Magnetic resonance imaging of the equine stifle: normal anatomy
Stifle imaging comparison between magnetic resonance images and macroscopic gross-section in a group of nine ponies and nine adult horses: normal anatomy.

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Abstract

Introduction: The equine stifle is a complex joint that may be the site of equine lameness, but diagnosis of pain can be frustrating using standard imaging techniques. Magnetic resonance imaging (MRI) of the equine distal limb has led to improvements in understanding of lameness pathogenesis. Until recently, MR imaging has been limited to the distal limb, but recently the use of MRI for clinical evaluation of the equine stifle has been reported. However there is little published information regarding the normal variation in MR anatomy of the equine stifle with which to compare horses with stifle lameness. The aim of this study was to describe normal MRI anatomy and variation in immature and adult equine stifles using comparison between anatomical cross-sectional slices and MR images.

Materials and Methods: Post-mortem stifles from 9 immature ponies and 9 adult horses without hind limb lameness underwent MRI using a 1.5 Tesla GE Signa Echospeed MRI system with spoiled gradient echo, T2* gradient echo, short Tau inversion recovery, proton density, and fast dual echo sequences in 3 planes. Stifles were then sectioned in sagittal, dorsal or transverse planes, to obtain anatomical slices for comparison with MR images. MR images from different sequences and planes were described and compared with digital photographs of the anatomical sections.

Results: Soft and osseous tissues of the immature and adult equine stifle could be clearly defined on MR images and corresponded well with macroscopic anatomy of the cadaver sections and the anatomy described in literature. Incidental findings included small lesions in cartilage, subchondral, cortical and cancellous bone, and ligamentar tissues likely indicative of normal variation.

Conclusions: This study provides an atlas of normal anatomy of the equine stifle, which could assist in future clinical evaluation and as a reference for improving understanding of stifle anatomy.
Introduction

The equine stifle is frequently involved in equine lameness. In 15% of hind limb lameness the origin of the lameness is situated in the stifle (Dyson 2002). A variety of equine orthopaedic injuries, like cruciate ligament, menisci, collateral ligaments, tendon and cartilage, osseous and capsular injuries can occur in the stifle (Latimer et al 2000, Martinelli 2004).

Most of these lesions can be diagnosed on base of history, clinical examination, radiography, nuclear scintigraphy, computed tomography (CT) arthrography and arthroscopy (Whitton et al 1998, Widmer et al 2000, Martinelli 2004, Dyson 2004, Bergman et al 2007). However, all these imaging techniques observe a part of the structures within the equine stifle, whereas computed tomography (CT) arthrography offers the most detailed examination of the stifle (Holcombe et al 1995, Widmer et al 2000, Bergman et al 2007). But to investigated the stifle in total, with great detail of soft tissue, Magnetic resonance imaging is a diagnostic technique that will come very close to achieve this. Magnetic resonance, in human medicine already been defined as the golden standard for diagnostic imaging of the knee. And MRI is also a established technique for lower limb injuries in horses and might give more additional information on soft tissue and osseous injuries in the hors knee (Peterfy et al 1994, Margaret et al 2000, Yochum et al 2005, Murray 2005, Murray 2007, Branch et al 2007). Its use for the knee joint in horses is mostly restricted by the wide and length of the bore of the available MRI, and the ability of the magnet table to handle larger weights. The best candidate for imaging of the stifle is a horse with long limbs and a narrow pelvis: all horses with femur lengths greater than 44 cm, tibial lengths greater than 44 cm and pelvic measurements less than 62 cm can have an entire stifle successfully imaged (Carter et al 2007). To interpret the obtained images of the stifle, knowledge of the normal MRI anatomy is necessary. Only one study has been published of two adult stifles with MR images of one sequence (Holcombe et al 1995). Information about the different MRI sequences of the stifle has not been published as far as the authors know. The aim of the present study is to describe the normal anatomy in the immature and adult equine stifle on magnetic resonance images and correlate anatomical cross-sectional slices with the obtained images to facilitate the interpretation of all these images. The hypothesis is that MRI images of the stifle give an accurate evaluation of anatomical structures within the stifle.

Materials & Methods:

Eighteen stifles were collected, 9 from immature ponies and 9 from adult horses. The immature ponies and the adult horses were clinically sound and did not have a history of hind leg lameness. The horses were humanly euthanized for reasons other than a musculoskeleton disease. The 9 pony stifles, 6 left and 3 right, were from 9 Welsh Mountain ponies, which were between 12 and 13 months old. The 9 adult stifles, 4 right and 5 left stifles were from 6 horses with a variation in age (5 - 24 years) and breed (Hannoverian, Thoroughbred cross, Irish horse, Thoroughbred (2), Shire cross).
To compare adult and immature anatomy, stifles were used from the same side.

