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Method - In the study group a uniform imaging methodology was applied and all images were reviewed and registered by referral source, clinical indication, efficacy of imaging and quality. Various classes of image findings were identified and subjected to a variety of small targeted prospective outcome studies. Those findings demonstrated to be clinically significant were then tracked in the larger clinical volume data set.

Results - MR Neurography demonstrates mechanical distortion of nerves, hyperintensity consistent with nerve irritation, nerve swelling, discontinuity, relations of nerves to masses, and image features revealing distortion of nerve at entrapment points. These findings are often clinically relevant and warrant full consideration in the diagnostic process. They result in specific pathologic diagnoses that are comparable to electrodiagnostic testing in clinical efficacy.

Conclusions - MR Neurography and DTI neural tract imaging have been validated as indispensable clinical diagnostic methods that provide reliable anatomical pathological information. There is no alternative diagnostic method in many situations. With the elapse of 15 years, tens of thousands of imaging studies, and hundreds of publications, these methods should no longer be considered experimental.

MR Neurography and Diffusion Tensor Imaging: Origins, History & Clinical Impact of the first 50,000 cases with an Assessment of Efficacy and Utility in a Prospective 5,000 Patient Study Group

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Abstract

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Introduction

The discovery of a series of MR pulse sequence strategies for tissue specific imaging of nerve and nerve tracts in 1991 and 1992 has opened a new diagnostic world in which a wide variety of pathologies involving nerves and neural tracts can be visualized directly (4, 5, 13, 18, 20, 24, 25, 36) these techniques are grouped under the terms “MR Neurography” for peripheral nerve and “Diffusion Tensor Imaging” or “Tractography” for the CNS. Many specialists in these two fields are unaware that they have a common origin in a shared set of fundamental imaging strategies and algorithms that grew out of a unitary development project.

The first DTI image showing curved neural tracts traversing the brain (Fig. 1) and the first neurography images were submitted in a series of UK patent descriptions by Filler et al between March and July of 1992 (18) and were published by the US patent office in 1993(19). Related images were published in the proceedings of the Society for Magnetic Resonance in Medicine annual meeting in Berlin in August of 1992 (25, 36).

Prior to these developments in 1992, it had been generally assumed among radiologists that peripheral nerve simply could not be imaged reliably. The potential to use diffusion MRI to tract trace through the brain was also not really anticipated in the clinical community. The strategy of using diffusion based MRI imaging sequences to help produce linear neural images was first discussed by Filler et al in 1991(20), and emerged as a workable technique through discoveries by Filler, Howe and Richards (in London and Seattle) and by LeBihan and Basser (in Bethesda) in the following months during late 1991 and early 1992. It represented a fundamental rethinking of neurological imaging data that transformed the legacy of cross sectional imaging from CT scanning that had been the conceptual basis of MRI into the realm of tract tracing that had dominated neuroanatomical research in the 1970's and 1980's.

Previously, the methodology of MRI had been directed at identifying methods to assign contrasting image intensities to various voxels (three dimensional pixels) in an MRI image slice. This was accomplished by a wide array of pulse sequences that manipulated aspects of the T1 and T2 relaxation time of protons. Positional information on the voxels was obtained by using magnetic gradients to assign unique magnetic field strengths to each location in the volume to be imaged, then using Fourier transforms to extract signal strength data from each voxel at various echo times after a simple or complex radiofrequency pulse. Diffusion MR *per se* was also known for decades – it acted as yet another source of obtaining contrast on the voxels by assessing relaxation rates (signal decays) that related to the degree to which nerve fibers tended to have water diffuse anisotropically (in a primary direction) rather than isotropically (in all directions)

(32, 33). This is the basis for the diffusion weighted imaging (DWI) that has been used to detect strokes for many years (28, 31, 35).

In MR angiography, we typically produce a series of image slices in which blood vessel voxels are bright and then reconstruct the vessel tree from a stack of slices with vessels shown prominently in each cross section. DTI works very differently. The critical insight was a modification in the fundamental data acquisition process of the MRI scanning system so that each voxel would yield not only image intensity data, but also directional data showing the tensor (3D vector) direction in three dimensional space. Each voxel would be represented by a small arrow pointed in the direction of the principal nerve flow in that volume. Instead of producing a cross section with dots, we produce an array of directional arrows along neural tracts and these can be strung together by various standard 3D graphics techniques to produce linear images of nerve tracts. In addition, pulse sequence modifications could be applied that made this data discoverable in peripheral nerve as well. The resulting neurograms then served as a model for discovering additional non-diffusion tractographic methods for peripheral nerve.

