How to Ultrasound the Carpal Canal and Caudal Antebrachium

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1. Introduction
Lameness associated with carpal sheath effusion results from a variety of underlying factors. Pathologic changes associated with the carpal canal include septic tenosynovitis, superficial digital flexor (SDF) tendinopathies, and desmopathies of the accessory ligament of the superficial (AL-SDFT) and deep digital flexor tendons.1–8 A recent report identified several cases with intrathecal tears of the accessory ligament of the superficial digital flexor tendon with associated hemorrhage in the carpal sheath.9 Although many equine practitioners exhibit proficiency with the ultrasonographic evaluation of the metacarpal structures, the more proximal carpal canal and antebrachium can be a source of frustration and intimidation. Previous reports have described the ultrasonographic anatomy and technique for evaluation of the AL-SDFT.2,10,11 This paper expands on these studies with a thorough anatomic review. The proposed technique describes the evaluation of each structure individually in transverse and longitudinal planes, in contrast with the more historic zone approach.11 By improving ultrasonographic proficiency and anatomic competency, the practitioner will be better equipped to diagnose various conditions of the equine carpal canal.

2. Materials and Methods
Anatomic Study
Three forelimbs from horses euthanized for unrelated reasons were obtained for the anatomic portion of this study. Ultrasound examination and magnetic resonance images (MRIs) of the limbs from the level of mid radius to mid metacarpus were performed postmortem on two of the limbs. Proton density (PD), proton dense fat-saturated, and T1-weighted gradient echo images were obtained in the transverse and sagittal planes. One of these limbs was frozen, and transverse, 2-mm cut sections were made to correspond with previously acquired ultrasound and MRIs. Figure 1 is used as a reference for corresponding anatomic locations of the transverse sections used in the subsequent figures. In a third cadaver limb, used solely to demonstrate the margins of the carpal canal, noniodinated contrast medium (30 mL iohexol® [350 mgI/mL], diluted to a total volume of 60 mL) was injected into the carpal...
Ultrasound Study
The caudomedial aspect of the limb is clipped with a No. 40 to No. 50 blade from 4 cm proximal to the chestnut to the mid metacarpus. The limb is washed with warm water and soap, dried, and ultrasound-coupling gel is applied. A high-frequency (8–18 mHz) linear transducer is used.

A total of 10 veterinary students and veterinarians were recruited to perform the technique as described on a standing horse. There were a total of seven veterinary students with minimal ultrasound experience and three veterinarians with novice to moderate ultrasound knowledge and skills and with minimal to no experience imaging the carpal canal. The written technique was provided to participants and followed in a step-by-step manner.

Carpal Sheath
The carpal canal contains the superficial and digital flexor tendons. Its proximomedial extent is bordered by the AL-SDFT or superior check ligament. The distal margin is bordered by the accessory ligament of the deep digital flexor tendon (AL-DDFT). The palmar carpal ligament borders the dorsal aspect of the carpal sheath and the palmar and medial margins are delineated by the palmar carpal retinaculum. In Fig. 2, intrathecal contrast medium shows the proximal extent (distal third of the radius) and distal extent of the carpal sheath, which extends to the mid-metacarpal region in most horses. The flexor retinaculum forms a band on the caudal aspect of the carpus, and spans from the accessory carpal bone to the medial collateral ligament and proximal aspect of the second metacarpal bone (Fig. 3). The tension of the flexor retinaculum results in restriction of the fluid within the carpal sheath at this level, which can be seen in Fig. 2 at the level of the accessory carpal bone. A larger accumulation of contrast is visible proximal to the flexor retinaculum.

Ultrasound examination of the metacarpal structures can identify effusion contained within the carpal canal, which is usually seen between the deep digital flexor tendon (DDFT) and the AL-DDFT. With more severe effusion, it is visible surrounding, or lateral and medial to the SDFT and DDFT. Proximal to the carpus, the largest accumulation of fluid is visible laterally between the ulnaris lateralis and the lateral digital extensor and medially between the flexor carpi ulnaris and flexor carpi radialis. In the authors’ experience, inadvertent introduction of gas can be present in the carpal canal after a low 4-point diagnostic block is performed. Many veterinary students and practitioners may be surprised by the distal extent of the carpal canal.