**Imaging**

Soon after death the limbs were removed 10 centimetres proximal and distal of the femorotibial joint and frozen, in natural position with no flexion or extension of the joint, immediately. The limbs were divided into 3 groups of each 3 adult and 3 immature stifles. The cadaver stifles were defrosted before they could be placed in coils, because of frozen artifacts (*). The stifles of the immature ponies were placed in a head coil and of the adult horses in a torso phased array coil for the sagittal and dorsal scans and in a body coil for the transverse scans. The stifle was positioned in the centre of the bore of a 1.5 Tesla GE Signa Echospeed MRI scanner (*). After setting the angle in the orientation scan, the stifles were scanned in sagittal, transverse and dorsal planes to obtain an evaluation of the joint from different directions.

The sequences used were T1 3D spoiled gradient echo, T2 3D gradient echo and STIR (Short Tau Inversion Recovery). In the ponies additionally a Proton density (PD), T2 fast spin echo were used. For the adult stifles these sequences could not be used because of the long scanning time of the fast dual echo. See table 3 for scanning properties which were used for the different sequences in the three planes.

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T1 gradient echo produces high-resolution images with relatively good signal strength and was used to obtain information of the bone and soft tissues of the joint. A T2* gradient echo demonstrates fluid accumulations and gives maximize signal contrast between fluid or soft tissue and bony and cartilage structures. STIR (Short Tau Inversion Recovery) creates a fat suppressed image and is useful for areas with a high content of fat to detect any fluid. Proton density (PD) gives a high signal in tissues with a high amount of water molecules and is useful for bone and soft tissue evaluation and provides high anatomical details. T2 fast spin echo is a sequence the same as T2 gradient echo, but it gives more detail (Russell *et al.* 2007, Murray *et al.* 2007). The signal intensity of each structure was studied (see table 2).

The MR images were interpreted by the authors and a radiology diplomat with the use of the software E-film workstation (**). A subjective comparison was done between the MR images and the gross anatomy slices from both immature and adult stifles. In all the matching images the anatomical structures were evaluated for differences in signal intensity, shape and abnormalities. The slices of the gross-anatomy were slightly different from the MR images as result of the positioning in the saw. After slicing, the MR images of the comparing stifle were reformatted with a MPR tool in the software E-film(**) which could change the slice angle in 3D directions to make a same angle as the gross-anatomy cutting angle. This adaption made it possible to compare in MRI and gross-anatomy in the same angle, however, by reformating the pictures the resolution was less detailed compared with the original MR images.
After imaging, the stifles were marked with black paint and a ruler through anatomical structures, which could be palpated on the outside of the stifle for the main orientation of the slices. Then the stifles were frozen in unforced position, as close as possible to the position in the MRI. Three immature ponies and 3 adult stifles were used in each plane for dissecting. The main orientation slices (figure 1.1-1.3) which were used for comparison in this study were based on the quantity and quality of visualizing the normal anatomy structures in the stifle. The orientation slices (figure 1.1-1.3) were made with a high-speed band saw at the desired thickness of 1 centimetre (table 1 and figure 1.1–1.3. Fig). Only the slices illustrated in table 1 and figure 1.1-1.3 where used in this study, the rest of the slices where stored for other research.

Digital photographs of each defrost slice were taken. The slices were used to facilitate an accurate interpretation of the anatomical structures and were compared to the corresponding MR images for identification and confirmation of each anatomical structure and its signal intensity.

<table>
<thead>
<tr>
<th>Number</th>
<th>Sagittal</th>
<th>Transverse</th>
<th>Dorsal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (the main orientation line)</td>
<td>Middle of the FTJ and tibia, through the grove of the trochlea ossis femoris patellaris, middle FPL and tibial crest. (two different slices for evaluating the separate cruciate ligaments)</td>
<td>Middle of the FTJ, parallel with tibial plate and 90 degrees with the tibia.</td>
<td>Cranial tip of the tibial crest and cranial tip of the lateral trochlea ridge.</td>
</tr>
<tr>
<td>2</td>
<td>Parallel, medial trochlea ridge</td>
<td>Parallel to the first transverse sectionline, through tibia with the attachment of the three patella ligaments.</td>
<td>Parallel to the first dorsal sectionline, through Extensor fosa</td>
</tr>
<tr>
<td>3</td>
<td>Parallel, lateral trochlea ridge</td>
<td>Parallel to the first transverse sectionline, through, Tibia</td>
<td>Parallel to the first dorsal sectionline, through collateral</td>
</tr>
</tbody>
</table>
with insertion of FPL on tibial crest.

<table>
<thead>
<tr>
<th>4</th>
<th>Parallel to the first transverse section line, through the femur trochlea, where the femur has the same wideness as the tibial plate.</th>
<th>Parallel to the first dorsal section line, through caudal part of the intercondylar space of the femur.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Parallel to the first transverse section line, through the tip of the distal patella.</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Orientation points for dissections, FTJ: femoraltibial joint, FPL: femoralpatellar ligament.

