Computed Tomography and Computed Tomography Arthrography of the Equine Stifle: Technique and Preliminary Results in 16 Clinical Cases

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Stifle lameness remains a diagnostic challenge. Computed tomography (CT) and CT arthrography are usable techniques in the horse, and they were useful for the evaluation of osseous and soft tissue structures in 16 clinical cases. This technique provided more complete diagnostic information, which allowed for directed therapeutic plans and more accurate prognoses. Authors’ addresses: Lingehoeve Diergeneeskunde - VetCT, Veldstraat 3a, 4033 AK Lienden, The Netherlands (Bergman, van der Veen, Weimer). Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis, CA 95616 (Puchalski); e-mail: e.bergman@delingehoeve.nl. © 2007 AAEP.

1. Introduction

The stifle is a large and complex joint that is frequently implicated in equine lameness. Although its anatomy has been described in detail, the definitive diagnosis of stifle injuries, particularly intracapsular soft tissue injuries, remains elusive.

Radiography, nuclear scintigraphy, ultrasonography, and diagnostic arthroscopy have been described for diagnosing equine stifle injuries, but limitations exist for each modality. Radiography and nuclear scintigraphy of the stifle are limited by the superimposition of the hindlimb musculature and the sheer size of the bones comprising the joint. These modalities, although useful for osseous, enthuses, and periarticular margin evaluation, are generally considered to be less useful for the diagnosis of soft tissue injuries. Currently, ultrasound is commonly used to diagnose many soft tissue injuries of the stifle; however, some specific anatomic structures cannot be visualized or are extremely difficult to examine consistently. Diagnostic arthroscopy is used in the evaluation of cartilage, portions of the menisci, and associated ligaments, but certain regions of the femorotibial joints are very difficult or impossible to visualize.

In people, magnetic resonance imaging (MRI) is the dominant imaging modality for evaluation of knee injuries, and it has largely replaced most other modalities. When MRI is unavailable, computed-tomography (CT) arthrography of the knee has been used with very good accuracy to diagnose cruciate ligament, cartilage, and meniscal injuries.
The use of CT has been reported for the diagnosis of equine locomotor pathology, and some reports value CT over MRI for the evaluation of osseous lesions.\textsuperscript{21–25} The addition of intravascular contrast material has also been described as a useful tool for the evaluation of tendon and ligament injury in the equine distal limb.\textsuperscript{26,27} One report describes the use of CT for evaluation of the equine stifte and shows its utility in evaluating the caudal aspect of the joint.\textsuperscript{28} Stifle CT arthrography has been described in the dog but to our knowledge, not in the horse.\textsuperscript{14} The purpose of this paper is to describe a technique for CT arthrography in the equine stifte and report preliminary results from routine CT and CT arthrography in 16 cases.

2. Materials and Methods

Control Group

Two cadaver hindlimbs obtained from two horses, euthanized because of colic, with no history of hindlimb lameness were used to develop the CT arthrography technique. The limbs were disarticulated at the coxofemoral joints and placed on the human table of a four-slice CT scanner.\textsuperscript{a} On each limb, one study consisting of four series was performed for the stifte. One study was performed without contrast material. The three sequential series were obtained after injection of contrast into the medial femorotibial joint (MFTJ) followed by the femoropatellar joint (FPJ) and the lateral femorotibial joint (LFTJ). For all imaging sequences, the tube output parameters were 140 K\textsubscript{v} and 266 mAs/slice. The tilt of the gantry was zero, and the pitch was 0.625. The rotation time was 1.5 s, and overlapping 1.3-mm slices were made. The images were obtained from proximal to distal and included 5 cm distal to the articular margin of the tibia to just proximal to the trochlear ridges of the femur. On these series, the field of view (FOV) was 20 × 20 cm, and the pixel matrix was 512 × 512. Each series took ~90 s.

