TITLE: TRUNCATION ARTIFACT IN MAGNETIC RESONANCE IMAGES OF THE CANINE SPINAL CORD

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Truncation artifact in magnetic resonance images of the canine spinal cord

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Abstract

The truncation artifact in magnetic resonance (MR) images is a line of abnormal signal intensity that occurs parallel to an interface between tissues of markedly different signal intensity. In order to demonstrate the truncation artifact in sagittal images of the canine spinal cord and the effect of changing spatial resolution, we conducted an experimental in vitro study. A section of fixed canine spinal cord was imaged using a 1.5T magnet. Spatial resolution was increased by increasing the acquisition matrix and reconstruction matrix, producing series of T2-weighted images with the following pixel sizes: A, 1.6mm (vertical) x 2.2mm (horizontal); B, 1.2mm x 1.7mm; C, 0.8mm x 1.1mm; D, 0.4mm x 0. 6mm. Plots of mean pixel value across the cord showed variations in signal intensity compatible with truncation artifact, which appeared as a single, wide central hyperintense zone in low resolution images and as multiple narrower zones in high spatial resolution images. Even in images obtained using the highest spatial resolution available for the MR system, the edge of the spinal cord was not accurately defined and the central canal was not visible. The experiment was repeated using an unfixed spinal cord specimen with focal compression applied to mimic a pathologic lesion. Slight hyperintensity was observed within the spinal cord at the site of compression although the cord was normal histologically. Results of this study suggest that caution should be applied when interpreting hyperintensity affecting the spinal cord in T2-weighted sagittal images of clinical patients because of the possibility that the abnormal signal could represent a truncation artifact.

Introduction

The truncation artifact (also known as Gibbs' artifact) in magnetic resonance (MR) images is a line of abnormal signal intensity that occurs parallel to an interface between tissues of markedly different signal intensity.[1,2] It has been observed in MR images of various anatomic structures in humans, including the brain, spinal cord, and articular cartilage.[3-5] In dogs, a truncation artifact may be observed in T2-weighted (T2w) sagittal images of the spine as a single or multiple hyperintense lines superimposed on the spinal cord[6-8] (Figure 1). Based on the hyperintensity, shape and position of this truncation artifact, it has been suggested that it could potentially be misinterpreted as a sign of a dilated central canal or a syrinx.[3,6] All MR sequences are subject to truncation artifact. In T1w images, the truncation artifact appears as a hypointense band superimposed to the parenchyma of the spinal cord.

Truncation artifacts cannot be eliminated completely from MR images because they occur as a consequence of the Fourier transformation used to construct the digital image from the signals obtained from a volume of tissue. Digital images contain a finite number of pixels, each with a finite dynamic range, and represent an approximation of the true signal intensity originating in tissues. Particularly at boundaries of tissues with markedly different signal intensities (e.g. tissue-fluid interfaces in T2w images), data are necessarily truncated in *k*-space, causing misrepresentation of signal intensities either side of the boundary.[2,4,5,9] Although it cannot be eliminated, the truncation artifact can be minimized by increasing spatial resolution (decreasing the pixel size), by applying pre-reconstruction filters (e.g. Hamming or Tukey) or by using post-processing optimization techniques (e.g. the Total Variation method) .[9, 10, 11]

The present study had two aims: 1, to demonstrate the truncation artifact in MR images of the normal canine spinal cord, including the effect on its appearance of changing spatial resolution; 2, to demonstrate variations in the appearance of the truncation artifact within the spinal cord at a site of compression.