Figure 1.1: Sagittal

Figure 1.2: Transverse
Figure 1.3: Dorsal

Table 2: Average signal intensity appearance of different structures in different sequences (Russell L. Tucker, Sarah N. Sampson, Magnetic Resonance Imaging Protocols for the Horse, Clin Tech Equine Pract 6:2-15, 2007)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>T1 gradient echo</th>
<th>T2 gradient echo</th>
<th>STIR Short Tau Inversion Recovery</th>
<th>Proton Density</th>
<th>T2 fast spin echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Subchondral bone</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>White</td>
<td>Grey</td>
<td>Black</td>
<td>Light grey</td>
<td>Grey</td>
</tr>
<tr>
<td>Cartilage</td>
<td>White</td>
<td>Light Grey</td>
<td>Light Grey</td>
<td>Light Grey</td>
<td>Grey</td>
</tr>
<tr>
<td>Tendon</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
<td>Grey</td>
<td>Black</td>
</tr>
<tr>
<td>Ligament</td>
<td>Dark Grey</td>
<td>Black</td>
<td>Black</td>
<td>Grey</td>
<td>Black</td>
</tr>
<tr>
<td>Fluid</td>
<td>Black</td>
<td>White</td>
<td>White</td>
<td>Grey</td>
<td>White</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>Grey</td>
<td>Grey</td>
<td>Grey</td>
<td>Grey</td>
<td>Grey</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slice plane</th>
<th>Sequence</th>
<th>TR(ms)</th>
<th>TE(ms)</th>
<th>Matrix size</th>
<th>Slice#/Width</th>
<th>Gap(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal</td>
<td>3D SPGR</td>
<td>8.2</td>
<td>3.3</td>
<td>512x512</td>
<td>68/3mm</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td>3D T2* GRE</td>
<td>7.5</td>
<td>3.2</td>
<td>512x512</td>
<td>68/3mm</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td>STIR</td>
<td>10500.0</td>
<td>35.4</td>
<td>256x256</td>
<td>22/4mm</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>PD FDE</td>
<td>4000.0</td>
<td>10.1</td>
<td>256x256</td>
<td>87/2mm</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>T2 FDE</td>
<td>4000.0</td>
<td>81.1</td>
<td>256x256</td>
<td>88/2mm</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 3: Scanning details, SPGR: spoiled gradient echo(T1), GRE: Gradient echo(T2*), STIR: Short Tau Inversion Recovery, PD: Proton density, FDE: fast dual echo.
Results:

Anatomy comparison in immature horse

In the stifle MR images the following soft tissue structures were consistently identified: the medial and lateral collateral ligaments (CL), medial and lateral meniscus (MM, LM), cranial and caudal cruciate ligament (CrCL, CaCL), medial, middle and lateral patellar ligaments (MePL, MiPL, LPL), the medial cranial meniscotibial ligament (CrMMTL) and lateral cranial meniscotibial ligament (CrLMTL), medial-caudal meniscotibial ligament (CaMMTL) and lateral-caudal meniscotibial ligament (CaLMTL), meniscofemoral ligament (MFL), and lateral and medial femoropatellar ligaments (MeFPL, LFPL). Apart of all the ligaments the following structures could be visualised: the femoralpatellar and medial and lateral femoralibial joint capsules within synovial fluid, the popliteus tendon, combined tendon of the long digital extensor and the peroneus tertius muscle attached to the extensor fossa with his surrounding tendon sheath filled with fluid and the expansion of the lateral femorotibial joint capsule under the combined tendon of the long digital extensor and the peroneus tertius muscle. Also blood vessels around the joints where visualised. Tendons and ligaments had homogenous low signal intensity on all sequences, and had a variation between dark grey till black depending on slicing in an angle with the ligament or the tendon and the thickness of the tissue. The ticker the ligament and the bigger the angle of the fibre alignment of the ligament the less homogenous the signal. The signal intensity was the lowest on 2D STIR. Fluid in the surrounding sheaths and in the joint had high signal intensity on GRE (gradient echo) and STIR (Short Tau Inversion Recovery) images and low signal intensity on SPGR (Spoiled gradient echo (T1)) images. The menisci had homogenous low signal intensity on 3D SPGR, GRE, T2 FDE (fast dual echo) and PD (proton density) images, although signal intensity was lower on 3D GRE, T2 FDE and PD images. On 2D STIR images, menisci had a homogenous very low signal intensity.

