest is completed, dynamic examination should be performed. The horse should be observed at first in a straight line at walk and trot on hard surface (Auer & Stick, 1999). Here it is important to note the synchrony, symmetry and pathway of the limb swing and how each hoof contacts the ground (Auer & Stick, 1999; Hinchcliff et al., 2004). Each foot should normally land heel first, then toe with the lateral and medial aspects of the hoof nearly equally in time. Deviations from normal footfall may indicate dynamic imbalance of the limb that could be due to abnormalities of conformation (Ross & Dyson, 2003). The horse should be trotted in a straight line, away from and toward the veterinarian, followed by in hand trotting on a circle on both right and left reign (Moyer, 2010). Afterwards the horse should also be worked in a lounge line in walk, trot and canter on soft ground, to observe the effects of differential loading between the inside and outside limbs (Hinchcliff et al., 2004; Moyer, 2010; Ross & Dyson, 2003). Canter or galloping may be necessary to appreciate the lameness. The motion examination should be performed on both soft and hard ground due to the fact that some lameness's get worse and more obvious on soft or on harder ground, depending on the cause (Ross & Dyson, 2003). It is also important to assess if the lameness is worsened with ridden work, because some horses thought to be lame are actually victims of poor riding technique (Moyer, 2010).

Forelimb lameness is usually easier to identify (Ross & Dyson, 2003) as the head rises immediately prior to and during weight bearing of the lame limb (head bob), and head dropping as the sound limb contacts the ground. Hind limb lameness can be seen as elevation of the hip ("hip hike"), dropping of the hip, toe dragging or decreased stride length, depending on the nature of the lameness (Auer & Stick, 1999). Severe hind limb lameness is often associated

with head bob in the contralateral front limb, due to weight shifting to the front (Hinchcliff et al., 2004; Ross & Dyson, 2003)

The lame limb is identified and the lameness is scored by its severity:

<b>Grade</b>	<b>Lameness scoring</b>
<b>0</b>	Sound;
<b>1</b>	Lameness difficult to observe and not consistently apparent regardless of circumstances;
<b>2</b>	Mild lameness and consistently apparent under certain circumstances;
<b>3</b>	Obvious lameness observable under all circumstances;
<b>4</b>	Severe lameness with extreme head nod and pelvic hike present;
<b>5</b>	No weight bearing.

**Table 5** Quantification of lameness severity (Ross & Dyson, 2003).

After determining the affected limb and the degree of lameness by watching the horse in motion, identification of the region of the limb is pursued by manipulation and flexion test (Auer & Stick, 1999; Moyer, 2010). The flexion tests are used to apply stress or pressure on an anatomic region of the limb during a period of time with the purpose of lameness exacerbation (Ross & Dyson, 2003). Following the flexion test, the horse is trotted and the effects of the flexion on the gait are observed (Hinchcliff et al., 2004). The amount and duration of pressure applied may affect the outcome, as horses are more likely to manifest a false positive response as the force increases (Auer & Stick, 1999). Flexion test lack specificity because it is nearly impossible to flex a single joint without to flex other joints or nearby tissues (Auer & Stick, 1999).

Clinical signs in horses with navicular disease are often first seen between 7 and 9 years of age, although it can occur earlier in age (Waguespack & Hanson, 2010). It is also very common, that a lameness develops after change of ownership due to the change in trimming and shoeing associated with different patterns and different periods of working and rest (Moyer, 2010; Ross & Dyson, 2003). Clinical signs in a horse with navicular disease can be extremely variable. The horse may show a tendency to stumble, associated with a shortening of the stride, may move better on a soft ground, may have coffin joint distention or even lameness. It is very common that the horse shows no lameness at all, and the only complain of the owner could be

loss of action, stiffness or unwillingness to jump (Hinchcliff et al., 2004). The response to distal limb flexion is extremely variable in horses with navicular disease. The lameness is usually worst on hard surface on a circle with the affected limb on the inside (Waguespack & Hanson, 2010). Often the horse response is negative when pressure is applied into the heels and frog region, although some authors have described a positive response fairly consistent in horses with navicular disease (Ross & Dyson, 2003, Waguespack & Hanson, 2010).

#### **1.5.4. Diagnosing Anesthesia**

After performing the dynamic examination, regional anesthesia should be performed to check from which part of the limb the pain arises. Perineural anesthesia should always be performed from distal to proximal (Moyer, 2010).

The first step is to perform a palmar digital nerve block, using no more than 2ml of mepivacaine per site, immediately proximal to the cartilages of the foot after palpating the nerve (Werner, 2013). The lameness is likely to improve in horses with navicular disease after 8 minutes, though sometimes an abaxial sesamoidean nerve block is necessary to achieve soundness (Ross & Dyson, 2003). After waiting the 8 minutes, the horse should be re-evaluated on both straight and circle, to determine if the lameness has improved and if it shifts to the contralateral limb (Ross & Dyson, 2003; Schramme et al., 2007). In horses with severe lameness, it is advised to perform lateromedial and dorsopalmar x-rays views of the foot, prior to blocking, to prevent possible fractures after anesthesia (Auer & Stick, 1999).

For the abaxial sesamoidean nerve block, it should be used no more than 4ml of mepivacaine, 2ml per site, at the base of the sesamoidean bones, below the fetlock joint (Schramme et al., 2015, Werner, 2013).

Typically, perineural anesthesia should first be performed, and after having a positive response intra-articular anesthesia can be considered. If a horse has a positive response to a palmar digital nerve or abaxial sesamoidean nerve block, the next step should be performing a DIPJ block. For that and independent of the approach, the area should be prepared sterile with chlorhexidine solution, scrubbing for at least 5 minutes and cleaning after with alcohol to avoid complications associated with sepsis (Auer & Stick, 1999; Werner, 2013). All the material used to perform this block should be completely sterile, i.e. gloves, needles, syringes, anesthetic drug bottle (Auer & Stick, 1999). For a coffin joint block, 6ml of mepivacaine is placed inside the joint, and the horse is re-evaluated after 5 minutes (Ross & Dyson, 2003; Schramme et al., 2015).

Navicular bursa anesthesia can also be performed with 3 to 4ml of mepivacaine, and similar to a coffin joint, the site of injection and material should be prepared in sterile fashion. It is best performed under radiographic or ultrasonographic control and the needle should be placed in the middle of the flexor surface of the navicular bone (Ross & Dyson, 2003; Schramme et al., 2007). Like the DIPJ anesthesia, the horse should be re-evaluated 5min after. A negative response to anesthesia of the distal limb makes it unlikely that the horse has navicular disease (Ross & Dyson, 2003).

### 1.5.5. Diagnostic Imaging

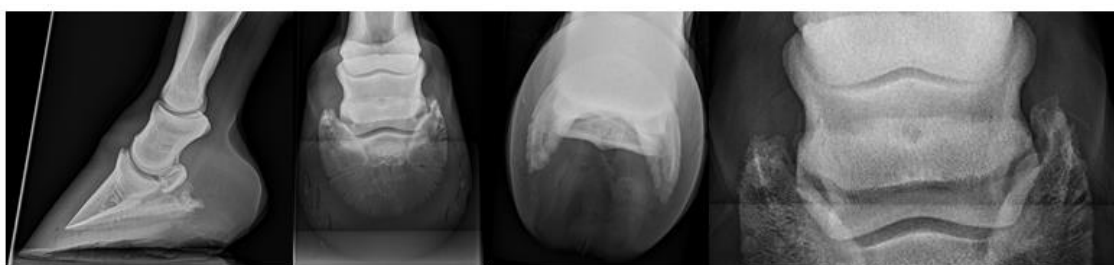
#### 1.5.5.1. Radiographic Examination

After localizing the foot as a source of pain, by clinic examination and diagnostic anesthesia, radiographs should be taken. To improve the quality of the x-rays and to reduce scatter, the shoes should be removed and the hoofs properly prepared (Ross & Dyson, 2003; Butler et al., 2000). It should include at least a lateromedial and dorsopalmar view in weight bearing position as well dorsoproximal-palmarodistal oblique and palmaroproximal-palmarodistal views in a hickman-block. Some extra x-rays can be taken like dorsolateral-palmaromedial and dorsomedial-palmarolateral views (Martinelli & Rantanen, 2002; Widmer & Fessler, 2002). Packing the sole with playdough will eliminate air shadows that might be confused with pedal bone fractures. (Butler et al., 2000).