By 1993, there were several major publications in these fields (15, 19, 23). In the subsequent fifteen years, over a hundred academic publications have reported on various aspects of this new imaging modality in peripheral nerve including several large scale formal outcome assessment trials (14, 26, 27). Nonetheless, most textbooks of radiology or neuroradiology do not devote any pages at all to nerve imaging (3), as if nerves were not a clinically significant part of the body. Most practicing physicians still do not appreciate that high quality diagnostically efficacious nerve imaging is available.

More than 2,000 studies have been published that explore DTI tractography in the central nervous system (34) although most of this has been in the past three years. The clinical impact of DTI is still difficult to predict. However, it encodes a great deal of information that is usually discarded in the course of CNS imaging. Because of this it has shown great promise for detecting subtle derangements of brain architecture that are difficult to appreciate with cross sectional imaging.

Formal outcome studies on the use of DTI for evaluation of traumatic brain injury (37), in predicting outcome after intracerebral hemorrhage (40), and for surgical guidance to optimize glioma resection (39) have appeared along with numerous preliminary studies for a wide variety of clinical uses in neuroscience such as in the evaluation of dementia in Alzheimer's (8) and in identifying subtle lesions involved in the etiology of epilepsy (10). Recent diffusion image presentation algorithms have also been used to further advance earlier work on the use of diffusion tensor imaging for peripheral nerve (24, 29, 38).

In the smaller but more clinical peripheral nerve imaging arena, MR Neurography has proven to be more efficacious than electrodiagnostic studies for identifying nerve compressions that will improve with surgical treatment. This has proven to be true both in diagnoses that are typically evaluated by electrodiagnostics such as carpal tunnel syndrome (26, 27) and also in diagnoses in which electrodiagnostics have proven difficult to rely on such as piriformis syndrome and related sciatic nerve entrapments (11, 14).

Utility for MR Neurography has now been established in evaluation of entrapment syndromes (1, 2, 14, 16, 30), nerve injury/evaluation of repair (9), nerve tumor assessment (6, 21, 22), as well as in the setting of neuritis and a variety of

neuropathies (17). It has also proven effective for evaluating nerve disorders affecting the young pediatric patient such as obstetrical brachial plexus palsy.

Over the 15 years since MR Neurography was initially brought into clinical use, about 25,000 peripheral nerve imaging studies have been conducted. DTI can be estimated to have been performed in conjunction with brain MRI scans in tens of thousands of patients mostly in the past two years. This report assesses utilization and diagnostic range for MR Neurography in a prospective group of more than 5,000 patients for whom standardized protocols were applied, research consent obtained, and clinical data collected and organized.

Methods

All patients had physical examination to identify a specific suspect nerve pathology. Images were ordered through St. George's Hospital Medical School (1992 to 1996) University of Washington Department of Radiology (1993 to 1995), UCLA or OliveView/UCLA Department of Radiology (1996 to 2001) or the Neurography Institute (2000 to 2007). Image protocols included matched T1 (anatomic) and neurographic image pulse sequences in multiple planes including at least one "nerve perpendicular" plane for fascicle assessment. For all MRN studies echo times were greater than 40 milliseconds (usually 70 to 100 ms) in order to assure that no magic angle effects could occur (7).

Results

Utilization by type of pathology:

The dominant class of pathology for which MRN studies were ordered in this group were in the area of nerve entrapment. Utilization in tumor (Fig. 2 and 3), trauma (Fig 4), and neuropathy represented only a very small percentage of the studies. However, this also reflects the relative incidence of these conditions. Nerve entrapment/degenerative problems such as carpal tunnel, piriformis syndrome, thoracic outlet syndrome and radicular spinal syndromes are far more prevalent. When correction for incidence of the major classes of disorders is considered, the utilization pattern appears to be similar for degenerative/pain/entrapment, neoplastic, and traumatic nerve pathology. Our study participants represented about 0.01% of the total incidence for the time period for these types of cases. Utilization for the evaluation of neuropathy is very low.

Utilization by body region/nerve

Use of MR Neurography is heavily concentrated in the are of large proximal nerves that are difficult to assess accurately by routine electrodiagnostic techniques and physical exam. Studies of the lumbosacral plexus, proximal sciatic nerve and other pelvic nerves (ilioinguinal, pudendal, femoral, obturator) constituted about 42% of cases.

Brachial plexus imaging accounted for an additional 18% of cases and lumbar spinal nerve studies were 5%. The remaining 35% were studies of knee/peroneal nerve, elbow/ulnar nerve, wrist/median nerve, ankle/tibial nerve, upper neck/occipital nerves, thigh/distal sciatic, calf, foot, upper arm, abdominal wall, face, intercostals, and various individual study types.

