COMPUTED TOMOGRAPHIC ARTHROGRAPHY OF THE INTERCARPAL LIGAMENTS OF THE EQUINE CARPUS

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Injuries of the intercarpal ligaments are an important cause of lameness in performance horses. The purpose of this prospective cadaver study was to determine whether computed tomography (CT) arthrography would be a feasible method for visualizing and characterizing intercarpal ligaments in the horse. One cadaver limb from each of eight nonlame horses was collected immediately after euthanasia. For each limb, overlapping 2.0 mm CT images were acquired before and after injection of iodinated contrast medium into the antebrachiocarpal joint, middle carpal joint, and carpal sheath. Spin echo magnetic resonance imaging (MRI) sequences were acquired in three planes using a 1.5 Tesla MRI scanner in three limbs. Following MRI, colored resin was injected into the synovial structures of these three limbs, limbs were frozen, and anatomic sections were obtained in three planes. Findings from CT arthrograms were compared to findings from precontrast CT, MRI, anatomic slices, and arthroscopy. Medial and lateral palmar intercarpal ligaments, radiocarpal and transverse intercarpal ligaments, and palmar carpal ligament were visible in CT arthrograms of all limbs. The proximal and distal entheses of all ligaments were readily identifiable. Findings indicated that CT arthrography is feasible for visualizing intercarpal ligaments and may be a useful adjunct imaging technique for diagnosing lameness due to suspected carpal ligament injury in horses. © 2013 *Veterinary Radiology & Ultrasound.*

Key words: arthrography, carpus, computed tomography, intercarpal ligament.

Introduction

THE CARPUS is an important source of lameness or poor performance in the equine athlete.[3] The intraarticular ligaments of the carpus (intercarpal ligaments) function to stabilize[1–4] the carpus and have been implicated as a source of lameness,[4–11] most frequently in racehorses.[12] The intercarpal ligaments can be grouped into dorsal, interosseous, and palmar ligaments.[1] The dorsal and interosseous ligaments are smaller and maintain carpal bone alignment. The palmar ligaments are stronger, and are rarely very distinct ligaments.[1] The palmar intercarpal ligaments have the common function of stabilization and prevention of carpal hyperextension.[1] The medial and lateral palmar intercarpal ligaments (medial palmar intercarpal ligament and lateral palmar intercarpal ligament) are two of the intercarpal supporting structures that have gained the most attention in recent reports.[8,9,12,13] Pathology of these structures has been confirmed in postmortem examination.[4,12] Antemortem diagnosis of intercarpal ligament pathology remains difficult due to the lack of specific clinical signs[8,9,13] complexity of the carpal anatomy and limitations with routine diagnostic imaging modalities. Radiography and ultrasound have a low sensitivity for the identification or diagnosis of pathology of medial palmar intercarpal ligament and lateral palmar intercarpal ligament.[14] Radiographic signs are limited to abnormalities at the ligament entheses and variation exists in the carpal bone margins that may or may not be associated with ligament damage.[15,16] Although arthroscopy has been used to diagnose injury in these structures,[8–10,13,17] only a small portion of the medial palmar intercarpal ligament[4,17] and lateral palmar intercarpal ligament[18] is visible with arthroscopy.

Magnetic resonance imaging (MRI) and computed tomography (CT) are increasingly available for use in lameness diagnosis in horses and their use has increased the ability to diagnose soft tissue injuries.[19–21] Magnetic resonance imaging is used clinically for the detection of intercarpal ligament disorders in people[22,23] and allows visualization of the carpal soft tissue and bone structures in horses.[24–26] Computed tomographic arthrography is used for clinical diagnosis of injury in human elbow joints[27] and the canine stifle, with high sensitivity and specificity reported for soft tissue and bone anatomy.[28,29] Computed tomographic

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anatomy of the equine stifle,[30] tarsus,[31] carpus,[26] and fetlock joint[32] has been previously described with and without intraarticular contrast. No previous studies were found describing detailed characteristics of equine intercarpal ligaments using CT arthrography. The objective of this study was to determine whether CT arthrography could be used to identify and characterize equine intercarpal ligaments, using high field spin echo MRI, gross anatomic sections, and arthroscopy as reference standards.