Material and methods

First part of the study

To conduct the in vitro experiment, the spinal cord was removed intact from the fresh cadaver of a client –owned 7 year old, 26 kg male Boxer dog, humanely euthanized for reasons unrelated to this study. Owner consent was obtained to perform necropsy and obtain tissues from the cadaver, for research purposes.. The dura mater was removed and the spinal cord with attached pia mater and fragments of arachnoid was cut into three sections of approximately equal length and fixed in 10% neutral-buffered formalin. To simulate the spinal cord surrounded by cerebrospinal fluid (CSF), the cervical section of the spinal cord was submerged in formalin in a plastic tray and placed on a phased-array spinal coil within the bore of a 1.5T magnet (Intera Pulsar System, Philips Medical Systems, Reigate, UK). Turbo spin-echo (TSE) sequences were used to obtain sagittal T2w (T2w) images with the following settings: echo time 120ms, repetition time 3154ms, 10 signals averaged, and field of view 102mm (vertical) x 159mm (horizontal long axis) x 26mm (right to left). A default ringing pre-reconstruction filter was used to reduce truncation artifact on the images obtained. Spatial resolution was progressively increased by increasing the acquisition matrix and reconstruction matrix, producing series of T2w images with the following pixel sizes: A, 1.6mm (vertical) x 2.2mm (horizontal); B, 1.2mm x 1.7mm; C, 0.8mm x 1.1mm; D, 0.4mm x 0. 6mm. Slice thickness was 1.8mm for each series. Series B used the default spatial resolution settings used at our institution for acquiring T2w TSE sagittal images of the spine of clinical canine patients of similar size to the cadaver used. Series D represented the highest spatial resolution available on this MR system. Transverse images of the spinal cord were also acquired using the same spatial resolution as series A.

For each series (A-D), sagittal MR images of the spinal cord were viewed at native resolution (i.e. not interpolated) and a 6-pixel wide region of interest (ROI) was selected from the central portion of the spinal cord that was parallel to the horizontal axis of the image. The ROI was placed over the same part of the cord in each image. This ROI was re-windowed so that the minimum pixel value was 0 and the maximum was 255, and the mean pixel value was calculated for each line of pixels across the spinal cord. A graph of pixel value was produced for each scan and aligned with the corresponding image of the spinal cord (Figure 2).

Following MR imaging, representative hematoxylin and eosin-stained histologic sections of the spinal cord were prepared and reviewed. The height and width and of the spinal cord and the sagittal diameter of the central canal were measured using an eyepiece graticule.

Second part of the study

An unfixed section of the cervical spinal cord from the fresh cadaver of a client-owned 5 year old, 30 kg male Greyhound dog was submerged in physiologic saline in a plastic tray. Owner consent was obtained to perform necropsy and obtain tissues from the cadaver, for research purposes. Two empty 5 ml plastic syringe barrels placed on either side of the spinal cord and held together using elastic bands were used to create focal compression of the spinal cord. Sagittal T2w images were obtained with the following settings: echo time 120ms, repetition time 3085ms, 10 signals averaged, and field of view 69mm (vertical) x 106mm (horizontal long axis) x 22mm (right to left). Four images series with the following pixel sizes were obtained: series A2, 1.6mm (vertical) x 2.3mm (horizontal); series B2, 1.1mm x 1.5mm; series C2, 0.8mm x 1.1mm; series D2, 0.4mm x 0.5mm. Slice thickness was 1.8mm for each series.

Results

First part of the study

A broad zone of increased signal, compatible with a truncation artifact, was evident along the midline of the spinal cord in all T2w TSE sagittal images. The zones of abnormal signal intensity associated with truncation artifact within the spinal cord and in the surrounding saline were relatively wider (up to 2mm) in images acquired at lower resolution (Figure 3). With increasing spatial resolution the zones of abnormal signal intensity became narrower and less intense, so that the apparent outer border of the spinal cord became more clearly defined. The abnormal signal within the spinal cord appeared as a single, wide central zone in low resolution scan images and as multiple narrower zones in images with higher spatial resolution. In transverse images of the spinal cord acquired using the same spatial resolution as scan A, multiple concentric zones of abnormal signal intensity were evident. Compared to a gross section of the cord, the apparent diameter of the spinal cord in transverse images was greater and the central canal was not visible (Figure 4). No spinal cord lesions were identified pathologically.

Second part of the study

In the areas where the spinal cord was not compressed the truncation artifact had a similar appearance in both sagittal and transverse images to that described in the first part of the study. In the lower resolution images (series A2, B2, C2) concentric truncation artifacts emanating from the two syringe barrels overlapped the spinal cord, impeding evaluation of the signal intensity of the spinal cord at the site of compression (Figure 5A-C). In the highest resolution images (series D2), the spinal cord at the site of compression had slightly increased signal intensity, apparently as a result of merging of hyperintense lines associated with truncation artifact (Figure 5D). This appearance may be compared with the increased signal that observed at sites of spinal cord compression in clinical patients (Figure 6).