Iodinated contrast material\textsuperscript{b} was diluted 1:1 with normal saline. All intra-articular injections were guided using a 12- to 5-MHz blended linear-array ultrasound transducer.\textsuperscript{c} For the FPJ, 80 ml of diluted contrast was applied. For the MFTJ and LFTJ, 60 ml of the same substance was used. After each intra-articular injection of contrast material, the leg was extended and flexed several times to distribute the contrast throughout the entire synovial cavity.

After the CT and CT arthrogram, the stifte joints were disarticulated and evaluated to confirm that no gross pathology was present involving the bone surfaces, menisci, or ligaments. The images generated from these limbs were used as controls for the clinical cases described.

Clinical Group

Sixteen horses (450–650 kg body weight [BW]) were included in the clinical group. All horses were referred between October 2006 and March 2007 to the equine referral hospital (Lingehoeve Diergeneeskunde, Lienden, The Netherlands) for evaluation of a moderate (2–4 of 5 on the American Association of Equine Practitioners [AAEP] lameness grading scale) hindlimb lameness. The lameness was localized to the stifte joint by intra-articular diagnostic anesthetic injections and by static and dynamic lameness examinations. In each case, a complete radiographic examination, including caudocranial, lateromedial, and caudolateral to cranio-medial oblique projections, was performed. An ultrasound examination of the affected stifte was performed in all horses using the cranial, medial, lateral, and flexed cranial approach previously described.\textsuperscript{5}

All of the horses in the study group had a CT combined with a CT arthrography examination performed on at least one suspected compartment.

CT Technique

Each horse had an IV catheter placed in one jugular vein and was pre-medicated with detomidined\textsuperscript{d} (0.01–0.02 mg/kg, IV). They were induced with ketamine\textsuperscript{e} (1 mg/kg) and midazolam\textsuperscript{f} (0.1–0.2 mg/kg, IV). An endotracheal tube was placed, and oxygen was administered while general anesthesia was maintained using an infusion of 500 ml of 5% guaifenesin\textsuperscript{g} with 1000 mg of ketamine and 10 mg of detomidine. The horses were positioned in dorsal or dorsolateral recumbency on a custom-built CT table\textsuperscript{h} with the lame leg down and positioned within the gantry (Fig. 1).

The lame limbs were positioned in full extension so that the longitudinal axis of the limb was parallel to the table and perpendicular to the plane of the CT gantry (Fig. 2). The opposite hindlimbs were in full flexion.

After the initial (pre-contrast) series was obtained, the suspected compartment of the abnormal stifte was clipped and aseptically prepared for ultrasound-guided intra-articular contrast injection. For the FPJ, 80–100 ml of the diluted contrast-material mixture was injected. For the femorotibial joints (FTJ), 60 ml of the same substance was used. After contrast administration, the leg was extended and flexed several times to allow the contrast to distribute throughout the entire synovial cavity. After injection and flexion and extension of the limb, the stifte was repositioned within the CT gantry, and another series using the same imaging parameters was obtained.

CT-Scanning Protocol

Tube parameters and imaging techniques were as previously described for the cadaveric limbs with the exception of the FOV. The FOV was adjusted to a maximum of 50 × 50 cm when and if the stifte was eccentrically positioned within the gantry.
Patient Management
Horses recovered unassisted in a routine fashion. The horses were maintained under supervision in the hospital for the two days after the procedure. They were observed for clinical signs related to complications of either the anesthesia and positioning or the intra-articular contrast injection.

Image Analysis
The images were evaluated using either eFILM WORKSTATION 2.0i or OsiriX 2.7j DICOM viewing software. All images were reviewed by two of the authors (HJB and SMP). Abnormalities were determined by consensus and by comparison to the control-group images. Two horses were euthanized on humane grounds and dissected for gross-pathology examination of the stifle joint.

3. Results
Images from the control group were easily obtained using the technique described above. The initial series and each sequential series with intra-articular contrast material provided quality diagnostic images. Beam-hardening artifact was observed on several images in all series obtained at the level of the distal femur and patella.