Materials and Methods

Animals

One forelimb was acquired from eight horses euthanized for reasons unrelated to the musculoskeletal system. Inclusion criteria were that that horse was not lame on initial presentation to the hospital The forelimb was transected at the level of the midradius immediately after euthanasia and stored at 4°C for a maximum of 48 h before imaging. Following imaging, the limbs were frozen at –20°C until sectioning. All procedures were preformed in accordance to animal care committee requirements.

Magnetic Resonance Imaging

Three randomly selected limbs were imaged using a 1.5 Tesla magnet (GE Medical Systems, Milwaukee, WI) MRI and a head radiofrequency coil. Sagittal, dorsal, and transverse T1 weighted spin-echo (T1), proton density (PD), and T2 weighted spin-echo (T2) pulse sequences were obtained. A 20 field of view, 3 mm slice thickness, and 0.5mm interslice gap were used. The MRI examination was carried out immediately prior to the CT examination. These limbs were imaged within 24 h of euthanasia.

Computed Tomography

All limbs were imaged precontrast using a 16 slice helical CT scanner (GE Medical Systems) with tube settings of 120 KV and 200 mA. The limbs were positioned with the long axis of the limb parallel to the CT table. A 20 × 20 cm field of view with overlapping 2.5 mm slice thickness with a 1.25 mm overlap were acquired and processed with a standard (soft tissue) algorithm. Scans of each limb were repeated following CT arthrography. For all injections, a solution of 200 mg Iodine/ml nonionic iodinated iohexol contrast media (GE Healthcare, Pittsburgh, PA) diluted 1:1 with 0.9% NaCl normal saline was used. The antebrachiocarpal and middle carpal joints were each injected with 10–12 ml of the contrast solution via a dorsal approach and with the limb in flexion. A lateral approach to the carpal sheath was used and 20 ml of the contrast solution was injected. The limb was then flexed and extended multiple times to maximize distribution of the contrast through the synovial spaces. The CT arthrogram scans were acquired using the same imaging parameters as those used for precontrast scans. Computed tomographic arthrogram scans were processed with an edge-enhancing, bone algorithm.

Anatomic Specimen Preparation

Three limbs were randomly selected for anatomic preparation (same limbs that underwent CT and MRI). Synovial fluid was aspirated from the radiocarpal and the middle carpal joint and the carpal sheath and replaced with a color-pigmented fluid. The limbs were stored at –20°C for a minimum of 48 h. A band saw (Butcher boy Ltd., Ayrshire, Scotland) was used to transect the limbs in 5-mm-thick slices in sagittal, dorsal, or transverse planes. The front and back faces of anatomic slices were photographed for comparison to the corresponding CT and MRI images.

Arthroscopy

The middle carpal joint and radiocarpal joint of three limbs was evaluated via arthroscopy to verify the location and document the extent of observation of the intercarpal ligaments. The three limbs selected underwent CT imaging only. The limb was secured to a stand in a way that would represent a live horse placed in dorsal recumbency and the joint was entered through a dorsolateral arthroscope portal.[34] The carpus was examined under flexion, to allow visualization of the medial palmar intercarpal ligament and lateral palmar intercarpal ligament. Still frame images were captured when the intercarpal ligaments were visualized.