Discussion

In low resolution MR images, the central hyperintense zone caused by the truncation artifact is much wider than the central canal. Within increasing spatial resolution, the hyperintensity associated with the truncation artifact appeared as multiple parallel zones in both sagittal and transverse images. This variation is compatible with previous experimental results that showed the truncation artifact to be a function of resolution relative to the dimensions of the object being imaged.[3] Constructive interference between the signal intensity waveforms produced on each side of an object can produce different numbers of peaks and troughs depending on the separation of the two borders of the object and the pixel size of the image.[3] Similarly, reduced cord diameter at sites of compression alters the appearance of the truncation artifact from multiple hyperintense zones into a single broad zone, as observed in the second part of study. In sagittal T2w images of the cervical spine of clinical patients, variation of the truncation artifact may also account for the hyperintensity observed in the spinal cord where it narrows at a site of compression; the abnormal signal intensity identified on this sequence should therefore be interpreted with caution.

The truncation artifact should be easy to recognize when it appears as multiple lines, but when it appears as a single hyperintensity it may be more difficult to distinguish from a lesion. This pitfall has been noted in MR images of articular cartilage[4], the menisci of the knee[12] and the spinal cord, in which a linear truncation artifact could be confused with hydromyelia or syringohydromyelia.[3] In a study of dogs with cervical disc disease, occurrence of the truncation artifact was thought to contribute to interobserver variations.[7] Although truncation artifacts are encountered in other MR sequences, it is the fact that they appear hyperintense when superimposed on neural tissues in T2w images that is problematic because most neural lesions are also hyperintense in T2w images. When uncertainty exists about whether a hyperintensity affecting the spinal cord may represent a lesion, additional imaging is indicated. For example, increasing spatial resolution (by increasing matrix size and/or decreasing field of view) will reduce the magnitude of the artifact.[6] If the image matrix is asymmetrical, aligning the critical boundary perpendicular to the higher frequency axis (usually the frequency-encoding direction) will diminish the truncation artifact.[2] Obtaining images in a different plane, such as transverse images, should also be considered if this reduces imaging across a boundary between tissues of markedly different signal intensity; however, for the spinal cord, sagittal, dorsal, and transverse images will be affected by truncation artifacts to a similar degree because the critical spinal cord-CSF boundary cannot be avoided.

In the present study, images were acquired of fixed spinal cord so that measurements based on MR images could be directly compared to measurements from histologic specimens without errors introduced by shrinkage of tissues during fixation. One disadvantage of this approach is that the signal intensity of the fixed spinal cord in T2w images is reduced compared to the cord in vivo because of removal of water during fixation. This likely reduces visibility of internal anatomy (i.e. grey-white matter boundary), but should not significantly affect the truncation artifact, which depends primarily on the spinal cord-CSF boundary rather than internal signal variations. In conclusion, caution should be applied when interpreting hyperintensity affecting the spinal cord in T2w sagittal images of clinical patients because of the possibility that the abnormal signal could represent a truncation artifact.

List of Author Contributions

Category 1

(a) Conception and Design

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

(b) Acquisition of Data

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

(c) Analysis and Interpretation of Data

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

Category 2

(a) Drafting the Article

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

(b) Revising Article for Intellectual Content

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

Category 3

(a) Final Approval of the Completed Article

T. Gregori, R. Lam, S.L. Priestnall, C.R. Lamb

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Legends

Figure 1. Example of a truncation artifact mimicking the central canal in a T2w sagittal image of the caudal cervical and cranial thoracic spine of a dog with surgically-confirmed thoracolumbar intervertebral disc extrusion (not shown). A centrally-located hyperintense line (arrowheads) within the thoracic spinal cord is suggestive of the central canal, but cranial to the first thoracic vertebra it splits into two lines; therefore, this line cannot represent the central canal.