The horses in the clinical group had a mean age of 10.3 yr (range = 3–18 yr). Twelve Dutch Warmbloods, two German Warmbloods, one Appaloosa, and one American Paint Horse were included in the study group. Intra-articular anesthesia of the MFTJ was positive in nine horses; four horses required anesthesia of all compartments of the stifle, and one horse improved after anesthesia of the LFTJ only. Ten horses had negative radiographs. Five horses had bone remodeling—three at the insertion of the cranial-medial meniscotibial ligament (CrMMTL), and two at the insertion of the caudal-cruciate ligament. One horse had an avulsion at the insertion of the caudal-cruciate ligament. Ultrasound examination revealed abnormalities in eight horses. The abnormalities included joint effusion in four horses and either medial meniscus (MM) or CrMMTL lesions in four horses. In two of the latter cases, the ultrasound findings were considered equivocal. The remaining eight horses did not have any abnormalities identified on a complete ultrasound examination. Three cases with no ultrasound abnormalities had abnormalities of the cruciate ligaments and/or entheses identified on CT.

Diagnostic CT and CT arthrography images were obtained for all horses in the clinical group. In some cases, size of the patient caused difficulty in positioning so that several attempts to position the stifle centrally in the gantry were made. In all cases, the proximal portions of the FPJ and entire patellae were not included in the examination because of the physical constraints of the gantry and the size of the horse. In all cases, the FTJs were completely imaged. Beam-hardening artifact was present in the images of the proximal aspects of the
Ultrasound-guided intra-articular contrast administration was successful in all cases. In three cases, contrast material was observed outside of the MFTJ in the periarticular tissues. Flexion and extension of the joint resulted in adequate distribution of contrast medium throughout the joint. For two days after administration, no clinical signs of reaction to the intra-articular contrast injection were observed.

The anesthetic time was <45 min in all cases. None of the clinical cases had complications related to the anesthesia. Four horses appeared stiff the day after the CT examination. The stiffness was interpreted as a result of positioning on the CT table. These clinical signs abated with conservative management: handwalking and using non-steroidal anti-inflammatory drugs. At discharge from the hospital, these horses had returned to their baseline lameness.

In all studies, software tools were used to increase the ability to identify and characterize the bone and soft tissue structures. Tools that were used in every case included window and level tools, and the multiplanar reformat (MPR) tool in both DICOM viewers were used in this study. The MPR tool was considered particularly important for evaluation of the cruciate ligaments and the menisci.

In the cadaver series obtained before contrast administration, the following soft tissue structures were consistently identified: the collateral ligaments (CL), MM and lateral meniscus (LM), cranial-cruciate ligament (CrCL) and caudal-cruciate ligament (CaCL), and three patellar ligaments (PL). After CT arthrography, the aforementioned structures were consistently identified along with several more structures: CrMMTL and lateral cranial meniscotibial ligament (CrLMTL), medial-caudal meniscotibial ligament (CaMMTL) and lateral-caudal meniscotibial ligament (CaLMTL), and meniscofemoral ligament (MFL). Multiplanar reconstructions (MPR) enabled further and better evaluation of the CrCL, CaCL, MM, and LM after CT and CT arthrography.

In the cadaver studies, the bony structures comprising the stifle joint were consistently well visualized. Attachment sites of the above-listed ligaments were consistently visible. The contrast material in the CT arthograms allowed for indirect evaluation of articular cartilage as a thin hypo-attenuating interface between the subchondral bone and the contrast material within the synovial fluid, but complete evaluation was inconsistent.

In the 16 clinical cases, identification of the anatomic structures, both bone and soft tissues, was similar to the cadaver studies. In the majority of cases (14 of 16), lesions were identified that correlated to the clinical examination. Most (12) of those 14 cases had multiple abnormalities identified.

The distribution of lesions by anatomic location is listed in Table 1. In three cases, communication between the MFT and the FPJ was documented.