The bony and cartilage structures in the stifle joint that were consistently visualized were cartilage, subchondral bone, cortical bone, cancellous bone with the trabecular structure and growth plates. The attachment sites of the above-listed ligaments and tendons were also consistently visible in the different sequences. The bony structures had different signal intensity on the different sequences. On 3D SPGR images, the articular cartilage is recognised as a layer of homogenous intermediate signal intensity with a smooth osteochondral junction and was clearly defined from the bone underneath it in all joints by the difference in signal intensity. On 3D GRE, T2 Fast spin echo and PD the articular cartilage was also visible as a layer of homogenous moderately high signal intensity. On 2D STIR images, the articular cartilage was barely visible and was recognized as a very thin layer of intermediate signal intensity. The distinction of proximal and distal cartilage layers in the femoralibial joints could clearly be recognised by the darker intensity signal of fluid or the menisci on 3D SPGR. On 3D GRE, T2 Fast spin echo the distinction between proximal and distal cartilage layers was made by...
the hypointense signal of the menisci and the hyperintense signal fluid line and a moderate signal intensity fluid line or hypointense signal menisci on PD. In the middle of the femoral-tibial joint it was not possible to make a distinction between the proximal and distal cartilage layer because the cartilage layers were very close to each other without a lower or higher signal in between. The SCB plate was easily recognized from the cartilage and the underlying cancellous bone as a homogenous low signal intensity with a regular osteochondral junction and a smooth but wavy deep border on 3D SPGR images. On 3D GRE, T2 Fast spin echo and PD images, the SCB plate had also a homogenous low signal intensity, with a smooth but wavy deep border. On 2D STIR images, it was not possible to define the SCB plate from cancellous bone. Cortical bone also had a homogenous low signal intensity with a regular and clearly defined corticocancellous junction on all sequences because of the lower signal intensity of cancellous bone, except 2D STIR images. It was not possible to define a boundary between cortical bone and SCB on all sequences. On 2D STIR images, it was not possible to define cortical bone from cancellous, because they had both a low signal intensity. Cancellous bone itself had a heterogeneous signal intensity with a well-defined trabecular pattern on 3D SPGR, GRE images, T2 Fast spin echo PD, because the trabecular pattern had a lower signal intensity. On a 2D STIR, the high signal intensity of fat was suppressed and cancellous bone had a homogenous low signal intensity that could not be distinguished from SCB, cortical bone or the trabecular matrix. Blood vessels walls have a hypointense intensity signal on 3D SPGR, GRE, T2 Fast spin echo, PD and STIR, but the fluid inside have different signal intensity depended on the sequence.
Adult-immature stifle image comparison

Figure serie1.1 sagittal: Lateral sagittal slice three of left pony stifle number 4. Cranial is to the left, proximal to the top. A: femur, B: Tibia, C: distal femur growth plate, D: patella, E: extensor fossa, F: proximal tibia growth plate, G: articular cartilage, H: subchondral bone; a: lateral patellar ligament, b: caudal lateral meniscus, c: combined tendon of long digital extensor and peroneus tertius, d: cranial lateral meniscus, e: fluid, f: femoropatellar joint capsul, g: fat tissue, h: m. rectus femoris, i: m. vastus lateralis, j: m. gastrocnemius caput lateralis, k: m. soleus, l: m. extensor digitorum lateralis, m: m. extensor digitorum longus, n: m. fibularis tertius.
**Figure serie 1.2 sagittal:** Midline-lateral sagittal slice one of left pony stifle number 4. Cranial is to the left, proximal to the top. A: femur, B: tibia, C: distal femur growth plate, D: patella, E: lateral cranial meniscotibial ligament attachment, F: proximal tibia growth plate, G: cartilage, H: subchondral bone, I: tibial crest growth plate, J: cortical bone; a: middle patellar ligament, b: cranial cruciate ligament, c: insertion tendo calcaneus and M. flexor digitalis superficialis, d: fat, e: bursa infrapatellaris proximalis, f: synovial capsule with fluid, g: lateral caudal meniscotibial ligament, h: m. rectus femoris, i: m. flexor digitalis superficialis, j: m. flexor digitorum longus, k: a. + v. poplitea.
1.2. 3D T2* GRE