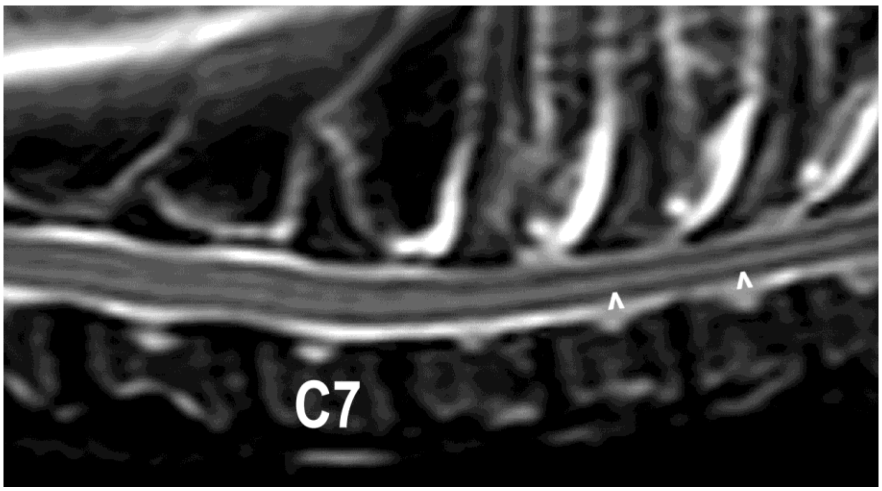

Figure 2. Representative T2w sagittal image of fixed spinal cord, region selected for determination of average pixel value, and corresponding graph of pixel value across the spinal cord.

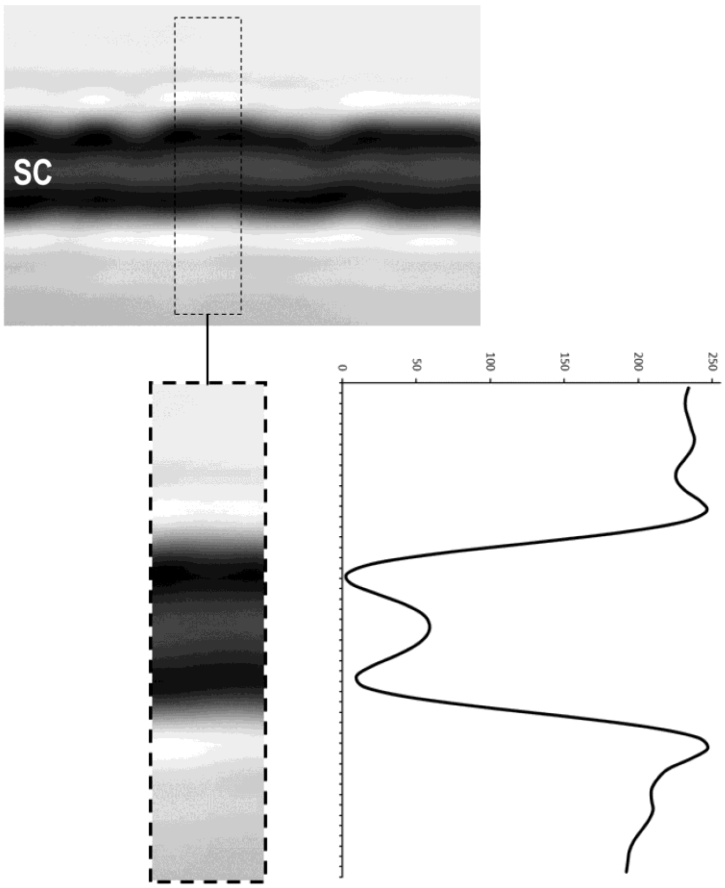

Figure 3. Examples of T2w MR images of fixed spinal cord obtained with the following pixel sizes: A, 1.6mm (vertical) x 2.2mm (horizontal); B, 1.2mm x 1.7mm; C, 0.8mm x 1.1mm; D, 0.4mm x 0. 6mm. The abnormal signal within the spinal cord that represents the truncation artifact appears as a single, wide central zone in low spatial resolution images (A & B) and as multiple narrower zones in images with higher spatial resolution (D).