Computed Tomographic Image Analysis

Computed tomography images for each limb were analyzed by two clinicians (S.N.G., S.M.P.) in both a bone and soft tissue window using commercially available image analysis software (eFilm, Merge Healthcare, Chicago, IL) Magnetic resonance images, gross preparation photographs, and anatomical text books[1,33] were used as references for identifying ligaments in the CT arthrography images. Multiplanar reformatting tools were used to inspect ligaments in transverse, dorsal, and sagittal planes. The medial palmar intercarpal ligament, lateral palmar intercarpal ligament, radiocarpal ligament, transverse intercarpal ligaments, and the palmar carpal ligament were marked as visible or not visible. A subjective visual assessment grade ranging from 0 to 3 was assigned for each of these ligaments based on the following grading criteria: 0 = ligament was not identified; 1 = ligament was identified based on density and anatomic location but the margins were not clearly visible; 2 = ligament was identified from origin to insertion but the margins were not clear; and 3 = ligament was clearly identified from its origin to insertion with clear ligament margins. For each ligament in each

TABLE 1. Median and Range of Subjective Visualization Scores for medial palmar intercarpal ligament and lateral palmar intercarpal ligament, RCL, TICL, and PCL as Seen on Computed Tomographic Transverse Arthrogram Images

	MPICL	LPICL	RCL	TICL	PCL
Median	3	3	3	3	3
Range	2–3	3	2–3	3	2–3

*MPICL, Medial Palmar Intercarpal Ligaments; LPICL, Lateral Palmar Intercarpal Ligament; RCL, Radiocarpal Ligament; TICL, Transverse Intercarpal Ligaments; PCL, Palmar Carpal Ligament.

carpus, two authors (S.N.G and S.M.P) assigned visual assessment grades by consensus. A median grade was calculated for the medial palmar intercarpal ligament, lateral palmar intercarpal ligament, radiocarpal ligament, transverse intercarpal ligaments, and palmar carpal ligament.

Results

Arthroscopy

Arthroscopy provided a small window of visualization for the medial palmar intercarpal ligament and lateral palmar intercarpal ligament. In all horses, the dorsal branch of the medial palmar intercarpal ligament was intact, obstructing visualization of the palmar branch and its insertion on the second carpal bone. It was not possible to completely evaluate the origin of both ligaments. Similarly, a small portion of the lateral palmar intercarpal ligament was visible through the dorsal portal. The body of the ligament, including where it divided to insert on the third and fourth carpal bones was visible, however the insertion point on these bones could not be assessed. Additional ligamentous structures such as the accessory carpoulnar ligament (ACU), accessory ligament of the fourth carpal bone (AC4), transverse intercarpal ligaments, radiocarpal ligament, palmar carpal ligament, and carpometacarpal ligaments ligament were not readily visible.

Computed Tomographic Arthrography

In all carpi, contrast medium appeared to be well distributed throughout each joint compartment and carpal sheath. The medial palmar intercarpal ligament, lateral palmar intercarpal ligament, radiocarpal ligament, transverse intercarpal ligaments, accessory carpoulnar ligament, palmar carpal ligament, and the accessory ligament of the fourth carpal bone were visible in all eight limbs. The visual assessment scores of the medial palmar intercarpal ligament, lateral palmar intercarpal ligament, transverse intercarpal ligaments, radiocarpal ligament, and palmar carpal ligaments are summarized in Table 1. The anatomy of the intercarpal ligaments in CT arthrography images was consistent with that seen in the MRI and anatomical preparations for the transverse plane (Fig. 2), sagittal plane (Fig. 4), and dorsal plane (Fig. 5) images. More intercarpal ligaments were visible using CT and MRI than arthroscopy. The medial palmar intercarpal ligament, lateral palmar intercarpal ligament, radiocarpal ligament, and transverse intercarpal ligaments were best identified on the dorsal plane images (Fig. 1). The palmar carpal ligament, accessory carpoulnar ligament, and accessory ligament of