Utilization by practitioner category

Most MR neurography studies were ordered by neurosurgeons (43%) and this appeared to represent a combined influence of diagnostics and surgical planning. Surgical planning as a reason for ordering was inferred when the study was ordered by a surgeon and the diagnosis was already established. Neurologists ordered an additional 21% of the studies, while pain specialists (12%), physiatrists (8%), orthopedic surgeons (6%) and various others ordering the remaining studies. Only a very small number were ordered for pediatric patients and these generally were not ordered by pediatricians.

Diagnostic efficacy and ordering

MR Neurography had a high diagnostic efficacy. More than 96% of studies resulted in either specific findings involving the nerve of interest or in a definitive statement that the nerve or nerves in question were entirely normal in appearance. The remaining 4% of studies were non-diagnostic because of movement, artifact from implants, body habitus or pain limiting appropriate positioning in the scanner, or ordering errors. Ordering errors arose because many practitioners were not experienced in ordering nerve imaging. For example, a neurologist or neurosurgeon (or staff member) seeking to evaluate sciatica due to piriformis syndrome would order a lumbar MRN instead of the necessary pelvic MRN because of the habit of using lumbar MRI for sciatica.

Contrast use

Intravenous gadolinium contrast was used in about 0.4% of cases. Where tumor was part of an initial differential diagnosis but not proven, contrast was not used. Only patients with known tumors received intravenous contrast.

Follow up imaging studies

About 1% of the studies were part of a repetitive set. These were generally patients who had a diagnostic MRN and then were referred for repeat imaging when symptoms recurred after treatment, extended time elapsed between initial imaging and

treatment, when recurrent tumor was suspected, or when new symptoms arose in the same body region. Generally, the use of repetitive imaging was lower that what has been reported for lumbar or cervical MRI.

Geographic distribution

The highest utilization of MR Neurography was in Southern California – accounting for about 82% of patients imaged. Usage was lower in other regions with the only other significant concentration being Northern California with the remainder coming from nearly all US States, England, Spain, France, Japan, Mexico and China.

Classes of image findings:

Image findings in MR Neurography studies include the presence of regions of nerve hyperintensity, distortions of normal nerve course, abnormal contours and alterations of nerve caliber (Fig. 5 & 6) – any of which can be classed by the degree or severity of the abnormality. These findings seem most reliable for the larger named nerves over 3 mm in diameter although there is no technical limit on the imageable size of a nerve. In trauma, assessments of nerve continuity (Fig. 4) and/or location of severed nerve endings are feasible although edema at a site of injury limits the utility of MR Neurography in acute injury settings.

Conspicuity and reconstructions

One important aspect of MR Neurography is to use MRI pulse sequences and acquisition strategies that tend to make nerve image intensity brighter than that of immediately surrounding tissues. When this is achieved, it greatly aids the process of generating three dimensional projection images as well as multi-planar reformatted images. This process often helps in the appreciation of overall nerve course and of variations of the various types of other image findings as they vary along the length of a nerve. Among the 5,000 cases evaluated, more than 99% were susceptible to 3D analysis. Findings in the 3D reports revealed additional information not appreciated in 2D analysis in 28% of cases The greatest amount of additional diagnostic information in these analyses occurred in the brachial plexus cases. Because of the significant incremental amount of clinical information provided by this type of analysis and the susceptibility of most studies to this, these were considered essential aspects of the diagnostic interpretation process in this group.

Multi-planar reformat and Maximum Intensity Projection (MIP) reconstructions were also important in limiting artifactual variations in nerve image intensity that can occur from partial volume averaging – this means that when a given sampled voxel is partially filled with nerve and partially filled with an adjacent low intensity tissue, the resulting pixel on the image will appear to show low intensity nerve. Reconstruction techniques such as multi-planar reformats in linear planes allow the reading clinicians to readily assess this sort of issue. Curved reformats made along a “nerve course plane”

drawn along the main nerve axis by a technologist or radiologist reduce the accuracy of the spatial information but provide for optimal reduction of image intensity averaging effects.

Image Findings in Brachial Plexus Studies

MR Neurography proved effective for identifying the presence of a variety of types of abnormalities in brachial plexus studies. These include distortions of the course of the proximal elements at the scalene triangle (Fig. 5, Fig. 6A-D), fibrous band entrapments affecting C8 and T1 spinal nerve and the lower trunk of the brachial plexus (Fig. 6F), gross distortions of the mid-plexus (Fig. 6G & 6H), irritation at the level of the first rib (Fig. 5), and distal plexus irritation.