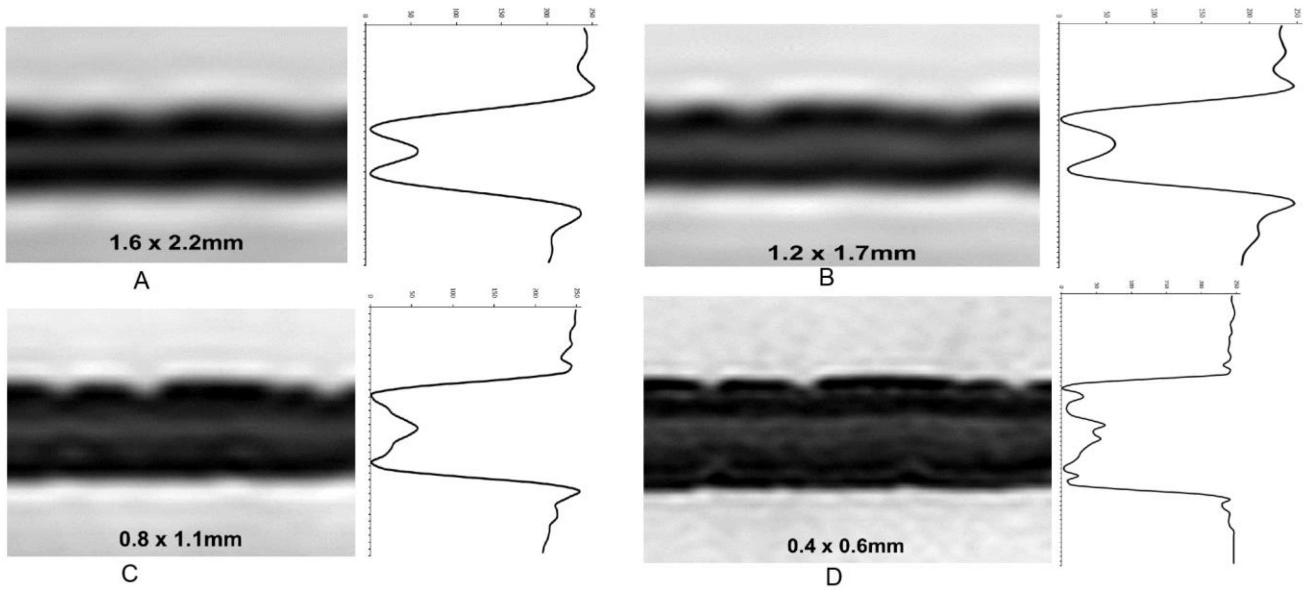

Figure 4. A) Transverse image of the spinal cord acquired using the same spatial resolution as series A. Multiple concentric, alternating zones of increased and decreased signal intensity are evident, representing truncation artifact associated with the curved spinal cord-fluid interface. B) Corresponding section of the cord. In the MR image, the spinal cord appears larger in diameter and the central canal is not visible.

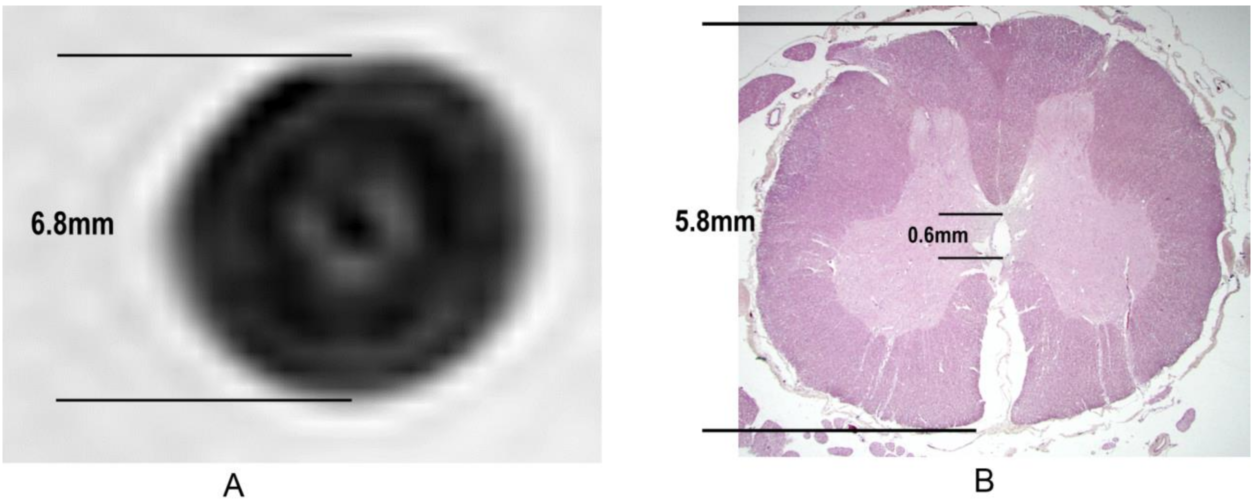

Figure 5. Examples of T2w MR images of unfixed, focally compressed spinal cord in a saline bath obtained with the following pixel sizes: A, 1.6mm (vertical) x 2.3mm (horizontal); B, 1.1mm x 1.5mm; C, 0.8mm x 1.1mm; D, 0.4mm x 0.5mm. In the lower resolution images (A-C), concentric truncation artifacts emanating from the two syringe barrels overlap the spinal cord, impeding evaluation of its signal intensity at the site of compression. In the highest resolution image (D), the spinal cord at the site of compression had slightly increased signal intensity, apparently as a result of convergence of hyperintense truncation artifacts arising from the dorsal and ventral surfaces of the cord.