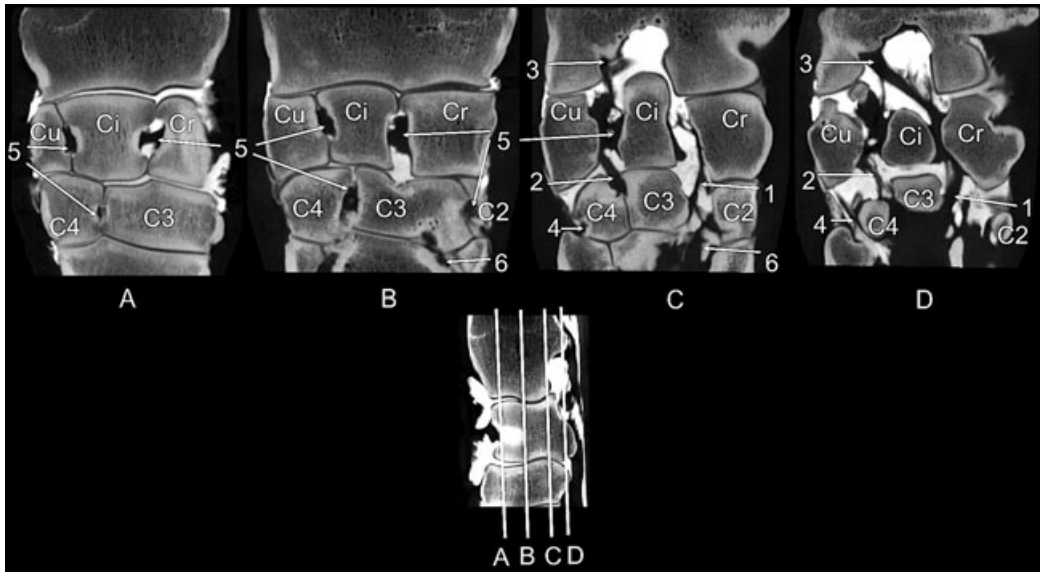

FIG. 1. Dorsal plane computed tomography (CT) images at the dorsal (A), middle (B), and palmar (C, D) aspects of the carpus in a horse cadaver limb. The medial (1) and lateral (2) palmar intercarpal ligaments, radiocarpal ligament (3), lateral collateral branch (4), transverse intercarpal ligaments (5), and palmar carpometacarpal ligaments (6) are identifiable in these images. The ulnar (Cu), radial (Cr), intermediate (Ci), second, third and fourth carpal bones (C2,C3,C4) are labeled.