In the clinical group, the most frequent lesion involved the CrMMTL and its insertion onto the proximal tibia (6 of 16 cases). Ultrasound and radiographs consistently underestimated the extent of bone remodeling in these cases (Figs. 3 and 4). CrMMTL abnormalities were best identified on CT arthrography of the MFTJ and were characterized as enlarged size, evidence of contrast material within the ligament, and irregular margination of the ligament borders (Fig. 5). Bone remodeling was commonly characterized by irregularly margined osseous proliferation or resorption at the entheses (Fig. 6).

The second most frequently observed abnormality was lesions of the MM (5 of 16 cases). These lesions were also most identifiable on CT arthrography of the MFTJ. Lesions were characterized by abnormal medial margination of the meniscus (medial bulging) or contrast-material extension into the meniscus from the joint space, which indicates a meniscal tear that has communication with the joint (Fig. 7). In two cases, the CT findings were confirmed with gross pathology (Fig. 8).

Evaluation of the entire cruciate ligament, either cranial or caudal, was inconsistent. They were best identified in horses having CT arthrography of all compartments of the stifle. Software tools were necessary to identify these ligaments. Cruciate-ligament abnormalities were identified in 8 of 16 horses. The CaCL (five of eight cases) was more frequently abnormal than the CrCL (three of eight cases). Lesions were characterized as enlarging or mineralizing of the ligament, fragmenting at the origin or insertion site, or bone remodeling through either loss or production at the origin or insertion site (Fig. 9).
Other lesions involved cartilage, subchondral bone, patellar ligaments, and enthesopathies of the deep digital flexor muscle and the tibial portion of the semitendinosus tendon of insertion (8 of 16 cases). Cartilage defects were identified by loss of the hypodense line between the subchondral bone shelf and the intra-articular contrast material (Fig. 10). In two cases, subchondral osseous cyst-like lesions with articular communication were identified on CT that could not be confirmed on radiographic examination. There were cases where the CT examination confirmed known lesions of the patellar ligaments, collateral ligaments, and lateral trochlear ridge of the femur.

4. Discussion

This study describes a feasible technique for equine stifle CT and CT arthrography and shows its clinical utility in 16 cases. Historically, CT has been infrequently used to evaluate the anatomy of the upper limbs for a variety of reasons, such as the physical constraints of the horse, gantry size, X-ray tube output, and difficulties in linking a table strong enough to support a horse to the CT scanner. Advances in all of these areas in addition to CT-scanner software and hardware improvements have made the technique reported possible. Multislice helical CT provides overlapping, cross-sectional images with very thin slices, which improves the resolution and the quality of images produced using software tools. Multiplanar reformatting, a software tool, is considered essential for complete evaluation of the stifle.

CT provides high-quality diagnostic images that, with the addition of intra-articular iodinated contrast material, enabled visualization and evaluation of the clinically important, currently problematic soft tissues. The technique of arthrography was relatively simple using ultrasound guidance. The diagnostic quality of images was improved by active manipulation of the stifle after injection. CT was vastly superior to radiography for evaluation of hard tissues including bone and dystrophic soft tissue mineralization. Mild radiographic abnormalities were generally markedly abnormal on CT images.

![Fig. 3. (A) Caudocranial, (B) lateromedial, and (C) flexed lateromedial radiographic projections of the left stifle of a horse with clinical signs of MFTJ disease. Lateral and cranial views are to the left. There is irregularly margined luency in A that is distal and medial to the intercondylar eminence of the tibia in the region of the insertion of the CrMML. There is periosteal proliferation on the medial aspect of the femoral epicondyle and periarticular margin of the medial aspect of the proximal tibia. On the lateromedial projections in B and C, irregular bone proliferation is present at the base of and cranial to the intercondylar eminence of the tibia.](image)

![Fig. 4. Ultrasound images from the horse shown in figure 3. (A) A reference image was obtained from the sound hindlimb. (B) In the affected limb, the CrMML is enlarged, heterogenous, and hypoechoic. The bone surface of the proximal tibia (T) is irregular.](image)
This improved visualization of bone remodeling is caused by the elimination of superimposition of bone and surrounding structures. In veterinary medicine, reports of CT for evaluation of the stifle are limited. One report describes the use of CT for evaluation of the

Fig. 5. (A and B) Transverse CT MFT arthrogram and (C and D) CT images obtained at the level of the proximal tibia. Medial is left, and cranial is at the top. Images on the left (A and C) were obtained from a control horse. Images on the right (B and D) were obtained in the clinical case shown in figures 3 and 4. The arthrogram in B shows the irregular margin of the CrMMTL (arrowheads) and irregular bone loss with surrounding sclerosis at its insertion site in the clinical case (arrows).