<b>Condition</b>	<b>Radiographic findings</b>
<b>Excellent</b>	Good corticomedular differentiation with a flexor surface of uniform thickness and with no lucent zones along the distal border or not more than 6 and all similar and narrow.
<b>Good</b>	As above but lucent zones on the distal border of the navicular bone are more variable in shape.
<b>Fair</b>	Slightly poor definition between cortex and medulla, less than 8 lucent zones along the dorsal border and mild enthesophyte formation on the proximal border of the navicular bone.
<b>Poor</b>	Poor definition between cortex and medulla as a result of medullary sclerosis, more than 8 lucent areas along the dorsal border.
<b>Bad</b>	Cyst-like lesions in the medulla. Lucent region or new bone formation on the flexor cortex of the navicular bone.

**Table 6** Classification of navicular bone findings in radiography (Ross & Dyson, 2003).

For many years radiography was the only available tool in diagnosing hoof problems, and as a result the veterinarians were limited to evaluating changes in bony structures (Martinelli & Rantanen, 2002) such as cyst-like lesion, keratoma, ossification of the hoof cartilages, laminitis, degenerative joint disease or fractures (Rijkenhuisen, 2006; Butler et al., 2000).

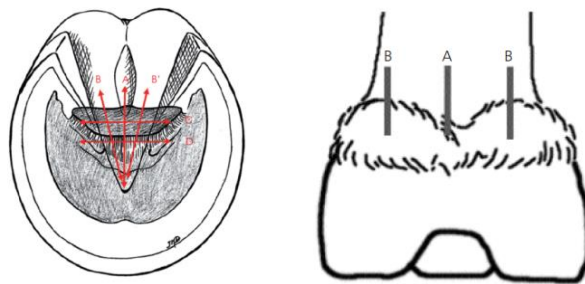


**Figure 11** X- Ray set from the hoof in a horse with a positive palmar digital nerve anesthesia. (A) Lateromedial view; (B) Dorsopalmar view; (C) Palmaroproximal-palmarodistal view; (D) dorsopalmar with the focus in the navicular bone. Note in (D) the accentuated irregularity in the proximal border of the navicular bone, X-rays from Pferdeklinik Leichlingen.

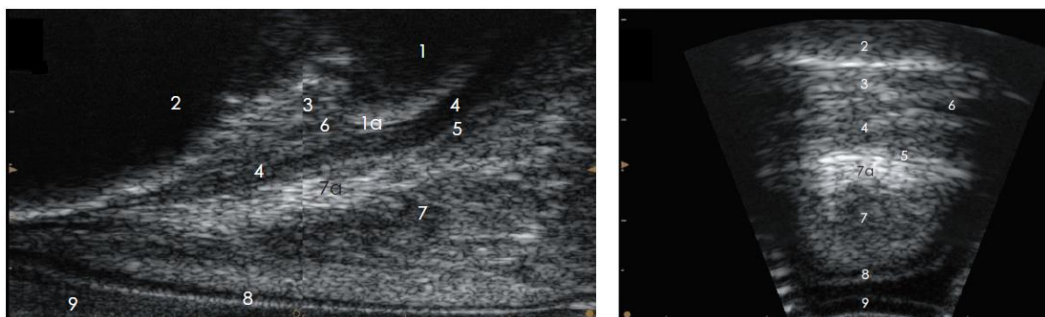
#### 1.5.5.2. Ultrasonography

Radiology of the foot can provide information but normally the diagnostic potential is limited to osteoarticular changes (Kristoffersen & Thoenes, 2003, Widmer & Fessler, 2002). Local anaesthesia can help in isolating the area of interest but does not tell the distribution and severity of the pathology. For these reasons it is common for the clinician to fail in obtaining a definitive diagnosis in horses suffering from palmar foot pain (Kristoffersen & Thoenes, 2003). Ultrasonography is a widely available technique complementary to radiography and routinely used in horses to assess soft tissues (Busoni & J.-M. Denoix, 2001). Ultrasound examination of the podotrochlear apparatus (PTA) includes the suprasesamoidean approach, performed at the distal part of the pastern over the bulbs of the heels, and an infrasesamoidean approach through the frog (transcuneal approach) (Jacquet & J.-M. Denoix, 2012; Busoni & Jean-Marie Denoix, 2001). The main limitations in both techniques are that only the proximal aspect of the PTA can be evaluated with the suprasesamoidean approach (Busoni & Jean-Marie Denoix, 2001) and individual hoof and frog conformation, which will limit access with the infrasesamoidean approach. Transcuneal ultrasound examination can be difficult or even impossible on a foot with a narrow frog or deep central cuneal sulcus limiting coupling between the probe and the frog surface (Jacquet & J.-M. Denoix, 2012).

In the suprasesamoidean approach, the PTA is examined using a 7.5MHz microconvex probe on sagittal, parasagittal and transverse section (J.-M. Denoix, 2011). In the transcuneal approach the preparation of the frog is essential to obtain a ultrasound images with quality (Jacquet & J.-M. Denoix, 2012). Before, the frog should be washed with water and soap, cleaned with a brush and then trimmed with a hoof knife (Kristoffersen & Thoenfer, 2003). After a wet bandage should be applied around the hoof and with a wet cloth packed under the sole. Ideally the horse should stand in a foot bath for 10-15 minutes (Busoni & J.-M. Denoix, 2001). Acoustic gel should be employed to improve the coupling of the probe with the frog surface, but the use of stand-off pad is not required as target anatomical structures are deep (Jacquet & J.-M. Denoix, 2012). The transcuneal ultrasound includes sagittal, medial and lateral parasagittal scans extending from the navicular bone to the distal insertion of the DDFT on the pedal bone. Transverse scans are performed at the level of the navicular bone, distal sesamoidean impar ligament and pedal bone (Busoni & J.-M. Denoix, 2001).



**Figure 12** Ultrasound of the PTA. On the left side, the palmar aspect of the foot showing the position of the probe to obtain sagittal (A), parasagittal (B and B') and transverse (C, D) (Jacquet & J.-M. Denoix, 2012). On the right, a diagram of the distal palmar pastern, showing the position of the probe to obtain sagittal (A) and parasagittal (B) scans (Kristoffersen & Thoenfer, 2003).



**Figure 13** Sagittal (A) and transverse (B) ultrasound scans from the PTA using the transcuneal approach: 1: Navicular bone; 2: Pedal bone; 3: DSIL; 4: DDFT; 5: Distal digital annular ligament; 6: Navicular Bursa; 7: Digital cushion; 8: Corium cunei; 9: Frog (Jacquet & J.-M. Denoix, 2012).

### **1.5.5.3. Magnetic Resonance Imaging (MRI)**

MRI has become increasingly more important in imaging horses with palmar foot pain. It is the most sensitive imaging modality in determining structural lesions in the navicular bone, degenerative changes in the articular cartilage of the DIPJ, lesions of the DDFT and impar ligament and collateral ligaments of the navicular bone and conditions previously grouped into the vague diagnosis of palmar heel pain (Barret et al., 2016). It is not only a good tool in terms of diagnostics, but it also helps in directing treatment and rehabilitation as well providing prognostic information (Murray, 2011; Barret et al., 2016 & Mair et al., 2005).

#### **1.5.5.3.1. Machine Preparation and Sedation**

Before starting the exam, several preparations must be made to ensure that image quality is optimized. Before the horse is sedated and placed into the magnet, the system should be calibrated based on the requirements of the manufacturer to make sure that it is working properly (Murray, 2001). In a standing procedure, moving the magnet up and down or back and forward can scare the horse and also if the magnet touches the limb, the horse might try to go out of the magnet. Positioning the horse before positioning the magnet might help to make the limb to be scanned straighter, especially in more proximal located areas (Mair et al., 2005). Bandages on the opposite limb can be useful, as the horse is less likely to feel the magnet if it brushes up against it during magnet driving (Murray, 2001).

Sedation techniques will vary from practice to practice because different horses will react differently. The goal is to have the horse standing relaxed in the magnet, and to avoid over-sedating as this results in leaning and swaying (Murray, 2001). Positioning the horse into the magnet is best accomplished with premedication. Most commonly, acepromazine, detomidine, romifidine and butorfanol are used in combination (Mair et al., 2005). For scanning areas located more proximal than the fetlock, it is advised to use romifidine with butorphanol, instead of detomidine to try to minimise the over-sedation effect. After premedication, the sedation can be administered by a continuous rate of infusion, that contains 10-15mg of detomidine per 500ml of 0,9% sodium chloride or Ringer Lactate or just by topping up with the same drugs used for premedication as necessary. In case of continuous rate of infusion, a catheter needs to be placed prior to the exam. (Murray, 2001; Mair et al., 2005) It is very important to create an environment that encourages the patients co-operation, with minimal

noise and with the horse standing has comfortable as possible reducing the wide-based stance and with the head rest on a stool (Murray, 2001).