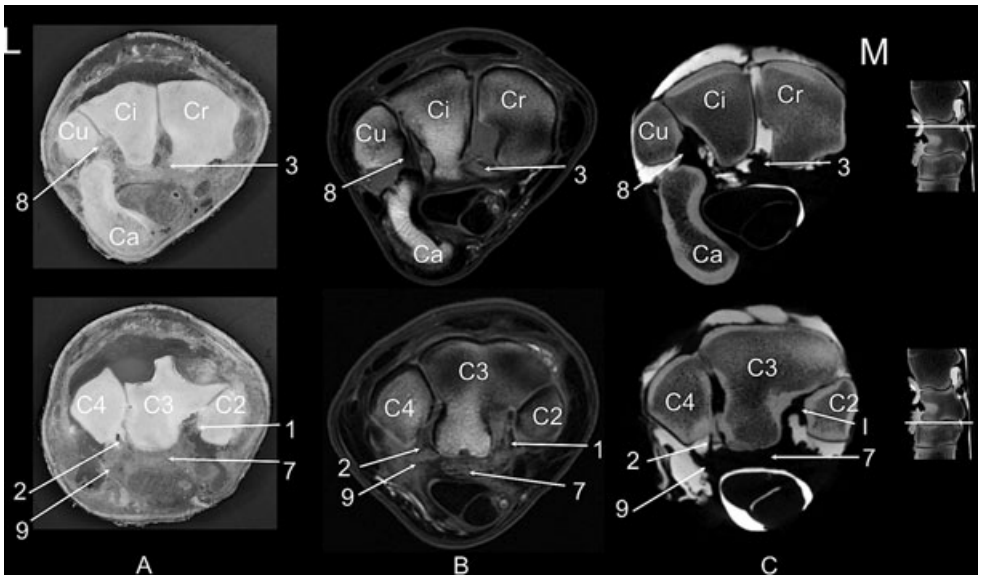

FIG. 2. Corresponding transverse anatomic slice (A), proton density magnetic resonance imaging (MRI) (B), and computed tomography (CT) arthrography (C) images of the carpus in horse cadaver limbs. The images were obtained from two regions through the carpus as indicated by the dorsal plane reference images. At the level of the ulnar (Cu), intermediate (Ci), and radial (Cr) carpal bones, the radiocarpal ligament (3), and accessory carpoulnar ligament (8) are identified. At the level of the distal row of carpal bones the medial (1) and lateral (2) palmar intercarpal ligament, common palmar ligament (7), and the accessory ligament of the fourth carpal bone (9) are identified. Lateral (L) is to the left and medial is the right of the images (M).

the fourth carpal bone were best seen in the transverse plane (Fig. 2). The medial palmar intercarpal ligament, lateral palmar intercarpal ligament, and radiocarpal ligament were best identified when images were reformatted into a dorsal plane and visualized in conjunction with the corresponding transverse and sagittal sections. Reformatting the images allowed ligaments to be identified in all three planes (Fig. 3). The medial palmar intercarpal ligament was identified as a bilobed structure with variation between limbs in the width of the branches. In all horses the medial palmar intercarpal ligament had a large origin on the distolateral aspect of the radial carpal bone (Fig. 4) before branching into two distinct branches of various width and inserting on the second and third carpal bones giving rise to a palmar and more dorsal branch (Fig. 3). Similarly, the lateral origin on the palmaromedial ulnar carpal bone and insertion on the third and fourth carpal bones was readily identifiable. This ligament was visualized as a single, wide ligament on CT arthrograms (Figs. 3 and 4). The radiocarpal ligament was best identified on the dorsal plane as a long, wide ligament originating at the palmar lateral aspect of the distal radius, and coursed in a distomedial direction to insert on the radial carpal bone (Figs. 1, 3, and 5). Small palmar carpometacarpal ligaments coursed obliquely from the distal row of carpal bones to the proximal metacarpal bone (Fig. 1). A small ligament was identified coursing from the distolateral ulnar carpal bone to the lateral fourth carpal bone (Figs. 1 and 5). In the transverse plane (Fig. 2) the accessory carpoulnar ligament, accessory ligament of the fourth carpal bone, and palmar carpal ligament were identified. The accessory carpoulnar ligament was visible on the CT arthrograms as a broad ligament from the accessory carpal bone to the ulnar carpal bone. The accessory ligament of the fourth carpal bone courses from the accessory carpal bone to the palmar fourth carpal bone. The palmar carpal ligament delineated by positive contrast in the joint space and carpal canal and its identification on CT arthrograms corresponded well with the anatomical and MRI images (Fig. 2).

Contrast medium was identified within the proximal suspensory ligament in all eight cadaveric limbs. The contrast was present in the region of the fat/muscular tissue of the origin and proximal body region. The contrast presence was well defined with clear distinction between regions with and without contrast medium. This was best seen in the transverse plane images (Fig. 6).

Discussion

To our knowledge, this is one of the first studies describing CT arthroscopic anatomy and characteristics of intercarpal ligaments in horses. Previously, traditional imaging modalities have not been successful at visualizing entire ligamentous structures.[4,14,18] Results of this study indicate that the entire medial palmar intercarpal ligament, lateral palmar intercarpal ligament as well as the radiocarpal ligament, transverse intercarpal ligaments, and palmar carpal ligament were easily identifiable by this method. The focus in this study was the medial palmar intercarpal ligament and lateral palmar intercarpal ligament as these have