Identifying Home Base
The starting location is just distal to the chestnut on the medial aspect of the radius. This area will herein be referred to as “home base” and serves as a reference point should the ultrasonographer become...
disoriented. Depth can be set between 4 and 5 cm, depending on the size of the horse, and focal zones are positioned in the near field at approximately 1 to 2 cm deep. When the transducer is placed on the palmar aspect of the limb, the marker is positioned laterally, corresponding with the left side of the screen. For imaging the structures as described, the transducer is held in the same orientation so that when it is placed directly on the medial side of the radius, the marker will essentially be directed caudally. (Note: Although this is not traditional radiology protocol, as structures are followed distally, the transducer indicator will end up in a normal lateral location.) The AL-SDFT can be identified at this level by placing the transducer in a transverse (short axis) plane, directly medial on the limb, just below the chestnut (Figs. 4 and 6).

Accessory Ligament of the Superficial Digital Flexor Tendon

The AL-SDFT will appear as the most echogenic structure adjacent to the caudal surface of the radius and is surrounded by the caudal antebrachial structures that are still predominantly muscle at this level (and will be described individually later) (Fig. 5). The vessels overlying it, including the median artery and cephalic vein (more superficial and cranial) are also used as landmarks. Cranial to the AL-SDFT, partially visible in the superficial portion of the image, is the curvilinear echogenic caudal surface of the radius. The flexor carpi radialis is visible directly superficial to the AL-SDFT. All descriptions will be given from this location at home base, with the probe in a transverse plane (Fig. 6).

Once identified, the ligament can be followed toward the SDF muscle in the transverse plane. As the ligament courses from the origin on the caudal cortex of the radius toward its insertion on the SDF, it can be visualized passing deep to the median artery. The curved walls of the median artery, as well as the flexor carpi radialis, create linear, anechoic edge artifacts in the deeper AL-SDFT. As the probe moves distally it must also be moved in a slightly caudal direction. The shape of the AL-SDFT changes from square proximally to oblong as it inserts into the SDF (Fig. 7). When the AL-SDFT inserts into the SDF near the level of the musculotendinous junction, the SDF may contain some muscle fibers at this level.

To evaluate the fiber pattern of the AL-SDFT in long axis, the probe is placed in transverse, directly under the chestnut, and rotated in a proximodorsal to distocaudal orientation (counterclockwise), to elongate the fibers. The marker of the transducer is oriented in a dorsal or proximal direction in long axis. As the probe is rotated, it must be pivoted on the central axis of the AL-SDFT; keeping the AL-SDFT in the center of the image will ensure that the probe remains on the AL-SDFT. The distinct double walls of the median artery can be visible in long axis.
axis when the fibers of the AL-SDFT have been elongated to their fullest extent.

Note: Evaluation of the entire AL-SDFT can be performed in the transverse plane from the origin on the radius, but imaging in the proximal region is made difficult due to poor contact by the chestnut. Due to the orientation of the AL-SDFT at its origin, obtaining a “true” longitudinal view of the origin has been difficult in the authors’ experience and relatively unrewarding.

Superficial Digital Flexor Tendon
From home base, the SDF muscle is located just caudal to the AL-SDFT. Depth setting of 3 to 4 cm with focal zones in the mid zone of the image is used. At the level of the chestnut, the SDF is composed
predominantly of muscle. Delineating the exact borders of the SDF muscle from the deep digital flexor (DDF) muscle is difficult at the level of the mid to distal radius. Determining the borders of the SDF from the DDF muscles in the distal radius can be performed with a retrograde approach. By identifying the borders of the SDFT in the proximal metacarpus and following it proximally through the carpal canal, the dorsal border of the SDF and caudal border of the DDF are more apparent at the level of the distal radius.