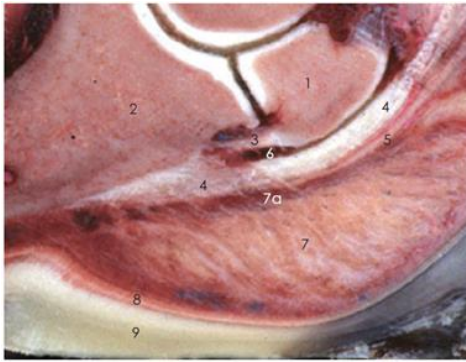
#### 1.5.5.3.2. Scanning Procedure

After removing both hoof shoes, a dorsoproximal-palmarodistal flexed x-ray view is taken to make sure that no pieces of the nails are left inside the hoof. After that, the horse gets the premedication and when the drugs start to work, the horse is positioned into the magnet. After positioning with the hoof straight and well centered into the magnet, the hoof or carpus coil is fitted around the foot, depending on how big the hoof is, and the magnet is moved around the leg as necessary to make some adjustment to the hoof positioning. To maximize image quality, it is imperative to choose the smallest RF coil that will fit around the region of interest. (Murray, 2001) Pilot sequences are then taken and used to check the correct positioning and alignment for the subsequent scans (Murray, 2001; Mair et al., 2005).

The sequences are taken in three planes: frontal, sagittal and transversal. Different clinics have different scanning protocols but normally can include 3-dimensional T1 scans, the STIR test, STIR FSE, T2 FSE, T1 SE, T1 GRE and STIR GRE.

## **1.6. Podotrochleosis**

Podotrochleosis is characterised by a chronic forelimb lameness associated with pain in the navicular area and surrounding structures (Ross & Dyson, 2003; Dyson et al., 2011). The syndrome maybe caused directly by a navicular bone lesion (Rijkenhuisen, 2006) but also by all the closely related structures such as collateral ligaments of the navicular bone, the impar ligament, navicular bursa and the deep digital flexor tendon (Schneider, 2007; Schramme, 2011). Because of the variety of problems that may cause the syndrome, several clinical manifestations are likely to be seen.



**Figure 14** Podotrochlear apparatus. (1) Navicular bone; (2) Pedal bone; (3) DSIL; (4) DDFT; (5) Distal digital annular ligament; (6) Navicular bursa; (7) Cushion; (8) Corion Cunae; (9) Frog. (Adapted from Jacquet & Denoix, 2012).

Horses of all breeds and used for various disciplines can be affected. So far, no exact cause as been found and several different theories exist (Ross & Dyson, 2003).

1. Vascular etiology with arteriosclerosis and thrombosis, resulting in ischemia in the navicular bone;
2. Non-physiological biomechanical factors: The DDFT exerts compressive forces on the distal third of the navicular bone, and some studies have demonstrated that the greatest forces are applied during the propulsion phase of the stride, during extension of the DIPJ, with increased tension on the DDFT and collateral ligaments;
3. Poor foot conformation: Horses with low heels have less flexion of the DIPJ resulting in increased pressure concentrated on the distal aspect of the navicular bone;
4. Anatomical shape of the navicular bone: Proximal articular margin being concave or undulating seem to be at highest risk of development of the disease;
5. Aging: Resulting in degenerative changes in the fibrocartilage, subchondral bone remodeling and cortical thickening, with focal areas of lysis within the navicular bone. Aging changes were documented in the region of insertion of the impar ligament and DDFT.

MRI is exceptional on detecting such subtle abnormalities, that are often undetectable by other imaging techniques and for that reason MRI is the gold standard technique to detect injuries in the hoof region. Also, MRI is very helpful in determining whether a case is a suitable candidate for palmar digital neurectomy or not (Murray, 2001).

### 1.6.1. Pathological Changes in the Navicular Bone and Navicular Bursitis

Navicular bone lesions can occur alone or together with injuries of other structures such as the DDFT, distal sesamoidean impar ligament (DSIL) or collateral sesamoidean ligament (CSL). These injuries can occur in different areas of the bone and they are labeled below in table 4 (Murray, 2001).

Area	Lesion
<b>Distal Border</b>	<ol style="list-style-type: none"> <li>1. Enteseophyte formation;</li> <li>2. Distal border fragment with no reaction;</li> <li>3. Distal border fragment with change in contour and signal intensity in adjacent navicular bone;</li> <li>4. Enlargement of synovial invaginations;</li> <li>5. Irregular thickness of distal cortex with mineralization.</li> </ol>
<b>Proximal Border</b>	<ol style="list-style-type: none"> <li>1. Enteseophyte formation;</li> <li>2. Mineralization;</li> <li>3. Proximal border fragment.</li> </ol>
<b>Flexor surface (Palmar border)</b>	<ol style="list-style-type: none"> <li>1. Endosteal irregularity;</li> <li>2. Increased thickness;</li> <li>3. DDFT adhesions;</li> <li>4. Focal increased signal in all sequences;</li> <li>5. Focal increased signal in STIR;</li> <li>6. Fibrocartilage loss;</li> <li>7. Focal disruption with reaction extending dorsally into the spongiosa.</li> </ol>
<b>Dorsal Border (Spongiosa/ Medulla)</b>	<ol style="list-style-type: none"> <li>1. Periarticular osteophyte formation;</li> <li>2. Cyst-like lesions;</li> <li>3. Diffuse increased signal on STIR;</li> <li>4. Focal increased signal on STIR (origin of DSIL or CSL);</li> <li>5. Diffuse or focal decreased signal on T1- and T2-Weighted images.</li> </ol>

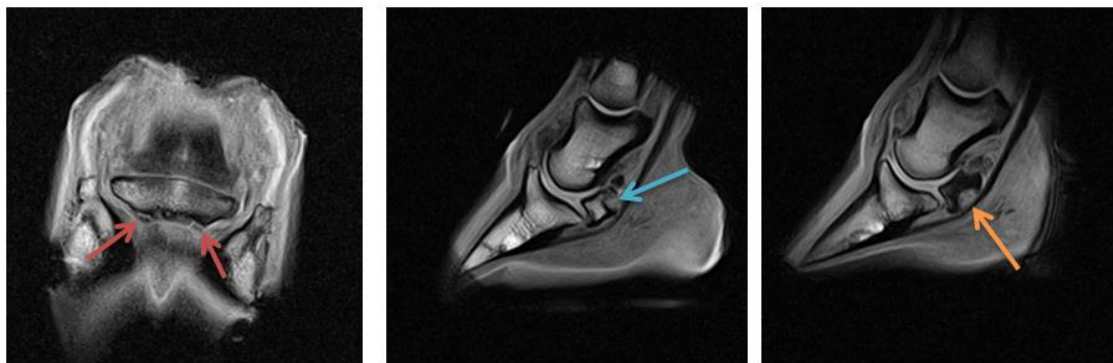
**Table 7** Navicular bone lesions (Adapted from Murray, 2001).

#### 1.6.1.1. Flexor Cortex and Spongiosa

There are some horses with no structural changes of the flexor cortex of the navicular bone but with a significant thickening with or without endosteal irregularity, detectable on T1\* and T2\*, and this has been associated with DSIL or CSL abnormalities. This place is susceptible to early degenerative changes, even in clinically sound horses. Early clinical lesions are characterised by focal fluid accumulation dorsal to the DDFT, reflecting loss of fibrocartilage, and increased signal intensity in STIR in the flexor cortex. More advanced lesions frequently appear with increased signal on T1 and T2-weighted and STIR, associated with an area with reduced signal on T1 and T2 weighted in the Spongiosa dorsal to the flexor cortex lesion and often, as mentioned above, with focal lesions of the DDFT in the same plane as the flexor cortex defect (Murray, 2001).

In some cases, the flexor cortex of the navicular bone has no abnormalities, but there are diffuse abnormalities on the Spongiosa (medulla) characterised by an increased signal on the STIR with decreased signal on T1W. Increased signal on STIR in the spongiosa can be associated with trabecular thinning, widened intertrabecular spaces and perivascular or interstitial edema, while increased signal on STIR in association with decreased signal intensity on T1W and T2W is associated with generalised osteonecrosis and fibrosis with irregular trabeculae, adipose tissue edema, capillary infiltration and adipose tissue disruption (Murray, 2001). Some studies from horses with less advanced pathological changes in the navicular bone detectable by MRI revealed a spectrum of abnormalities associated with regions of high signal intensity in fat-suppressed images that include perivascular or interstitial edema, enlarged bone spaces, fibrovascular tissue in bone spaces, medullary fibrosis, focal bone necrosis, marrow fat edema and adipose tissue disruption (Murray, 2001).