Fig. 6. Transverse images through the subchondral bone of the proximal tibia in (A) a control horse and (B) the clinical case shown in figures 3–5. Medial is left, and cranial is at the top of the image. There is a region of sclerosis caudal, medial, and distal to the insertion site of the CrMMTL (arrowhead). There is irregular bone loss associated with the CrMMTL enthesis that extends distally into the proximal tibia and away from the joint surface (arrow).
equine stifle and similarly concludes that CT adds information to radiography regarding bone fragmentation, bone remodeling, and evaluation of the soft tissue structures of the caudal aspect of the FTJs. In this report, negative-contrast arthrography using carbon dioxide also helped to

Fig. 7. Sagittal plane images (A, C, and E) through the MFTJ of a control horse on the left and (B, D, and F) through the MFT of a clinical case on the right. Cranial is to the left. Images progress from abaxial (A and B) to axial (E and F) from top to bottom. In the control horse, contrast material distributes around the medial meniscus. The margins of the meniscus are clearly demarcated and smoothly margined compared with the clinical case on the right (B, D, and F). Contrast material is present within the cranial horn of the MM. The contrast material has an arborizing pattern axially and a more linear pattern abaxially that is consistent with a complex meniscal tear. There is increased synovial volume in the caudal aspect of the MFTJ of the clinical case.

Fig. 8. Gross pathology pictures obtained from the clinical case shown in figures 3–6. Medial is left, and cranial is at the top. (A) The proximal aspect of the tibia with the menisci in place are shown. The CrMMTL is abnormal (arrow), and a tear is identified within the axial margin of the meniscus (arrowhead). This meniscal tear was identified on the CT exam but not the ultrasound examination. (B) A close-up image of the CrMMTL (arrow) and meniscal tear (arrowhead) are shown.
identify meniscal lesions. In our study, CT was useful to evaluate the caudal and cranial aspects of the joint, and intra-articular positive-contrast arthrography aided in evaluation of not only the menisci but also their associated ligaments in addition to the cruciate ligaments. This improve-

Fig. 9. (A) Caudocranial radiograph and (B and C) frontal-plane reformatted CT images from a horse with stifle lameness. On the radiograph in A, there is remodeling of the proximal aspect of the intercondylar eminence of the tibia and the margins of the intercondylar fossa. There is possibly a free osseous fragment superimposed over the intercondylar fossa. The radiograph also shows lucency in the region of the CrMMTL insertion. The CT images of the same region show all of those findings with more detail and show fragmentation or soft tissue mineralization in the CrCL and enthesophyte formation at its insertion.

Fig. 10. (A) Transverse CT image through the subchondral bone of the proximal tibia of a horse with CrMMTL injury and secondary joint disease. (B) The white line shows the plane from which the frontal plane reformatted CT image was obtained. (C) This pathology specimen from the same patient shows the proximal tibia beneath the medial meniscus. Medial is left, and cranial is at the top. The arrow in B shows that the thin, lucent line produced by the presence of cartilage between the contrast material and the subchondral bone shelf has been lost. This cartilage lesion shown in C was associated with a focal subchondral lucency and marked subchondral sclerosis that was not seen on the radiographs of the same horse shown in figure 3.
In human medicine, CT arthrography is proposed as an accurate alternative method to MRI for the diagnosis of cruciate ligament and meniscal injuries. In these studies, sub-millimeter overlapping slices greatly increased the overall resolution of the images obtained. These studies state that the images developed through use of the multplanar reformatting tool are greatly improved with overlapping thin slices and that with this tool, imaging planes similar to those acquired in MRI can be evaluated. Likewise, we found that the MPR software tools were invalid for the identification of soft tissue lesions, and we used it in all cases.