Imaging of the SDF muscle and tendon in transverse is accomplished by sliding the transducer slightly caudally along the caudomedial aspect of the distal radius. As it courses distally, the musculotendinous junctions are visible as well-defined hypoechoic to anechoic areas surrounded by the echogenic tendon fibers (Fig. 8). In long axis, these muscle units are visible as triangle-shaped hyperechoic areas that blend into hyperechoic tendon fibers (Fig. 9). Evaluation of the SDFT at the level of the carpus is performed with the ultrasound beam directed in a slight caudomedial to craniolateral direction. The lateral location of the accessory carpal bone prevents imaging the SDFT from a palmar/caudal approach through the carpal region, and thus the transducer is maintained in a more medial position. Distal to the accessory carpal bone, the remainder of the SDFT can be viewed from a palmar approach. The musculotendinous junctions should not be mistaken for tearing and/or lesions. If a hypoechoic area is found, it should be followed proximally to determine whether the hypoechoic area blends normally into muscle at the level of the distal radius. The contralateral limb should also be evaluated for comparison.

Deep Digital Flexor Tendon

From home base, the DDF muscle is visible deep to the AL-SDFT. Depth setting should be increased up to 6 to 7 cm and the focal zones lowered to the far field of the image to evaluate the entire DDF muscle in the distal radius region. Frequency may be lowered or a microconvex, mid-range frequency trans-
ducer, can also be used to evaluate the deeper muscle of the DDFT. Using a trapezoidal view option helps include more structures at this level of depth when using a linear probe.

The radial head of the DDF muscle is visible deep to the AL-SDFT and just caudal to the radius. It is more echogenic than the adjacent muscle and has a smooth echotexture (Fig. 10). The ulnar and humeral muscle bellies of the DDF are caudal to the radial head, and are hypoechoic, with normal hyperechoic muscle striations. To evaluate the entire DDFT muscle, the probe must be moved caudally and laterally to image the more laterally located ulnar and humeral heads, which may be indistinct from the adjacent SDF muscle. A similar medial approach for imaging the DDFT can be applied as was used to image the SDF through the carpal region, due to the accessory carpal bone.

Flexor Carpi Radialis

From home base, the flexor carpi radialis (FCR) is the most superficial structure, adjacent or just caudal to the radius, and superficial to the previously identified AL-SDFT. Imaging of the remaining structures is performed at approximately 3 to 4 cm of depth, with the focal zones moved to the near field (1 cm deep). The FCR is a relatively smaller structure in relation to the other caudal antebrachial structures. Proximal to the chestnut, it is predominantly muscle. As it courses distally along the medial aspect of the radius, the muscle fibers condense into tendon fibers, at the level of the chestnut, and can appear bi-layered, with a mix of hypoechoic muscle and hyperechoic tendon fibers (Fig. 11). The FCR can be followed distally on the medial aspect of the carpus to its insertion on the proximal aspect of the second metacarpal bone (head of the medial splint bone). The FCR has a tendon sheath at the level of the carpus, which is contained within the flexor retinaculum.

To evaluate the tendon in a longitudinal imaging plane, the tendon can first be identified in transverse and the transducer rotated counterclockwise to elongate the fibers. The linear hyperechoic surface of the radius is identified just cranial to the FCR and as the transducer is slid caudally, the first visible structure is the FCR. Similar to the SDF, the triangular, hypoechoic termination of the muscle is visible, as it blends into the linear, hyperechoic tendon fibers (Fig. 11).

Flexor Carpi Ulnaris

The cranial margin of the flexor carpi ulnaris (FCU) muscle is partially visible from home base; it is located directly caudal to the FCR. The remainder of the muscle is visible by sliding the probe caudally. As the FCU courses distally, it can be imaged from a more caudal approach. Similar to the FCR, it has a bi-layered appearance (Fig. 12). As the muscle condenses into the tendon fibers, it is located superficial and just caudal to the SDFT, and can be followed to its insertion on the palmar/caudomedial aspect of the accessory carpal bone. To evaluate the muscle and tendon in long axis, it can be identified in transverse and the transducer rotated counterclockwise. Alternatively, from the radius, it can be identified by

Fig. 9. A. Sagittal proton dense fat-saturated MR image showing the musculotendinous junction of the SDF and DDF. The hyperintense muscle fibers blend into the hypointense tendon fibers. B. On the corresponding, long axis ultrasound image, the triangular-shaped end of the hypoechoic muscles of the SDF and DDF are visible blending into the hyperechoic linear tendon fibers (arrows).