Incidence and etiology of primary bursitis is still not known as its relationship to the development of navicular disease. Villous hypertrophy, hyperplasia of synovial lining cells and venous congestion were described in association with navicular disease. In a study with horses diagnosed with palmar foot pain, some of them showed no signs of acute inflammation within the bursa but marked chronic synovial proliferation was seen. There also seems to be a positive association, between abnormalities of the bursa and lesions in the dorsal aspect of the DDFT or flexor surface of the navicular bone (Murray, 2001).



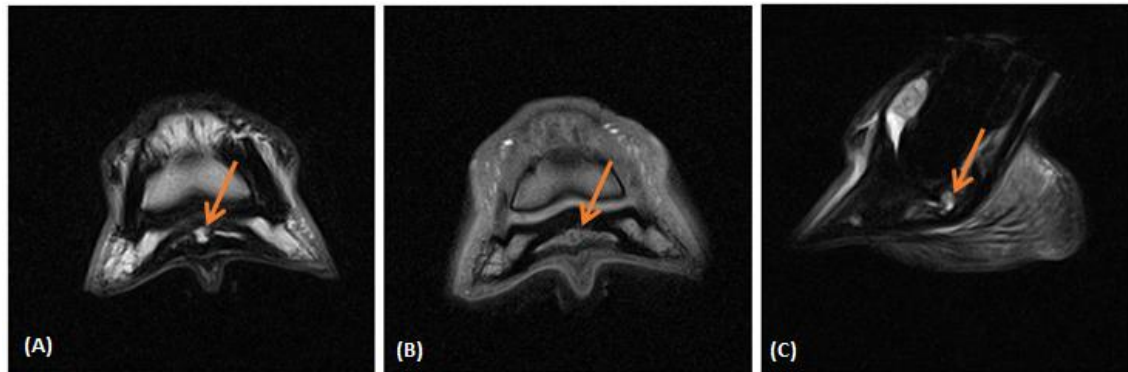
**Figure 15** MRI Findings in the navicular bone. The left picture is a T1GRE Frontal scan showing two distal border fragments (red arrows). The middle picture a T1GRE Sagittal scan showing a cyst defect in the proximal border a flexor surface (blue arrow). The right picture also a T1GRE Sagittal scan showing a cyst defect in the flexor surface (orange arrow). Notice in the right picture, the a general navicular bone reaction, represented as a “black navicular bone” in this T1GRE sequence, unlike the middle picture showing a normal “greyish navicular bone” in the same sequence.

### 1.6.2. Distal Sesamoidean Impar Ligament Injurie

Usually, lesions on the distal sesamoidean impar ligament (DSIL) are characterised by enlargement of the ligament as areas with lower signal intensity on T1W and higher signal on T2W and STIR in acute injuries, sometimes with changes on the distal insertion on P3, like enthesophyte formation. Sometimes there is also a loss of separation between the DSIL and DDFT due to adhesion formation (Murray, 2001).

In chronic injuries, the navicular bone appears with several cortical indentations variable in size with elongation of the flexor cortex or with endosteal irregularity in the distal insertions on P3 (Murray, 2001).

Lesions on the DSIL often appear in association with lesions on the navicular bone involving the proximal or distal border or the medulla like enthesophyte formation, distal border fragments and abnormal mineralization. In addition, increased signal intensity in STIR on the origin of the DSIL in the navicular bone is likely to be seen in association with increased signal intensity on the insertion of the CSL in the navicular bone as well. Lesions on both DSIL and CSL were seen in association with navicular medulla lesions, particularly focal and linear increase signal intensity in STIR extending from the CSL insertion to the DSIL origin (Murray, 2001).



**Figure 16** Lesion DSIL. (A) Frontal T2FSE scan showing a core lesion (red arrow) and (B) the same lesion in frontal T1GRE. (C) STIR FSE Sagittal showing increased signal in origin of the DSIL in the navicular bone.

### 1.6.3. Collateral Sesamoidean Ligament Injuries

These injuries are rarely seen alone. In acute lesions the ligament is enlarged and appears with increased signal intensity in all the sequences sometimes together with focal increased signal on STIR, on the insertion in the navicular bone or linear increased signal extending from the distal insertion of the CSL to the DSIL origin. Chronic injuries can appear with enthesophyte formation in the proximal border of the navicular bone and with a loss of separation between the CSL and DDFT due to adhesion formation (Murray, 2001).

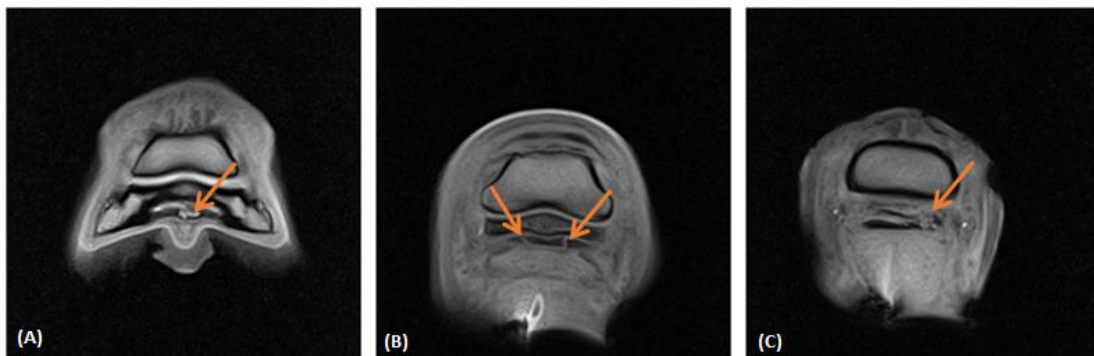
### 1.6.4. Deep Digital Flexor Tendinopathy in the Foot

Injuries of the DDFT are a common cause of foot lameness in the horse and it may happen alone but it can also appear in combination with other lesions in other structures of the hoof (Murray, 2001).

Primary injuries can be the result of repetitive overload stress but also the result of degenerative ageing changes and are the principal cause of lameness as they often involve one lobe and extend over a variable distance proximodistally. They usually comprise core lesions proximal or distal to the navicular bone (Murray, 2011 & Schramme, 2011).

DDFT injuries can be manifested as a diffuse disease, dorsal margin abrasions, tearing, sagittal splits and core lesions and they can originate at any level (Barret et al., 2016). Sagittal splits, dorsal margin abrasion and core lesions occur very often at the level of CSL and the navicular bone (Barret et al., 2016; Murray, 2011 & Schramme, 2011). Cases with navicular bone and DDFT lesions often have multifocal lesions involving the medial and lateral lobes, as defects in the flexor cortex of the navicular bone frequently have focal adhesions to the DDFT. Core lesions are associated with swelling of the affected lobe, resulting in a loss of the normal

mediolateral symmetry. (Murray, 2011) Possible risk factors for DDFT injuries include hoof conformation and the angle of the DDFT as it passes over the navicular bone, the horse's athletic discipline as it appears that the risk increases with the height and intensity of jumping, previous palmar digital neurectomy and the presence of navicular bone disease. Horses with palmar nerve neurectomy have increased risk of progression and deterioration of existing DDFT lesions, because of continued overloading of the compromised but desensitized DDFT following surgical procedure (Schramme, 2011). Caution is warranted in horses with navicular problems and even more in cases with flexor surface erosive lesions as they are often accompanied by DDFT damage. Neurectomy in these cases can lead to further DDFT damage or even a rupture and for that reason is contraindicated (Barret et al., 2016). Although dorsal abrasion lesions on the DDFT are commonly diagnosed in association with navicular bone disease, more exactly with degenerative changes in the flexor surface of the navicular bone, the correlation between sagittal splits and core lesion on the DDFT with navicular disease is still unclear (Murray, 2001).