1.2. Fast STIR

1.2. T2 Fast spin echo (FDE)

1.2. Proton density (FDE)
Figure serie 1.3 sagittal: Midline-medial sagittal slice one of left pony stifle number 4. Cranial is to the left, proximal to the top. A: femur, B: tibia, C: distal femur growth plate, D: patella, E: proximal tibia growth plate, F: cortical bone, G: cartilage, H: subchondral bone; a: middle patellar ligament, b: caudal cruciate ligament, c: medial caudal meniscotibial ligament, d: attachment meniscofemoral ligament, e: fat, f: bursa infrapatellaris distallis, g: femoral-patellar joint capsule with fluid, h: m. rectus femoris, i: m. flexor digitalis superficialis, j: m. flexor digitorum longus.
3. 3D T2* GRE
3. STIR
3. T2 Fast spin echo(FDE)
3. Proton density
Figure Serie 1.4 sagittal: Medial sagittal slice two of left pony stifle number 4. Cranial is to the left, proximal to the top. A: femur, B: tibia, C: distal femur growth plate, D: cartilage, E: subchondral bone, F: proximal tibia growth plate; a: medial patellar ligament, b: cranial medial meniscus, c: caudal medial meniscus, d: accessory cartilage of patella with the attachment medial ligament, e: fluid, f: m. vastus medialis, g: m.rectus femoris, h: m gastrocnemius caput mediale.
1.4. 3D T2* GRE
1.4. STIR
1.4. T2 Fast spin echo (FDE)
1.4. Proton density
Figure Serie 2.1 dorsal: Cranial dorsal slice one of right pony stifle number 7. Medial is to the right and proximal to the top. A: Patella, B: medial trochlea ridge, C: lateral trochlea ridge, D: cartilage, E: tibial crest with growth plate, F: accessory cartilage of patella, G: subchondral bone, a: medial patella ligament, b: lateral patella ligament, c: fat tissue, d: m. extensor digitorum longus, e: m. fibularis tertius, f: m. rectus femoris.
Figure Serie 2.2 dorsal: Cranial dorsal slice two of right pony stifle number 7. Medial is to the right and proximal to the top. A: Femur, B: patella, C: tibia, D: proximal growth plate of the tibia, E: tibial crest growth plate, G: cartilage, H: subchondral bone, I: distal growth plate of the femur, J: cartilage defect with subchondral bone reaction, a: medial patellar ligament, b: combined tendon of long digital extensor and peroneus tertius, c: attachment of combined tendon of long digital extensor and peroneus tertius in the extensor fossa, d: lateral femoropatellar ligament, e: femoropatellar joint capsule with synovia, f: fat tissue, g: m. biceps femoris, h: m. rectus femoris, i: m extensor digitorum longus, j: m. fibularis(peroneus) tertius, k: recessus subextensorius of the femorotibial joint with synovia.
**Figure Serie 2.3 dorsal:** Middle dorsal slice three of right pony stifle number 7. Medial is to the right and proximal to the top. A: Femur, B: tibia, C: proximal growth plate tibia, D: distal growth plate femur, E: fibula, F: cartilage, G: subchondral bone, a: cranial cruciate ligament, b: lateral collateral ligament, c: lateral meniscus, d: lateral cranial meniscotibial ligament with the attachment, e: medial meniscus, f: medial cranial meniscotibial ligament, g: attachment of m. poplitea, h: attachment of cranial cruciate ligament on intercondylar eminentia, i: m. vastus lateralis, j: m. rectus femoris, k: m. extensor digitorum lateralis.
2.3 T2* GRE

2.3 STIR

2.3 T2 FDE

2.3 Proton density
Figure Serie 2.4 dorsal: Middle dorsal slice three of right pony stifle number 7. Medial is to the right and proximal to the top. A: Femur with cancellous bone and the trabecular bone, B: tibia, C: proximal growth plate tibia, D: distal growth plate femur, E: cartilage, F: subchondral bone, G: cortical bone, a: caudal cruciate ligament, b: attachment of cranial cruciate ligament, c: medial meniscus, d: medial collateral ligament, e: lateral meniscus, f: tendon of m. poplitea, g: caudal medial meniscotibial ligament, h: blood vessels within the fossa intercondylaris, i: m poplitea, j: m. gastrocnemius caput laterale, k: m. adductor et m. semimembranosus, l: caudal lateral meniscotibial ligament.
2.4 T2* GRE

2.4 STIR

2.4 T2 FDE

2.4 Proton density
Figure Serie 2.5 dorsal: Caudal dorsal slice four of right pony stifle number 7. Medial is to the right and proximal to the top. A: Femur, B: tibia with cancellous bone and trabecular bone, C: caudal part of proximal growth plate tibia, D: caudal part of distal growth plate femur, E: cartilage, F: subchondral bone, G: cortical bone, a: ligaments meniscofemorale, b: medial meniscus, c: femorotibial joint capsule with fluid, d: m. poplitea, e: m. gastrocnemius caput laterale, f: m. semimembranosus.
2.5 T2* GRE

2.5 STIR

2.5 T2 FDE

2.5 Proton density
Figure serie 3.1: Distal transverse slice three of left pony stifle number eight at the tibial crest. Cranial is to the top, lateral to the left. A: tibia, B: fibula, C: tibiae crest growth plate, D: tibia crest; a: insertion of patellar ligaments(middle), b: tendon long digital extensor, c: medial collateral ligament, d: lateral collateral ligament, e: artery and vena poplitea, f: m.flexor digitorum longus, g: m gastrocnemius caput medialis, h: m. flexor digitalis superficialis, i: m. flexores diggitatorum profundus, j: m. extensor digitalis longus, k: m. extensor digitorum lateralis.
Figure series 3.2: Distal transverse slice two of a pony stifle number eight. Cranial is to the top, lateral to the left. A: tibial plate, B: cartilage, C: subchondral bone; a: medial patellar ligament, b: middle patellar ligament, c: lateral patellar ligament, d: combined tendon of long digital extensor and peroneus tertius, e: medial collateral ligament, f: lateral collateral ligament, g: cranial medial meniscotibial ligament, h: caudal medial meniscotibial ligament, i: medial meniscus, j: caudal cruciate ligament, k: part of lateral menisci, l: tendon of m. poplitea, m: a.+ v. poplitea, n: m. extensor digitalis longus, o: m. extensor digitalis lateralis, p: m poplitea, q: m. flexor digitorum longus, r: recessus subextensorius of the femorotibial joint with fluid.
3.2. 3D T2* GRE