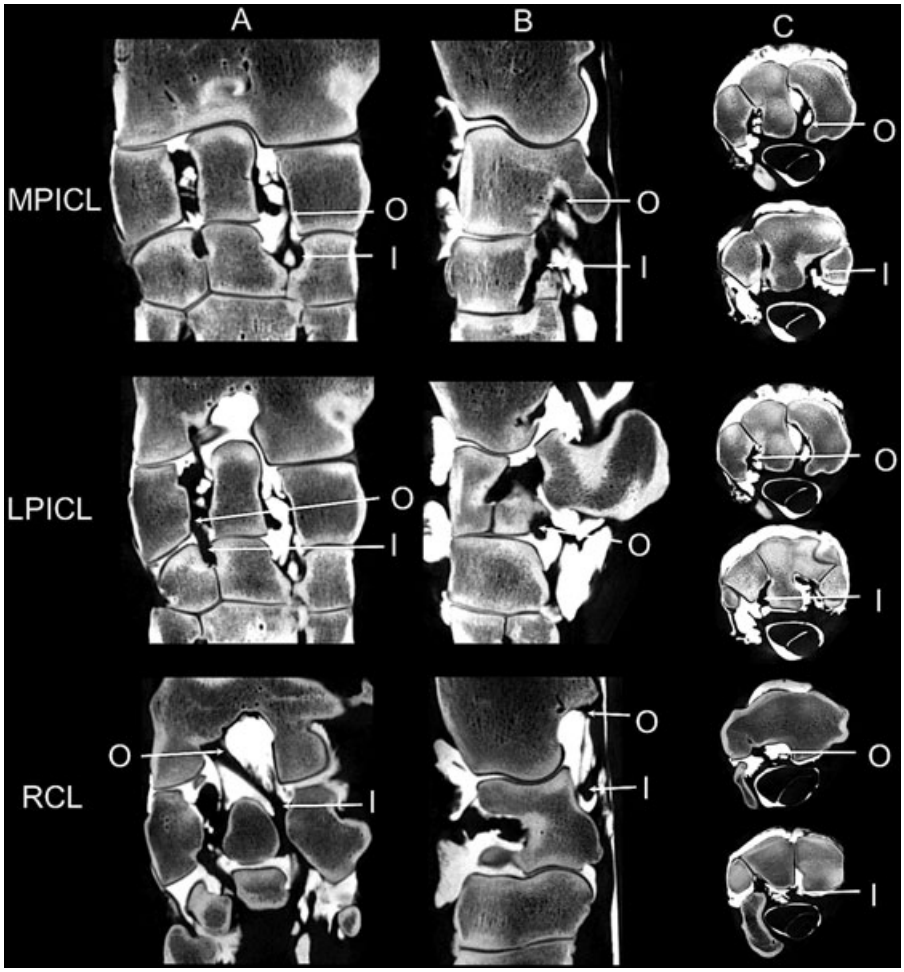

FIG. 3. Reformatted computed tomography (CT) arthrography images of the medial (MPICL) and lateral (LPICL) palmar intercarpal ligaments and the radiocarpal ligament (RCL) in a horse cadaver limb. The origin (O) and insertion (I) of each ligament is identified in the dorsal (A), sagittal (B), and transverse (C) planes.

gained more recent interest as a source of carpal instability and lameness. Previous reports describing injury of these ligaments using arthroscopy have varied in their conclusions of the true incidence.[4,8–10,12] This variation is likely due to the fact that many horses do not undergo surgery unless there is osteochondral fragmentation or other radiographic changes on initial examination, as well as the inability to visualize the whole medial palmar intercarpal ligament[4,17] and lateral palmar intercarpal ligament[5,18] at the time of arthroscopy. In all three limbs examined arthroscopically in the current study, there was only a small portion of the body of the medial palmar intercarpal ligament and lateral palmar intercarpal ligament observed. The origin and insertion of neither were readily visible and this is consistent with previous reports.[4,5,17,18] It should be noted that a single dorsal approach was used in all three limbs. It is possible that a palmar lateral approach may have provided more visualization of the lateral palmar intercarpal ligament.[24]