Fig. 10. Transverse ultrasound image obtained just distal to the chestnut. The smooth echotexture of the radial head of the DDF muscle is visible in the center of the image (d), adjacent to the hypoechoic muscle of the SDF and DDF (ulnar and humeral heads). a, radius; b, AL-SDFT; d, DDF radial head; i, median artery.
sliding caudally from the fibers of the FCR to the FCU.

Ulnaris Lateralis

From home base, as the probe is moved from medial to lateral the muscles can be identified in order: FCR, FCU, ulnaris lateralis (UL). Depth is further decreased to approximately 3 cm and focal zones are maintained in the near field. The UL is located laterally on the antebrachium, caudal and lateral to the FCU. It is a superficial and relatively slender muscle belly, with a bi-layered appearance similar to previously described structures (Fig. 12). As it becomes tendinous just proximal to the accessory carpal bone, it is located more caudolaterally. It briefly forms a distinct tendon before splitting into a cranial and caudal component. The caudal component inserts proximolaterally on the caudal aspect of the accessory carpal bone. The cranial component is less distinct and courses in an oblique, dorsodistal direction to insert proximally on the fourth metacarpal bone. To find the muscle/tendon in long axis, the previously described approach of either rotating the transducer from transverse into longitudinal or sliding the probe around the limb, and following the structures from medial to lateral (FCR, FCU, UL) can be used.

3. Results

Ultrasound images corresponded well with MR and gross images, validating the description of the anatomic and ultrasonographic appearance.

This technique was used by a total of 10 individuals inexperienced in evaluation of the carpal canal and caudal antebrachium. Following this technique, exams were performed successfully and all structures were identified. All scans were directly observed by one of the authors to confirm the correct structures were identified and proper technique was used. There were no observable time differences to successfully image the structure based on the ultrasonographer’s experience. Total examination time varied between 30 and 60 minutes. Most ultrasonographers became comfortable with readily identifying home base by the time they reached the DDFT section of the exam. Using the retrograde approach for delineating the borders of the SDF and DDF muscles in the distal antebrachium was helpful for most people. Following the UL over the car-

Fig. 11. A. Transverse and B. Long-axis ultrasound images of flexor carpi radialis (between the arrows) at the level of “home base.” A. Cranial is to the right and caudal to the left of the transverse image. B. Proximal is on the left of the long-axis image. The FCR appears bilayered, with hypoechoic muscle fibers and the more superficial hyperechoic tendon fibers. The triangular-shaped musculotendinous junction is visible in the long axis image. The AL-SDFT is visible deep to the FCR. The fibers of the AL-SDFT are elongated in the long axis image. b, AL-SDFT.

Fig. 12. Transverse images at the level of the distal radius showing the bilayered appearance, created by the musculotendinous junction, of the FCR and UL. A. Gross image. B. Proton dense fat-saturated MR image. C. Ultrasound. B. The intermediate signal intensity muscle fibers in the MR image correspond with C, the hypoechoic muscle fibers in the ultrasound image. B. The hypointense tendon fibers in the MR image correspond with C, the hyperechoic tendon fibers in the ultrasound image. g, FCR; h, UL.
pus and maintaining contact with the limb was the most difficult part of the examination. Addition of a standoff pad for this structure increased contact and improved visualization of the UL at its insertion.