In human medicine, the knee is not divided into separate compartments, making contrast administration less complicated than in the horse. To manage this problem, multiple compartments were injected in most horses. It is interesting to note that communication between the MFTJ and FPJ was documented in only three clinical cases.

CT arthrography offers two distinct advantages over radiography and ultrasound. The first advantage is identification of lesions not previously seen and additional concurrent lesions. The second advantage is that CT arthrography enables a more complete evaluation of the extent of known or suspected lesions. In cases where the radiographic examination was suspicious or positive for pathology, CT was consistently able to define the nature of the abnormality and the extent of the disease. This was particularly true for the enthesis of the CrM-MTL, CrCL, and CaCL. In several cases, ultrasound accurately identified the lesions (CrM-MTL and MM), but the CT scan documented other lesions or more extensive pathology than was suspected. In three cases, ultrasound examination did not find any abnormalities, and cruciate-ligament pathology was identified on CT images. This is consistent with the difficulty that is commonly encountered in obtaining diagnostic ultrasound images of this structure.

Nuclear scintigraphy and arthroscopy are also used for the diagnosis of stifle pathology. Nuclear scintigraphy is a physiologic or functional test that can be used to identify sites of active bone remodeling and is useful for the identification of enthesopathies. CT is not a functional test, and activity or inactivity of bone lesions must be inferred using the imaging characteristics and clinical information. The depiction of the anatomy on CT images is superior. Diagnostic arthroscopy is useful for direct visualization of the cartilage and soft tissues in the regions of the joint that are accessible. In most of the clinical cases, the proximal portion of the FPJ and PL were not included in the CT examination because of the size or positioning of the patient. These regions of the joint are particularly amenable to arthroscopic, ultrasonographic, and radiographic evaluation. Important regions of the FTJs are inaccessible to arthroscopic evaluation. Additionally, the extent of subchondral bone pathology can be underestimated if the articular surface of the lesion is small.

MRI is commonly used for soft tissue injury of the human knee. It is a non-invasive technique that does not use ionizing radiation to generate images. Furthermore, contrast resolution is generally considered to be superior to CT for soft tissues. CT arthrography has sensitivities and specificities similar to MRI for the evaluation of menisci and cruciate ligaments. A comparison of the two techniques for equine stifle pathology is not possible at this time, because no reports of stifle MRI are found in the literature. There are two comparison reports of CT and MRI for locomotor pathology in the horse. When both techniques agree, they both conclude that MRI was better for evaluation of the soft tissues, but CT was superior for evaluation of bone pathology.

CT arthrography has some limitations. The most obvious limitation is not specific to this technique and is that the horse must undergo general anesthesia. In the current climate of equine practice, it is acceptable to undergo general anesthesia for diagnostic purposes either for imaging or arthroscopy. Although the risks of anesthesia must be discussed with the owner, this limitation is becoming less of a barrier. Another limitation that must be addressed is our ability to interpret novel imaging techniques. Until the body of knowledge increases about this and other advanced imaging techniques, great care should be taken in image interpretation.

In conclusion, the techniques of equine stifle CT and CT arthrography are feasible and clinically useful. CT should be considered complementary to a complete clinical examination and other diagnostic...
imaging modalities. In this group of clinical cases, CT was useful to define the extent of suspected or previously diagnosed injuries and to identify injuries that were elusive. This information allows clinicians to develop more directed therapeutic plans or provide a more accurate prognosis. Future use of the described technique will increase our knowledge of equine stifle disease.

References and Footnotes


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*Ketamine, AST Pharma, NL-3420 DC Oudewater, The Netherlands.*

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*Eurovet, 5531 AE Bladel, The Netherlands.*

*Philips, 5656 AE Eindhoven, The Netherlands.*

*eFILM, Merge Healthcare North America, Milwaukee, WI 53214.*