Previous studies using contrast arthrography and CT have described canine stifle joint anatomy and meniscal ligament injury,[28,35] human carpal and shoulder injury,[22,23,27,36] as well as equine shoulder,[37] stifle,[29,30] tarsus,[31] fetlock,[32] and carpal anatomy.[24,26] This imaging technique has been found to have high specificity and sensitivity for documenting stifle joint soft tissue and bone anatomy.[28,29] In the current study, the positive contrast medium surrounded the ligaments and provided good delineation of both the MPICLs and LPICLs from their origin to insertion. These findings indicated that CT arthrography may be able to identify fraying or rupturing of the medial palmar intercarpal ligament or lateral palmar intercarpal ligament in a clinical setting and may provide a useful adjunct diagnostic method for horses with middle carpal joint pain and minimal radiographic changes.

Multiple other intercarpal ligaments were identified with CT arthrography in the current study. These included the accessory carpoulnar and accessory ligament of the

FIG. 4. Sagittal plane images of the medial (A) and lateral (B) aspects of the carpal joint identifying the medial (1) and lateral (2) palmar intercarpal ligaments in a horse cadaver limb. The computed tomography (CT) arthrography images corresponded well with proton density magnetic resonance imaging (MRI) and anatomic slice images.

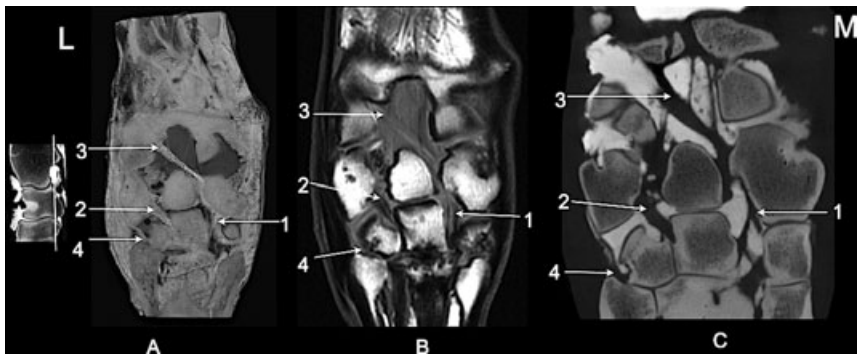

FIG. 5. Dorsal plane anatomic slice (A), proton density magnetic resonance imaging (MRI) (B), and computed tomography (CT) arthrography (C) images of the carpus in equine cadaver limbs. The dorsal plane images allow visualization of the medial (1) and lateral (2) palmar intercarpal ligament, and radiocarpal ligament (3) on each of the images. A smaller lateral ligament is identified coursing from the ulnar carpal bone to the lateral aspect of the fourth carpal bone (4). This branch of the lateral collateral ligament is identified on all images.

fourth carpal bone, which may contribute to palmarolateral stabilization.[1] A smaller ligament was observed coursing on the lateral aspect of the ulnar and fourth carpal bone and may represent the deep branch of the lateral collateral ligament[1,2,24] and may contribute further to palmarolateral stability. The role of injury of these intercarpal ligaments in equine lameness remains unknown but further investigation may now be possible through CT arthrography.

This study also identified a possible communication between the contrast medium laden synovial fluid and the internal structure of the proximal suspensory ligament in these cadaveric limbs. The presence of contrast within the proximal suspensory ligament was noted in every limb included in the study. The exact site of communication was not clearly elucidated as scanning occurred subsequent to injections of all compartments. It is possible that the synovial fluid originated from the carpal joints, most likely middle carpal or carpometacarpal, or the carpal sheath. The clinical implications of this finding are also unknown. Synovitis has been implicated as a factor in the development of cruciate ligament injury in dogs.[28] Carpal arthrosis from exercise[38] may predispose the suspensory ligament to injury. Or the corollary, suspensory desmopathy may alter