3.2. STIR

3.2. T2 FDE

3.2. Proton density
Figure series 3.3: Middle transverse slice one of pony stifle number eight. Cranial is to the top, lateral to the left. A: medial femurcondyle, B: lateral femurcondyle, C: cartilage, D: subchondrale bone, E: eminentia intercondylare of the tibia, a: medial patellar ligament, b: middle patellar ligament, c: lateral patellar ligament, d: combined tendon of long digital extensor and peroneus (fibularis) tertius, e: medial collateral ligament, f: lateral collateral ligament, g: lateral meniscus, h: cranial lateral meniscotibial ligament, i: cranial medial meniscotibial ligament, j: caudal lateral meniscotibial ligament, k: cranial cruciate ligament, l: caudal cruciate ligament, m: a.+v. poplitea, n: m. flexor digitorum longus, o: femorotibial joint capsule with fluid, p: m. gastrocnemius caput medialis, q: m. semimembranosus, r: m. adductor, s: m. gastrocnemius caput lateralis.
3.3 T2* GRE

3.3 STIR

3.3 T2 FDE

3.3 Proton density
Figure series 3.4: Middle transverse slice four of pony stifle number eight. Cranial is to the top, lateral to the left. A: femur, B: cartilage, C: subchondral bone, a: medial patellar ligament, b: middle patellar ligament, c: lateral patellar ligament, d: combined tendon of long digital extensor and peroneus(fibularis) tertius, e: lateral collateral ligament, f: medial collateral ligament, g: insertion of m. poplitea, h: cranial cruciate ligament with its femur insertion, i: ligamentum meniscofemorale, j: a.+v. poplitea, k: femoropatellar joint capsule with fluid, l: caudal cruciate ligament with its femur attachment, m: m. gastrocnemius caput lateralis, n: m. flexor digitorum longus, o: m. adductor.
Figure series 3.5: Proximal transverse slice five of pony stifle number eight. Cranial is to the top, lateral to the left. A: femur, B: cartilage, C: distal growth plate femur, D: cartilage of patella, E: subchondral bone, a: medial patellar ligament, b: middle patellar ligament, c: lateral patellar ligament, d: lateral femoropatellar ligament, e: medial femoropatellar ligament, f: medial part femoropatellar joint capsule with fluid, g: lateral extension of femoropatellar joint capsule with fluid, h: biceps femoris, i: m. gastrocnemius caput lateralis, j: m. flexor digitorum longus, k: m. sartorius et m. gracilis, l: a. +v. femoris caudalis.
3.5 T2* GRE

3.5 STIR

3.5 T2 FDE

3.5 Proton density
Comparison adult versus immature.

In the adult stifle the anatomy on MRI was similar as in the immature ponies. The differences found are based on the higher amount of fat in trabecular bone, stiffer ligaments (less fluid, more collagen fibers) and stiffer menisci in the adult horse and remodelling of both soft as osseous structures. Between the adult group and the immature group a small variation in signal intensity was noted, but these variations were so small that the same scanning protocol was used. The differences in signal intensity are described and illustrated with pictures (fig 4-6). Due to the high amount of fat in the cancellous bone, it was clearly defined from the hypointense signal intensity of subchondrale bone and cortical bone on SPGR, T2* GRE. The growth plates were not or barely visible in all adult horses except for the two year old Thoroughbred, because these growth plates close at the age of 24-30 months, (Figure 5). The cruciate ligaments had less sharp boundaries in the adult horse on all sequences, because of soft tissue around the ligaments (Figure 6). The tendons and ligaments and especially the cruciate ligaments, were sliced in a different angle on the MRI than they were positioned in the intact knee, had a bigger angle effect which made hyperintense and hypointense signal artefacts in the cruciate ligament. Also the thickness of the ligaments in the MRI slices are responsible for a higher signal intensity (Figure 5). The tendons, ligaments and of the adult stifle also had a lower signal intensity on all sequences, because of lower amount of fluid and higher amount of fibrosis (Figure 4, 5). In the adult horse the menisci had lower signal intensity on all sequences compared with the immature stifles. The number of abnormalities observed is higher in the adult horse.
Transverse Adult Images 4: Middle transverse slice one (Figure 1.2) of left stifle of 7 yr. old Irish horse. Cranial is to the top, lateral to the left. A: tibia, B: Cartilage, C: Medial femurcondyle, a: medial patellar ligament, b: middle patellar ligament, c: lateral patellar ligament, d: combined tendon of long digital extensor and peroneus(fibularis) tertius, e: medial collateral ligament, f: lateral collateral ligament, g: cranial medial meniscotibial ligament, h: caudal medial meniscotibial ligament, i: caudal cruciate ligament, j: lateral meniscus.
Sagittal Adult Images 5: Middle sagittal slice one (Figure 1.1) of left stifle of 7 yr. Old Hanovarian. Cranial is to the left, proximal to the top. A: femur, B: tibia, C: cartilage, D: subchondral bone, E: origin of the distal femur growth plate, a: cranial cruciate ligament, b: caudal cruciate ligament, c: tendon m. gastrocnemius, d: middle patellar ligament.
Dorsal Adult Images 6: Middle dorsal slice three (Figure 1.3) of right stifle of the 7 yr. Old Hanovarian. Lateral is to the left, proximal to the top. A: femur, B: tibia, C: cartilage, D: subchondrale bone, a: cranial cruciate ligament, b: caudal cruciate ligament, c: medial meniscus, d: lateral meniscus, e: tendon of m. poplitea, f: lateral collateral ligament.
Incidental anatomy defects in the stifle joint.