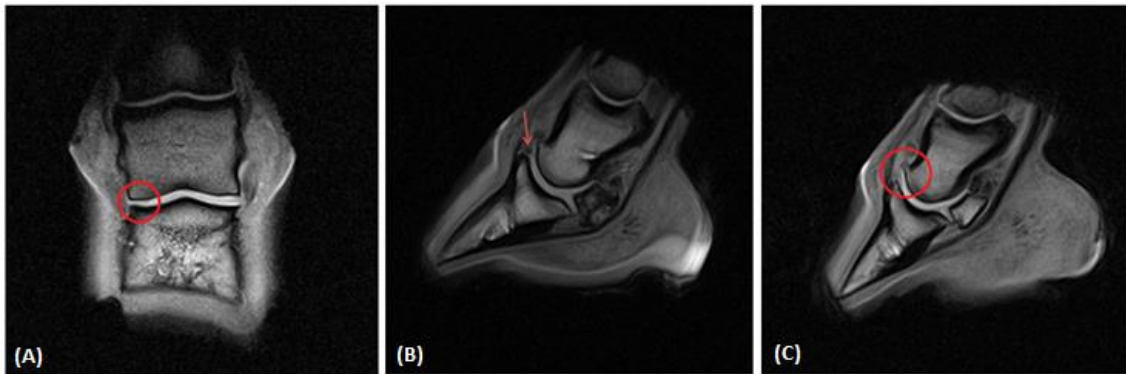
**Figure 17** Lesion DDFT. (A) T1GRE transverse showing a DDFT core-lesion distal to the navicular bone, before the distal insertion on P3; (B) Transverse T1GRE with DDFT splits in both medial and lateral lobe, at the level of the navicular bone; (C) T1GRE HR Transverse showing a big core lesion on the lateral lobe of the DDFT with adhesions to the navicular bursa.

### 1.6.5. Distal Interphalangeal Joint (DIP)

MRI has provided a noninvasive way to assess the joint and evaluation of the cartilage, subchondral bone and intra and extra-articular soft tissues as the joint capsule and collateral ligaments (Barret et al, 2016).

Distention or effusion of the DIP with or without soft tissue proliferation, is a very common but non-specific finding in many lame horses and does not necessarily reflect primary joint disease (Murray, 2001). The articular cartilage is more difficult to evaluate in low-field

systems due to the inferior resolution. Normally it is associated with focal decreased signal in T1 sequences or cartilage surface irregularity. If there is an excessive cartilage loss the joint space will be thinner but variation within the joint space should be evaluated with extreme care because it can be influenced by the way the horse is standing and the position of the limb in the magnet (Murray, 2001). This can be accompanied by irregularities in the adjacent subchondral bone, or increased signal in STIR images (Murray, 2001).



**Figure 18** Lesion DIP Joint. (A) T1GRE HR Frontal showing thinning of the cartilage of the DIP joint in the medial aspect (red circle); (B) T1 GRE 3D Sagittal showing a presence of a fragment (red arrow); (C) Osteophyte formation in the dorsal aspect of P2.

#### 1.6.6. Collateral Ligaments of DIP Joint

Acute injuries of a CL of the DIP joint is characterised by increased signal intensity in all images sequences often with swelling and in association with DIP joint effusion. Transverse images are the most sensitive in the detection of lesions but frontal images can also be useful (Murray, 2001).

The lesions may be restricted to one portion of the ligament or extend throughout its entire length. The medial CL is more frequently injured however, both ligaments may be injured (Murray, 2011). The lesions are often accompanied by endosteal or periosteal reaction, i.e. subchondral bone reaction or enthesophyte formation at their origin (P2) or distal insertion (P3) (Murray, 2001).

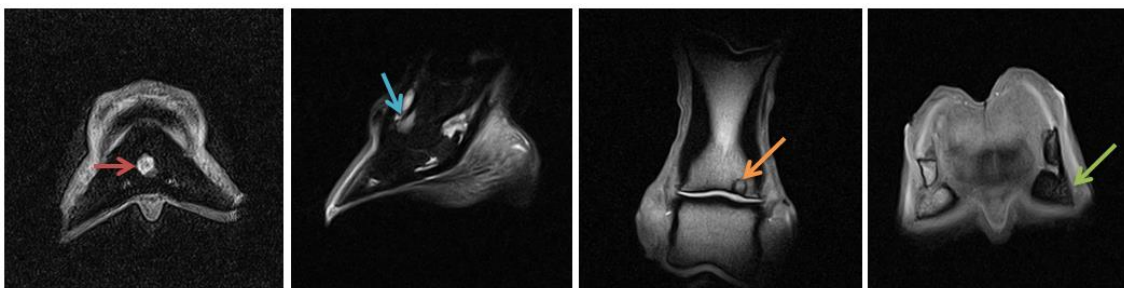
T2 FSE and STIR sequences are preferable as the lateral CL is susceptible to magic angle artifact, resulting in an increased signal intensity in T1 and T2 GR and PD sequences. Confirmation of a lesion requires a presence of swelling of the ligament and/or periligamentar tissues, increased signal in T2 FSE and STIR sequences or complete disruption of the ligament architecture reflecting partial rupture or associated osseous changes (Murray, 2001).



**Figure 19** Lesion collateral ligaments of the DIP joint (A) T1 GRE Transverse; (B) T2 FSE PSAT Transverse; (C) PDW FSE Transverse. Note the increased size of the ligament (Red arrows) and increased signal in both T2 FSE and PDW FSE showing the presence of inflammation. (D) T<sup>2</sup> FSE Frontal also showing swelling and increased signal.

### 1.6.7. Middle and Distal Phalanges

The most common lesions include bone trauma, osseous cyst-like lesions (OCLL), fractures and axial defects in the palmar process of P3. Bone trauma appears as focal or diffuse reduced signal intensity in T1- and T2-W and increased signal intensity in STIR images. The distal dorsal aspect of the middle phalanx is a common site for such lesions but not necessarily involving other soft tissues. Mild and diffused decreased signal intensity in T1- and T2-W images in the middle palmar process of P3 has been a common finding but appears to be clinically irrelevant (Murray, 2001). OCLL normally occur in the subchondral bone on either P2 or P3 and usually have high signal intensity in STIR. Fractures tend to appear as a linear increased signal intensity in STIR with reduced signal intensity in T1- and T2-W adjacent to the fractures (Murray, 2001).



**Figure 20** MRI findings in the middle and distal phalax. From the left to the right: First picture, a STIR GRE Frontal scan, showing a cyst in the pedal bone (red arrow); Second picture, a STIR FSE Sagittal, showing dorsal P2 Bone edema (blue arrow); Third picture, a T1 GRE Frontal 3D, showing a cyst like lesion in the distal aspect of P1 with connection to the pastern joint (orange arrow); Fourth picture, a T1 GRE Frontal HR, showing a pedal bone wing reaction (green arrow).

### **III- LOW-FIELD MRI IN PODOTROCHLEOSIS: CASELOAD**

#### **1. Material and Methods**

The 95 horses in this study were brought as referral cases or examined as first opinion in the clinic, between September 2015 and September 2016. Signalment included age and breed. Follow-up examinations were conducted at least 2 months after the initial examination.

The horses selected for this study presented with an acute or chronic forelimb lameness, uni- or bilateral and showed positive response to either digital palmar nerve or abaxial sesamoidean anesthesia. The result of clinical and other imaging techniques were inconclusive and did not explain the cause of lameness. Horses selected in this study had no evidence of other forelimb pathology elsewhere. Both feet or just one were examined on the MRI, depending if the horse was bilateral or unilateral lame. Lesions in the navicular bone were divided depending affected area as following: proximal border, spongiosa or dorsal surface, distal border and flexor surface. The lesions were defined only by presence or absence and not by their nature and severity.

The MR images were acquired by using a 0,27T Hallmarq. Pulse sequences were obtained in three planes. Sequences used included T1 3D GRE, T1 SE, STIR FSE, T1 GRE HR and T2 FSE. In some cases some extra scans were included like T2 GRE, STIR GRE and PDW SE. Transverse images were orientated perpendicular to the flexor surface, sagittal pictures were orientated perpendicular to the distal insertion of the DDFT and frontal pictures parallel to the flexor surface or perpendicular to the distal insertion of the DDFT.

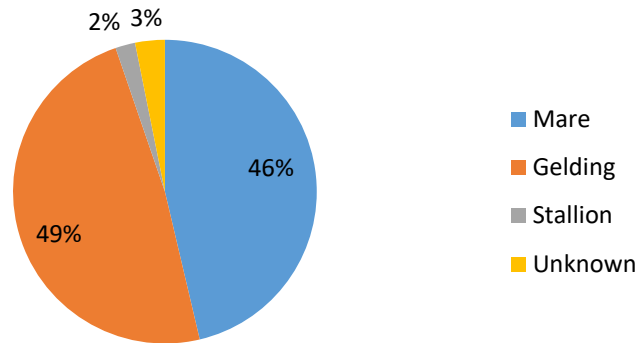
Descriptive statistics were performed on all data to establish the frequency of occurrence of the lesions in the PTA that included lesions in the navicular bone, navicular bursa, DSIL, collateral sesamoidean ligaments, DDFT, DIPJ, collateral ligaments of the DIPJ, middle and distal phalanx. Abnormalities were only recorded if they were repeatable in more than one plane and in more than one pulse sequence. Artifacts and common anatomic variations were not classified as abnormalities. A certified veterinarian specialist in diagnostic imaging from Pferdeklinik Leichlingen analyzed the images from this study and recorded the lesions found.