4. Discussion

There are a number of descriptions of injuries to the AL-SDFT throughout veterinary literature, with recent renewed focus on this topic. Injuries to the SDFT and AL-SDFT were the two most common injuries in a group of 121 horses with carpal sheath effusion. Early reports described a carpal canal syndrome, occurring most commonly in flat or steeplechase racehorses that was associated with fracture of the accessory carpal bone. This led to a syndrome of thickening of the tendons including the flexor retinaculum and secondary effusion of the carpal sheath and was treated with transection/removal of a portion of the flexor retinaculum. With improved technology and the increased use of ultrasound in veterinary medicine, knowledge of specific soft tissue injuries in the carpal canal are now identified. These injuries include injury to the AL-SDFT, characterized by thickening of the AL-SDFT, irregular fiber pattern, and tearing into the SDF in combination with carpal sheath effusion. This injury is most commonly described in young horses with high levels of activity. Other abnormalities in this region include distal radial osteochondromas of the caudal distal radius as a cause of carpal sheath synovitis and associated desmopathy of the DDFT. These were reported predominantly in flat Thoroughbred racehorses (18/22), but a few horses (4/22) of other disciplines were also included.

Tearing of the radial head of the DDF muscle with associated tenosynovitis of the carpal sheath has also been described, mostly in flat racehorses. This group had a slightly older population with a mean age of 4.5 years (range, 2–9 y). Most recently, ultrasound was valuable for diagnosis of intrathecal tears of AL-SDFT, with several tears causing intrathecal hemorrhage in the carpal sheath.

As veterinary care improves, the geriatric or senior horse population has provided new focuses in veterinary medicine. Specifically, rupture of the SDFT in the carpal canal region in a group of aged horses was recently presented. An additional report describes similar findings in a group of nine horses ranging in age from 18–22 years. Interestingly, another study of horses with injury to the SDFT within the carpal sheath, specifically at the level of the carpus, reported these horses to be older, with a mean age of 18 years and predominantly Quarter Horses (9/12 cases). In contrast with the other 22 horses in the study, injuries distal to the accessory carpal bone occurred in younger horses (mean age, 6.3 y), that were predominantly Thoroughbreds used for flat racing.

Injuries in this region are most common in Thoroughbred racehorses; however, additional indications for scanning this region include ruling out septic carpal sheath tenosynovitis from wound communication or associated tendon or ligament injuries from direct lacerations to this region.

The approach described allows for complete evaluation of the structures of the carpal canal and the technique can be readily learned by a novice ultrasonographer. A few things to keep in mind include when starting at home base, the approach is directly medial on the limb and just distal to the chestnut (Fig. 2). A common error is to start from a more caudal position on the limb. Also, using the fundamental ultrasound principle of keeping the structure of interest in the center of the image, improves evaluation of the structure along its length. Many structures are oriented in an oblique manner within the limb; if the transducer is moved directly distal when following the AL-SDFT, the structure will begin to “slide off” the screen. Small corrections to center the structure before moving distally again will improve exam quality and accuracy. Lastly, having knowledge of where tendons and ligaments insert is useful in case the ultrasonographer becomes disoriented or if normal anatomy is distorted due to pathologic changes. By identifying the structure at its insertion, a retrograde approach can be used to follow it proximally to the muscle belly in the distal antebrachial region.

One limitation of the study was that the cadaver limbs were imaged in nonweight-bearing positions, which created relaxation artifact in the AL-SDFT. Individual ultrasound skill and experience is also a limiting factor. With better ultrasound technique and hand-eye coordination, following smaller and obliquely oriented structures, such as the FCR or UL, was easier for more experienced ultrasonographers, but proved to be more difficult for those with novice skill level. Although this paper aids imaging of the normal carpal canal and caudal antebrachial structures, it does require practice and experience to identify pathologic changes, especially if subtle.

Approaching imaging of the carpal canal and caudal antebrachium as a complete, systematic examination, using a standardized approach will help increase familiarity with the anatomy over time. Identifying home base as a reference point helps guide the ultrasonographer to find the remaining structures, which may be unfamiliar. This technique expands on the previously described approach, but incorporates using an individual structure approach to evaluate the entire caudal antebrachium.

Acknowledgments

Declaration of Ethics

The Authors declare that they have adhered to the Principles of Veterinary Medical Ethics of the AVMA.
Conflict of Interest
The Authors declare no conflicts of interest.

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