Anatomy defects in the cartilage lining and the underlying subchondral bone were noticed in the immature ponies (1-2%) as well as in the adult mature horses, whereas the incidence was 50% higher in the adult horses. Lesions occurred in the femurotibial and the femoropatellar joint (Figure series 1.2 and 2.2). Cartilage damage (1-2%) was the major abnormality that was found and located in the femorotibial joints and femoropatellar joints, both in the lateral as the medial. The abnormalities consisted of an irregular cartilage surface, mostly with subchondral bone thickening (Figure 6,7,8, 9). In the 24 year old Shire cross a cartilage tear was found on the tibia plate which stretches out as long as the medial femurcondyle. Underneath the tear a subchondral bone reaction was observed. The meniscus had a lower signal intensity near the cartilage tear, pointing out fibrosis of meniscus tissue. The cartilage of the femur was not irregular, but had subchondral bone thickening underneath. The 5 year old Thoroughbred had a cystic lesion in the lateral trochlea ridge, with calcification inside. Also a cartilage split in between the trochlea ridges, was seen on both stifles. In the 7 year old Irish horse oedema was found in the middle patellar ligament. The fluid in the ligament was in the distal third part of the structure and was scattered over the whole thickness of the ligament (b in Figure 4). The incidental anatomy defects on which where found on MRI were confirmed in gross-section images.

Figure 6: Middle dorsal slice number four. Abnormalities in 7 yr. old Hanovarian, Lateral is to the left, proximal to the top. A: cartilage defect, B: thick, irregular subchondrale bone.
**Figure 7**: Medial sagittal slice number two. Abnormalities in 24 yr. old Shire Cross, Cranial is to the left, proximal to the top. A: wavy irregular cartilage, B: subchondrale bone thickening under the cartilage defect.
Figure 8: Medial sagittal slice number two. A cartilage tear with bone and meniscus reaction in the 24 yr. old Shire Cross. Cranial is to the right, proximal to the top. A: cartilage tear, B: subchondrale bone reaction under cartilage tear, C: medial meniscus which has a lower signal intensity on the side of the cartilage tear, with less fluid, D: subchondrale bone thickening on the upper side of cartilage tear.
**Figure 9:** Proximal transverse slice number four. Cartilage defect with bone reaction in the 7 yr. old Irish horse. Cranial is to the top, lateral to the left. A: cartilage irregularity, B: with subchondrale bone reaction underneath, thicker low signal intensity layer under the cartilage.