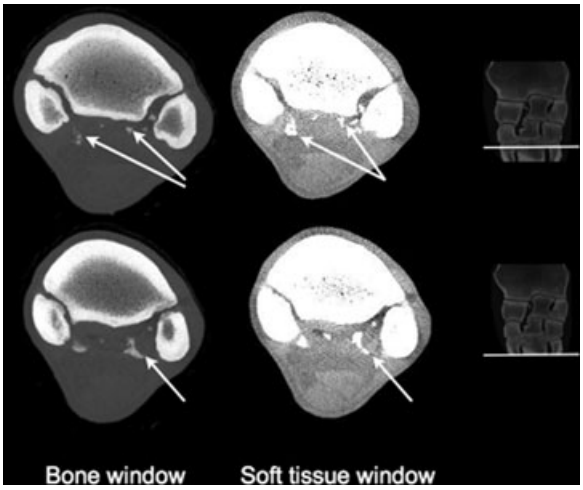

FIG. 6. Computed tomographic arthrography images demonstrating contrast enhancement in the region of the proximal suspensory ligament in an equine cadaver forelimb. This is best identified in the transverse plane and in both the bone and soft tissue window images.

joint homeostasis through subsequent synovial fluid abnormalities. Furthermore, this discovery may help to explain previously reported complications of diagnostic anesthesia, whereby proximal metacarpal region nerve blocks provided anesthesia to the carpal joints.[3] It has also been reported that carpal joint anesthesia can cause regional analgesia of the suspensory ligament.[3,39] In both instances, the synovial communication would provide direct transfer of anesthetic agents to the other region. Finally, synovial communication with the proximal suspensory ligament may have implications for therapeutic agents, in that therapeutic agents could possibly be administered via regional synovial structures to treat suspensory desmopathy. This finding warrants further investigation to confirm the nature and consistency of the communication.

Computed tomography arthrography images were acquired rapidly. In a clinical setting, this would provide additional presurgical information while minimizing the anesthetic time, unlike MRI, which can take an hour or longer. Images could be reformatted in the sagittal, transverse, and dorsal planes as needed for visualization of structures. The dorsal plane postcontrast images were found to be most useful in the current study for identifying the entirety of the medial palmar intercarpal ligament, lateral, radiocarpal ligament, and transverse intercarpal ligaments, as well as the bony origins and insertions. Although these structures may also be appreciable with MRI, CT arthrography offers the advantage of requiring less time. As with high field MRI, CT arthrography would require general anesthesia in the clinical setting. Furthermore, in this study, ligament anatomy in the CT arthrogram images corresponded well with ligament anatomy in the MRI and anatomic slice photographs. This finding indicates that, in a clinical setting, CT arthrography would be a valid alternative to MRI.

One limitation of our study was that our cadaver limbs were obtained from a variable population of horses. Findings therefore may not have accurately represented findings in the true population of horses that tend to sustain these injuries (racehorses). Only one limb was imaged from each horse, thus no contralateral comparisons could be made between individual cases. Also, the exercise history for each case was unknown. The set volume of 12 ml and concentration of contrast medium was chosen for injection into the joints based on published joint injection recommendations[40] and observations in a previous pilot study. Injecting a different volume or different concentration was not attempted, therefore effects of varying volumes and concentrations on different sized horses remain unknown. As this was a cadaver study in horses with no known carpal disease, the effects of synovitis or other joint diseases on CT arthrographic visualization of intercarpal ligaments in live horses also remain unknown. Safety of the injection procedure in live horses also warrants further investigation.

In conclusion, findings from our study indicated that the intercarpal ligaments of the equine carpus, namely the medial palmar intercarpal ligament and lateral palmar intercarpal ligament, can be visualized using CT arthrography. Furthermore, ligament anatomy depiction in CT arthrography images corresponded well with that observed in MRI and gross anatomic slices. Findings support further development of CT arthrography as a noninvasive adjunct imaging method for diagnosing intercarpal ligament damage in horses and providing additional presurgical information. Further studies are needed in live horses with and without clinical lameness to better assess the safety and efficacy of this technique.

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