Statistical correlations between the outcome and variables of treatment were analysed using a Chi-square test. All analyses were performed with statistical analysis software, SPSS, with a significance level of 0,05.

## 2. Results

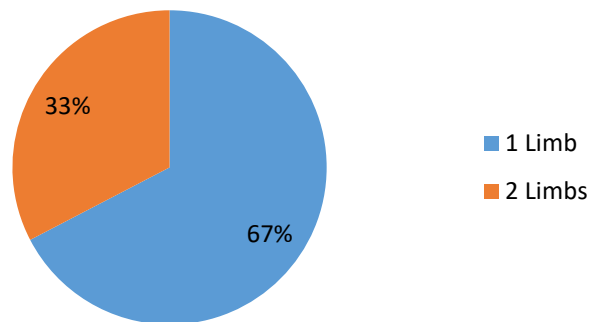
### 2.1. Case Frequency Analysis: Description of the Sample

As explained before, 95 horses were used in this study: 44 mares, 2 stallions, 46 geldings and 3 were the sex was not recorded.



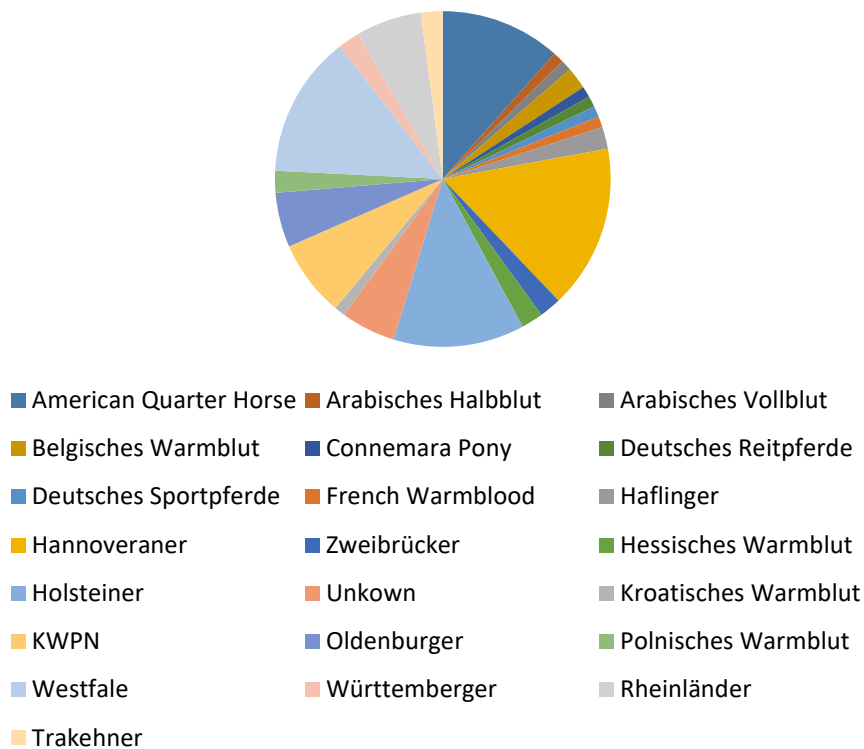
**Figure 21** Sex distribution in the sample.

67,4% of the horses were presented with unilateral lameness and therefore underwent only unilateral MR examination. The other 32,6% of the horses presented with bilateral lameness and were subjected to MR examination of both front feet.



**Figure 22** Distribution of the lameness: Unilateral vs. Bilateral

This study contemplated 95 sport horses, with the highest number of cases from the breed Hannoveraner (16%), followed by Westfalen (14%), Holsteiner (13%) and American Quarter Horses (12%). The riding disciplines were not recorded.

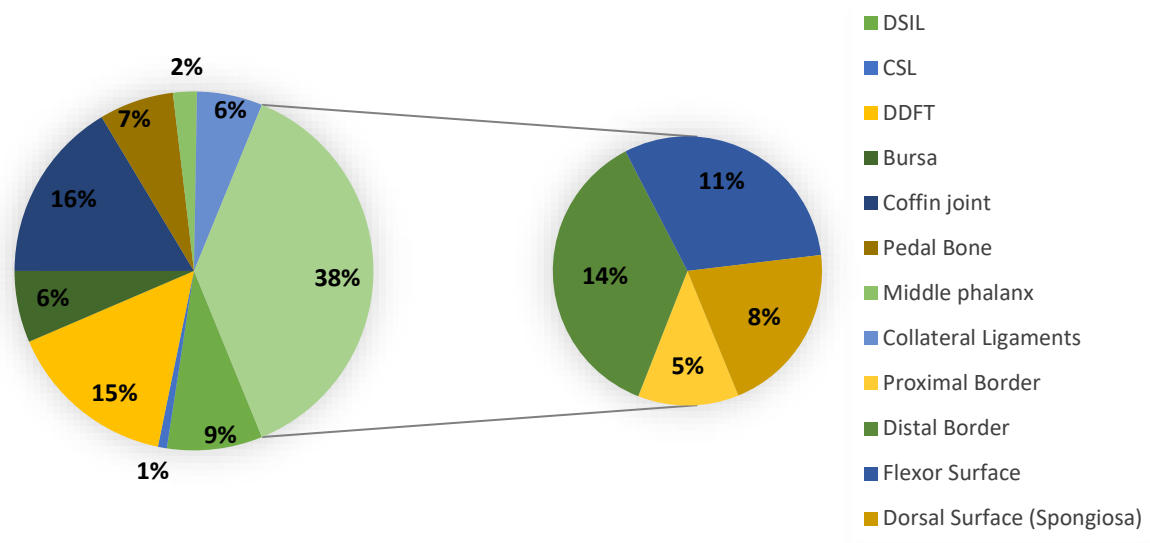


**Figure 23** Breed distribution in the sample

## 2.2. Prevalence of Lesions found on the MRI

All findings that might contributed to a lameness were considered as a lesion, although some findings might not have been the main cause. Anatomical variations and artifacts were not taken into consideration.

Navicular bone lesions had a prevalence of 38%, most of them being lesions in the distal border (14%), followed by lesions on the flexor surface (11%), dorsal surface (8%) and the proximal border (4,6%). The second most common lesion found were coffin-joint lesions with a prevalence of 16,4%, followed by DDFT lesions with a prevalence of 15,3% and DSIL lesions with 8,6%. Lesions with less prevalence were pedal bone (6,7%), navicular bursa (6,5%), collateral ligaments (5,9%), middle phalanx (2,2%) and CSL pathologies (0,8%).



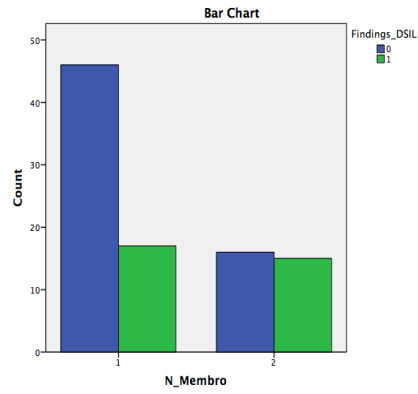
**Figure 24** Prevalence of lesions found in the MRI.

### 2.3. Lesions in Unilateral and Bilateral Limb Lameness

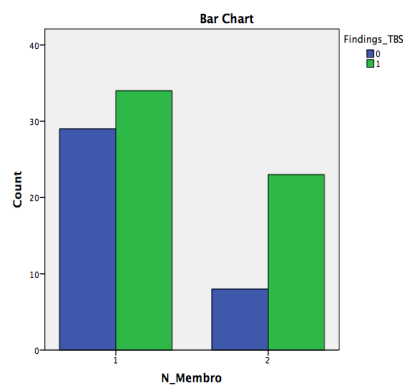
As seen in the figure 25, 26 and 27 and annex 1, there is a statistic relationship between both variable, i.e. the type of lameness (uni- or bilateral) and DSIL, DDFT or DIPJ (coffin joint) lesions (p-value=0,035; p-value= 0,047; p-value= 0,027).

Lesions of the DSIL were seen equally in horses with uni- and bilateral lameness but there is a proportion between bilateral lameness and number of horses with this lesion.