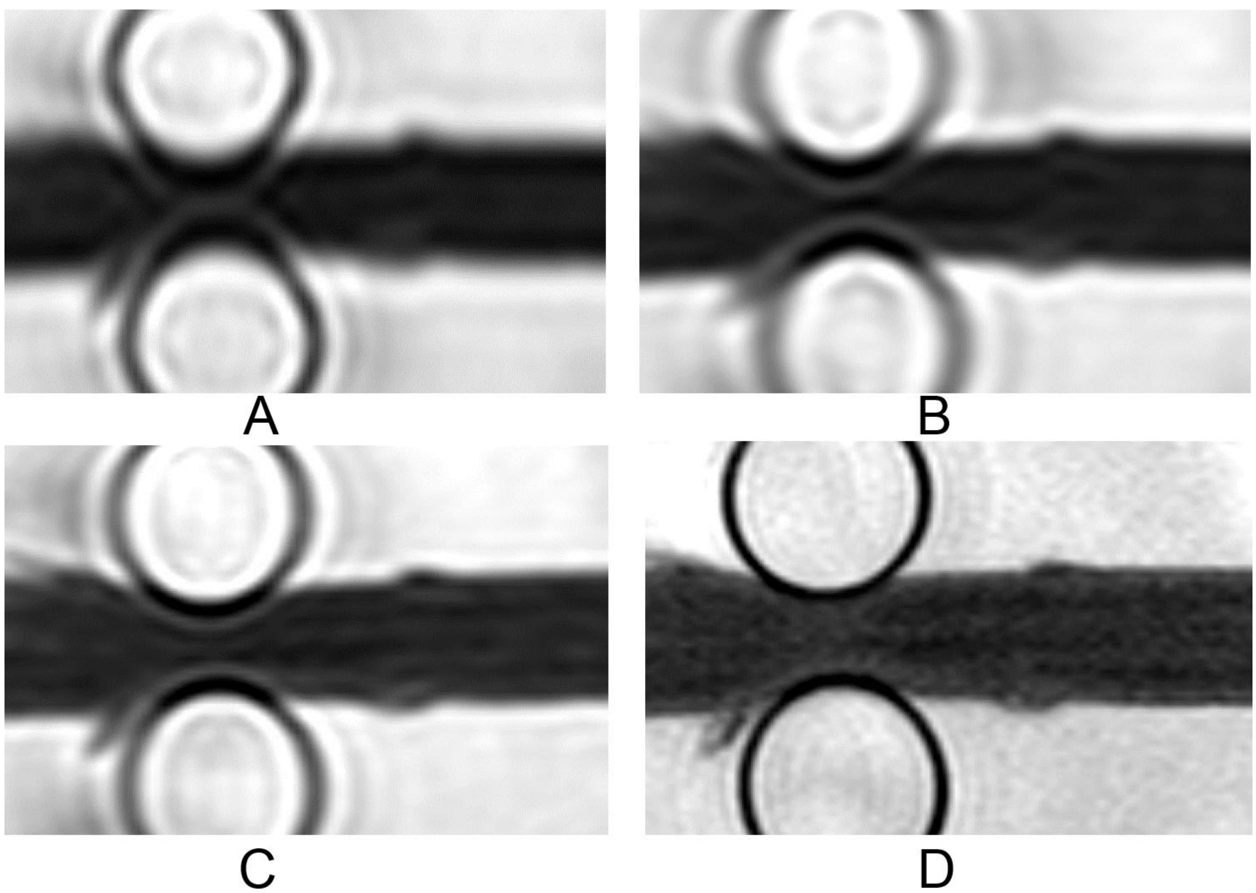

Figure 6. T2w sagittal image of the cervical spine of a dog with surgically-confirmed intervertebral disc extrusion at C4/5.At the site of disc extrusion (arrowhead) the cord is displaced dorsally and is narrowed compatible with compression and is relatively hyperintense. Although this hyperintensity could represent a spinal cord lesion, it is possible that it is formed by the convergence of hyperintense truncation artifacts arising from the dorsal and ventral surfaces of the cord.