**Figure 10:** Cranial dorsal slice number one. Cystic lesion and cartilage split in the 5 yr. old Thoroughbred, medial is to the right, proximal to the top. A: calcification in a cystic lesion, B: cartilage split in between the trochlea ridges, C: subchondral bone thickening under the cartilage split with low signal intensity.
Figure 11: Proximal transverse slice number five. Cartilage split in the 5 yr. old Thoroughbred. Medial is to the left, cranial to the top. A: cartilage split in between the trochlea ridges, B: with directly underneath subchondral bone reaction.
In this study the normal anatomy of the equine stifle is described in detail on magnetic resonance images and is corresponding well with the macroscopic anatomy of the cadaver sections. All the parts of the equine stifle that are described in the anatomy literature could be clearly seen on the magnetic resonance images (Dyce et al. 1996, Budras et al. 2005). It was possible to obtain information of cartilage, cortical bone, subchondral bone, trabecular bone, cancellous bone, menisci, ligaments, tendons, muscle and blood vessels which is not all possible with other available diagnostic imaging tools. MRI is still in its infancy in relation to the anatomical description and injury locations in the lower limb and stifle, but is developing fast. The obtained results are in agreement with the conclusions reported earlier, that MRI offers the best evaluation technique of all anatomical structures of the equine stifle, in particular of soft tissue structures (Peterfy et al. 1994, Widmer et al. 2000, Murray et al. 2005, Bergman et al. 2007). Bergman et al. 2007 described the value compared to CT and considered that CT gives in most cases higher detail of bony structures and also good soft tissue evaluation, but compared to magnetic resonance imaging the evaluation of soft tissue is less. The obtained information of the current study appoint that MRI imaging allows assessment of the structures inside the knee joint and offers the opportunity to detect injuries in the stifle joint. However, whereas in human medicine MRI is already established as a golden standard for stifle imaging, it is still too early to say that MRI is the golden standard for stifle evaluation in the horse. Scanning stifle joint is only possible for horses with long legs and a narrow pelvis and can only be performed under general anaesthesia (at least 2 hours) (Peterfy et al. 1994, Yochum et al. 2005, Carter et al. 2007).

MRI might permit the diagnosis of various lesions within the stifle joint that cannot be diagnosed by other means, just by offering the opportunity to visualise the anatomic structures (soft and bony tissue) that otherwise can not be visualised. Depending on the character of the lesion, the T2 gradient echo, STIR, T2 fast spin echo and proton density are useful for fluid accumulations, where in SPGR, T2 gradient echo, proton density and T2 fast spin echo are useful for shape defects, bone and cartilage defects.

The differences found between immature and adult horses are a higher amount of fat, stiffer ligaments (less fluid, more collagen fibers) and stiffer menisci and remodelling of cartilage and subchondral bone in the adult horse. This differences are the result of the influence of exercise load and aging, which lead to adaptation of the anatomical structures (Soler et al. 2007). Between the adult group and the immature group, there was a small variation in signal intensity, but the adult group had also a wider variation in age, history and breed. It is therefore essential for interpreting normal anatomy to keep in mind the age of the horse.

The cruciate ligaments had a signal intensity difference in different scans. This effect might be caused by the magic angle effect (Murray et al. 2007) which is an artifact, but could also be explained by the thickness of the ligament on MRI slices.
The signal intensities in the cadaver specimens could be different in live animals because of the loss of fluid and blood in the cadavers, the freezing and the absents of blood flow. However, the normal anatomy and the abnormalities found in this study will be really close to normal anatomy and abnormalities found in the live horse. Because in the lower limb ante mortem and post mortem imaging of the same horse had a good correlation between the signal intensity of different anatomical structures (Murray et al 2006, Branch et al 2007, Carter et al 2007).

Although this study was meant to describe the normal anatomy on MRI imaging, pathological findings were observed as well. The animals had no history of hind limb lameness, which indicates that lesions can occur without any clinical relevance and might be considered as lesions within the normal physiological or anatomical variation or as true abnormalities. It is also possible that these lesions were not severe enough to give lameness in the live horse, but could give problems in the future (Pfirrmann et al 2002, Murray et al 2006). The described lesions indicate how important experience with MRI is to give a good evaluation of a clinical case and to give a final diagnosis, treatment and prognosis after a whole clinical examination with further diagnostic techniques. By knowing the variation in MRI images in the normal horse, it is possible to understand the importance of different increased or decreased signal intensities in the equine stifle lameness. In diagnostic imaging it is important to find out if the lesion is within normal variation, an image artefact or a real abnormality. A further study on the comparison between MRI and other techniques can give more information on possibilities for diagnostics of lesions.

The current study gave a description of the MRI images compared to macroscopic views, however no objective measurements were made. With further research and experience, it is likely that more lesions can be identified by an even more detailed description of the normal images. In this study it was hard to cut the slices in the exact same direction as the slices of the MRI, which made it difficult to measure different stifle structures for both the anatomy as the lesions. Scanning after dissecting, might solve this problem and give an exact match between gross-anatomy and the MRI scans for an accurate comparison. Another limitation of this study is that no other diagnostic techniques were used prior to the MRI imaging and no objective opinion can be given on the fact if the observed lesions could have been found by other diagnostic imaging techniques. The use of ponies and horses which have differences in size, growth speed and genetics was not considered by the authors as a major limitation. The gross anatomy of both species is very related and the aim of this study was to describe the normal anatomy of horses and ponies in general of different breeds, and ages; a at random selection of the population with no selection of breed, age or history was used. This study provides an atlas of normal anatomy of the knee, which can be a help in clinical cases and as a reference for other research projects. For further specification of size and intensity of lesions in the equine stifle and an accurate comparison between gross anatomy and MRI, measurements of normal anatomy structures in normal scans have to be correlated accurate with cross-section material, for a good interpretation of the lesion.
References:


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