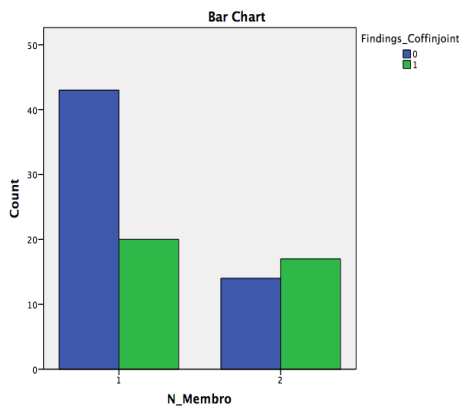
This proportion was a little higher in horses with lesions in the coffin joint. Lesion found on the DDFT were less in bilateral limb lameness as they were in unilateral limb lameness but there is a bigger proportion in horses with lesions in the DDFT and bilateral lameness. According to the results from this study, lesions found in the DDFT, DIPJ and DSIL seemed to have a tendency to appear bilateral.



**Figure 25** DSIL lesions in unilateral and bilateral lameness. Findings DSIL 0: Absent 1: Present. N\_\_Membro 1: Unilateral lameness 2: Bilateral lameness



**Figure 26** DDFT lesions in unilateral and bilateral lameness. Findings DDFT (TBS) 0: Absent 1: Present. N\_\_Membro 1: Unilateral lameness 2: Bilateral lameness



**Figure 27** Coffin-joint lesions in unilateral and bilateral lameness. Findings Coffin-Joint 0: Absent 1: Present. N\_\_Membro 1: Unilateral lameness 2: Bilateral lameness

## 2.4. Association of Lesions

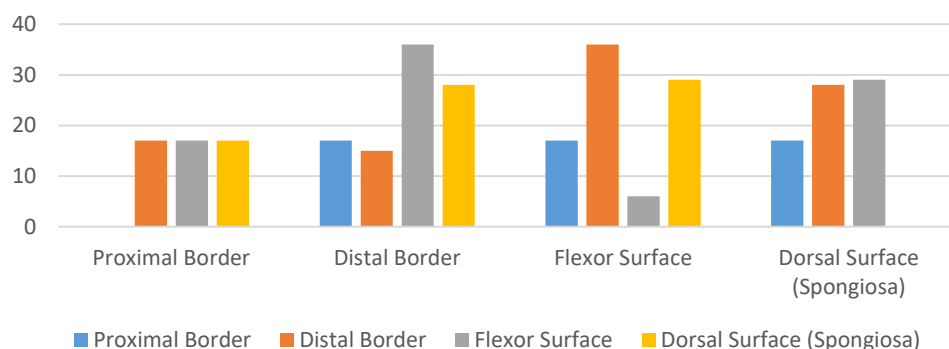
It was studied the hypothesis of association between lesions found on the MRI of horses with frontlimb lameness localized in the foot. Between all lesions found in the horses that underwent a MRI study, it several relevant statistical relationships were seen.

The strongest statistical relationship was found between lesions in the different areas in the navicular bone, i.e. proximal border, dorsal surface, distal border and flexor surface. The association between the presence of lesions in the dorsal and flexor surface had the strongest statistical relationship among them all (p-value<0,001; phi-coefficient: 0,729) followed by association of lesions in the proximal border and dorsal surface ( p-value<0,01 , phi-coefficient: 0,704). The association between the presence of lesions in the proximal and distal border had the lowest score between all areas of the navicular bone, but still with a strong positive statistical relationship (p-value<0,001; phi-coefficient: 0,434). The results suggest that normally there is not a singular area affected in the navicular bone but a more diffuse disease should be expected, maybe the reflect of a rapid evolution. The exact results can be observed in table 8.

Variables Crossed	Chi-square	Phi
Findings_DorsalSurfaceSpongiosa * Findings_FlexorSurface	p<0,001	0,729
Findings_ProximalBorder * Findings_DorsalSurfaceSpongiosa	p<0,001	0,704
Findings_DistalBorder * Findings_DorsalSurfaceSpongiosa	p<0,001	0,570
Findings_DistalBorder * Findings_FlexorSurface	p<0,001	0,548
Findings_ProximalBorder * Findings_FlexorSurface	p<0,001	0,513
Findings_ProximalBorder * Findings_DistalBorder	p<0,001	0,434

**Table 8** Statistical relationships found in the variables of the areas of the navicular bone.

Approximately 38% of the horses in this study did not present any lesion in the navicular bone at all. As seen in the graphic bellow, no horse presented lesions in the proximal border and dorsal surface without association to other areas of the navicular bone. 18% of the horses presented with diffuse lesions, affecting all four different areas. 12% of the horses presented lesions affecting the distal border, dorsal and flexor surface. 9% of the horses presented lesions affecting the distal border and the flexor surface and a minority of 1% with lesions affecting the flexor and dorsal surface.



**Figure 28** MRI findings in the navicular bone.

Some associations had a negative statistical relationship and are listed in the table 9.

Variables Crossed	Chi-square	Phi
Findings_DDFT * Findings_CollateralLigaments	0,002	-0,316
Findings_DDFT * Findings_PedalBone	0,005	-0,293
Findings_DistalBorder * Findings_CollateralLigaments	0,018	-0,241
Findings_DSIL * Findings_CollateralLigaments	0,019	-0,233
Findings_FlexorSurface * Findings_CartilageDIPJoint	0,029	-0,218

**Table 9** Negative statistical relationships found.

The strongest negative relationship found was between the presence of lesions in the DDFT and collateral ligaments of the DIPJ (p-value=0,002; phi-coefficient: -0,316). The rest of the variables had a weak negative relationship (-0,200<phi-coefficient<0,299). The results shown in the table 9 suggest that the presence of one of the lesions (i.e. DDFT) increases the probability of non-occurrence of the other lesions (i.e. pedal bone and collateral ligaments).

The association of the remaining variables is listed in table 10.

Variables Crossed	p-value	Phi
Findings_DDFT * Findings_Bursa	0,006	0,277
Findings_PedalBone * Findings_CollateralLigaments	0,023	0,239
Findings_Bursa * Findings_CartilageDIPJoint	0,024	0,237
Findings_PedalBone * Findings_CartilageDIPJoint	0,033	0,220
Findings_Bursa * Findings_Coffinjoint	0,031	0,218
Findings_DistalBorder * Findings_Bursa	0,042	0,200

**Table 10** Positive statistical relationship found in the rest of the variables

### **3. Discussion**

The main objective of this study was to investigate the prevalence of lesions associated with the PTA in sport horses that underwent an MRI examination of the front feet. The second aim was to investigate which lesions do commonly appear together.

The results support that pain localised to the foot may be associated with MR changes in a variety of structures, and that lesions to several structures may occur concurrently, probably due to the closed anatomical relationship between some of the structures (Dyson & Murray, 2007; Murray et al., 2006).

Abnormalities in the navicular bone (40%), DIPJ (16%), DDFT (15%) and DSIL (9%) predominated in the investigated population. Concurrent lesions in the navicular bone, DDFT and DSIL are already well documented (Wright et al., 1998).

In the investigated population, lesions or alterations in the DIPJ were usually not associated with any other concurrent pathology of a adjacent structures. This suggests that it seems to occur mostly as a separate disease process from the other structures supported by R.M in 2006 (Murray et al., 2006). Other studies suggest that the close anatomical relationship between the DIPJ and the navicular bone can potentially lead to an association of lesions (Dyson & Murray, 2007) and to other microinjuries of the DSIL and DDFT (Kimberly et al., 1997). This is caused by major-weight bearing pressures and dorsiflexion movements during normal locomotion (Dyson & Murray, 2007). The mechanical loading triggers a cascade of molecular events that may lead to disease in susceptible individuals by increasing the production and release of free radicals, cytokines, fatty acid catabolites, neuropeptides and matrix-degrading enzymes. These molecules may be involved in the remodeling of articular and subchondral bone structures. If the adaptive capacity of a joint is exhausted, an increase in biomarkers may be detectable (Rijkenhuisen, 2006). Changes in biochemical markers in the DIPJ and navicular bursa have been observed in horses with clinical “navicular disease”. The increase of biochemical markers are an expression of an active inflammatory process, but in chronic cases they do not always reflect the damage accumulated over a long time period (Rijkenhuisen, 2006). Therefore their reliability for indicating pathology in any given joint has not been confirmed yet (McIlwraith, 2005).

In this study, pathologic findings in the cartilage of the DIPJ had a positive statistical relationship with findings in the pedal bone, reflecting the extension of the lesions to the subchondral area. There was also a positive statistical relationship between cartilage defects of

the DIPJ and navicular bursa pathology. Concurrent lesions of the dorsal surface of the navicular bone and DIPJ pathology were seen in several horses, but no statistical relationship was found.

Findings in the DSIL had no statistical relationship to findings in the DDFT, navicular bone, CSL or navicular bursa as it was described in previous studies (Dyson & Murray, 2007; Murray et al., 2006). Findings of the DSIL had a negative statistical relationship with findings of the collateral ligaments of the DIPJ, not supporting previous studies (Dyson et al., 2011). This could be related to the population of horses which were included in this study.

Findings in the DDFT were a common feature. There was a positive statistical relationship between findings on the DDFT and findings in the navicular bursa. Association of DDFT lesions with pedal bone and collateral ligament injuries of the DIPJ had a negative statistical relationship. In previous studies, there was found an association of lesions between the DDFT and DSIL and/or CSL (Dyson & Murray, 2007), but this was not observed in the horses in this study. Association of lesions between the DDFT and the navicular bursa can be expected due to the close anatomy, particularly in cases with lesions of the dorsal surface of the DDFT and navicular bursitis (Schramme, 2011). Lesions of the DDFT are more often seen at the level of the CSL and navicular bone followed by the level of the DSIL and distal insertion (Dyson & Murray, 2007). This study suggests that the increase of and DDFT injuries potentially decreases the possibility of bone injuries at the level of the palmar process of the pedal bone and the likelihood of collateral ligaments of the DIPJ pathology. Although when looking at the biomechanical closed relationship of these two structures one would expect otherwise. This also could be a result of case selection.

There was a positive association between lesions of the navicular bursa and distal border lesions of the navicular bone as described previously in other studies (Dyson et al., 2003; Dyson and Murray, 2007).

There was also a positive association between lesions in the collateral ligaments of the DIPJ and lesions of the pedal bone. It has been suggested that lateromedial or rotational motion of the DIPJ may result in damage to the collateral ligaments that might occur within the body of the ligament or at the attachments of the ligament to the pedal bone (Zubrod et al., 2005). Though in this study, no relationship was found between lesions of the collateral ligaments and coffin joint pathology (annex 4), the same results were observed in another study (Murray et al., 2006).

There was a negative statistical relationship in the association of lesions between the collateral ligaments of the DIPJ and the distal border of the navicular bone and DDFT, not yet supported by other studies.

Some of the associations already described in previous studies didn't had a significant statistic relationship in the horses from this study. This and other not explainable relationships found in the sample or any association not described in the consulted references might be a result of some limitations. The limitations included the fact that horses with unilateral limb lameness were only subjected to an unilateral MRI examination due to the costs of the examination but decreasing the study rigorousness. Another limitation was that the inclusion criteria of the horses in this study included the lack of findings in clinical examination and other imaging diagnostic techniques. This may lead to a loss of findings of expected associations, since horses with lesions diagnosed by radiology were automatically non selected.

## 4. Conclusion

Palmar foot pain is a common cause of lameness in the horse and can be the result of several clinical conditions. Results of this study support that several combinations of problems might contribute to the lameness seen in affected horses.

The wide variety of possible injured tissues within the hoof makes it challenging to the clinicians to define the exact diagnosis. It is essential to obtain a detailed history and to perform an accurate lameness investigation prior to the MR examination. Diagnostic anesthesia should always be performed (except cases with suspected hairline fractures) to assure that the hoof is the primary source of pain. Other diagnostic imaging modalities like radiology and ultrasonography should also be performed prior to MR exam, to exclude or confirm differential diagnoses, when possible.

MR examinations are expensive and for this reason should only be carried out when other imaging techniques fail to achieve a final diagnosis, or when further information about the nature of the lesions and distribution is necessary. MRI is a useful tool not only in providing a specific diagnosis in cases that were previously grouped into the vague diagnosis of palmar heel pain, but also in providing a more accurate prognosis and a more targeted treatment and rehabilitation.

The amount of possible lesions and associations of lesions found in this study, were quite extensive, which makes a more structured categorization of possible lesion associations almost impossible. For this reason, every case should always be evaluated as a individual situation.

The increasing knowledge of underlying molecular biologic processes, anatomy, possible pathologies and their response to medical or surgical treatment and rehabilitation helps in conceiving possible outcomes and evolution of the pathology itself.

Navicular bone pathologies continue to be a major cause of frontlimb lameness, but concurrent or associated injuries of other related structures such as the DDFT, DSIL or DIPJ should always be considered due to their close anatomical relationship.

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## Annexes

### Annex 1

<b>Variables Crossed</b>	<b><i>p-value</i></b>	<b>Phi</b>
N_Membro * Findings_DSIL	0,035	0,212
N_Membro * Findings_CSL	0,296	-
N_Membro * Findings_DDFT	0,047	0,195
N_Membro * Findings_ProximalBorder	0,269	-
N_Membro * Findings_DistalBorder	0,501	-
N_Membro * Findings_FlexorSurface	0,280	-
N_Membro * Findings_DorsalSurfaceSpongiosa	0,178	-
N_Membro * Findings_Bursa	0,098	-
N_Membro * Findings_Coffinjoint	0,027	0,222
N_Membro * Findings_PedalBone	0,132	-
N_Membro * Findings_P2	0,527	-
N_Membro * Findings_CollateralLigaments	0,257	-
N_Membro * Findings_CartilageDIPJoint	0,257	-

### Annex 2

<b>Variables Crossed</b>	<b><i>p-value</i></b>	<b>Phi</b>
Findings_DorsalSurfaceSpongiosa * Findings_Bursa	0,270	-
Findings_DorsalSurfaceSpongiosa * Findings_Coffinjoint	0,094	-
Findings_DorsalSurfaceSpongiosa * Findings_PedalBone	0,520	-
Findings_DorsalSurfaceSpongiosa * Findings_P2	0,463	-
Findings_DorsalSurfaceSpongiosa * Findings_CollateralLigaments	0,265	-
Findings_DorsalSurfaceSpongiosa * Findings_CartilageDIPJoint	0,092	-
Findings_DorsalSurfaceSpongiosa * Findings_DSIL	0,362	-
Findings_DorsalSurfaceSpongiosa * Findings_CSL	0,669	-
Findings_DorsalSurfaceSpongiosa * Findings_TBS	0,170	-
Findings_DorsalSurfaceSpongiosa * Findings_ProximalBorder	p<0,001	0,704
Findings_DorsalSurfaceSpongiosa * Findings_DistalBorder	p<0,001	0,570
Findings_DorsalSurfaceSpongiosa * Findings_FlexorSurface	p<0,001	0,729

### Annex 3

<b>Variables Crossed</b>	<b><i>p-value</i></b>	<b>Phi</b>
Findings_DSIL * Findings_CSL	0,738	-
Findings_DSIL * Findings_DDFT	0,449	-
Findings_DSIL * Findings_ProximalBorder	0,543	-
Findings_DSIL * Findings_DistalBorder	0,074	-
Findings_DSIL * Findings_FlexorSurface	0,504	-
Findings_DSIL * Findings_DorsalSurfaceSpongiosa	0,362	-
Findings_DSIL * Findings_Bursa	0,587	-
Findings_DSIL * Findings_Coffinjoint	0,071	-
Findings_DSIL * Findings_PedalBone	0,172	-
Findings_DSIL * Findings_P2	0,082	-
Findings_DSIL * Findings_CollateralLigaments	0,019	-0,233
Findings_DSIL * Findings_CartilagDIPJoint	0,267	-

### Annex 4

<b>Variables Crossed</b>	<b><i>p-value</i></b>	<b>Phi</b>
Findings_CollateralLigaments * Findings_CartilagDIPJoint	0,248	-
Findings_CollateralLigaments * Findings_DSIL	0,019	-0,233
Findings_CollateralLigaments * Findings_CSL	0,449	-
Findings_CollateralLigaments * Findings_TBS	0,002	-0,316
Findings_CollateralLigaments * Findings_ProximalBorder	0,183	-
Findings_CollateralLigaments * Findings_DistalBorder	0,018	-0,241
Findings_CollateralLigaments * Findings_FlexorSurface	0,239	-
Findings_CollateralLigaments * Findings_DorsalSurfaceSpongiosa	0,265	-
Findings_CollateralLigaments * Findings_Bursa	0,283	-
Findings_CollateralLigaments * Findings_Coffinjoint	0,199	-
Findings_CollateralLigaments * Findings_PedalBone	0,023	0,239
Findings_CollateralLigaments * Findings_P2	0,595	-