In most peripheral nerve studies it has proven useful for identifying areas of irritation by a comparison of results from following serial nerve cross sections oriented to be perpendicular to the principal long axis of nerves to images taken to be more or less parallel to the long axis. In nerve-perpendicular images, the fascicle pattern can generally be observed. This will demonstrate expansion of the fascicle compartment at the expense of the interfascicular compartment at areas of focal hyperintensity. The nerve-parallel images can provide a linear overview. In general effective interpretation of nerve parallel images depends on the ability of the MR Neurography imaging sequence to make the nerve brighter than surrounding tissues. In this fashion the nerve image plane can be adjusted by multi-planar reformatting or the nerve can be assembled by maximum

intensity projection. If this is not done, then partial volume effects at the edges of nerves can lead to artifactual appearance of variation of image intensity within an image. In the brachial plexus, multi-planar reformatting is usually sufficient to generate a series of images that can reliably confirm the existence of a focal change in nerve image intensity. This is aided by positioning the patient in the scanner in a way that tends to straighten the plexus. When a change in the fascicle pattern shows increased intensity in the nerve perpendicular views that matches to a change seen in nerve parallel views, there can be a very high level of confidence about the clinical reality of nerve edema at the location that appears abnormal in the image.

MR Neurography in the Pelvis

The use of MR Neurography has revolutionized neurologic diagnosis in the pelvis (11, 12, 14). Although sciatic pathologies have been an important part of the advance, the ability of MR Neurography to track other nerve elements in the pelvis has gone a long way to resolving what had been a troublesome “black box.”

In the face, neck arm and hand patients tend to be very effective in identifying the location of pain, numbness and dysfunction. Physical exam is straightforward and well understood by many clinicians. Electrodiagnostic studies are readily applied. In the pelvis, the situation is quite different. Although the sciatic nerve in the leg poses similar accessibility to what the clinician experiences in the upper body, there has been great difficulty in applying physical exam, imaging, and electrodiagnostics in the pelvis. Further, patients often have a great difficulty explaining the location of pains. It is

common for low buttock pain to be described as “back pain” while patients readily distinguish between shoulder and neck. The term “groin” pain could refer to problems involving the femoral nerve, ilioinguinal nerve, genitofemoral nerve, pudendal nerve, obturator nerve or nerve to the obturator internus among others.

The ability to reliably locate all of these nerve elements in MR Neurography images greatly aids physical exam. The ability of Open MR guided injections to distinguish superior gluteal nerve, inferior gluteal nerve, posterior femoral cutaneous nerve, cluneal nerve (superior, middle, inferior), nerve to obturator internus, nerve to quadratus femoris has also supplemented the role of MR Neurography for identifying pathology in these nerves. Simply by clarification of the nerve course anatomy, it has also greatly enhanced the efficacy of physical exam and clarified the meaning of a variety of new types of physical exam maneuvers.

With regard to lower extremity radiculopathy, it has made it convenient to determine distinctions by imaging that help locate impingements in spinal foramina, at the distal foramen, at lateral marginal osteophytes several centimeters distal to the foramen (Fig. 7), in the lumbo-sacral plexus, on the medial aspect of the piriformis muscle, in association with division of the nerve by the piriformis muscle (Fig. 8), at the ischial margin, at the tendon of the obturator internus, at the distal ischial tunnel on the lateral aspect of the ischial tuberosity and at various locations in the thigh.

Reliable identification of anatomical variants of the sciatic nerve now plays a critical role in improving the safety of surgeries for the release of pelvic sciatic nerve entrapment. Isolated section of a single piriformis segment in patients with a split nerve

passing through a split muscle can cause nerve compromise after surgery if this condition is not detected in advance (Fig. 9).

Identification of the presence or absence of pudendal nerve irritation in the Alcock canal (Fig. 10) along the medial aspect of the obturator internus muscle or at the rectal branch of the pudendal nerve proximal to its entrance to the Alcock canal (Fig. 11) has also been quite useful clinically (12).

Imaging of the complete course of the L4 spinal nerve as it progresses into the femoral nerve has made it possible to search for abnormalities along the intra-abdominal and intra-pelvic course that were previously almost impossible to diagnose. Identification of abnormalities along the ilio-inguinal and genitofemoral nerves are similarly greatly aided by MR Neurography.

Distal entrapments including less common problems such as posterior interosseous nerve entrapment of the distal radial nerve as well as common issues such as peroneal nerve entrapment at or above the fibular head, tarsal tunnel syndrome, cubital tunnel syndrome and carpal tunnel syndrome benefit from MR Neurography imaging when physical exam or electrodiagnostic studies show that locations other than the most routine sites may be involved. For instance, median nerve entrapment in the distal forearm can lead to failure of treatment if only the flexor retinaculum is addressed. Ulnar entrapment in Guyon's canal, and proximal peroneal nerve entrapments along the tendon of the biceps femoris just distal to the sciatic bifurcation are other specialized issues that can best be investigated by imaging. Electrodiagnostics can be misleading if they are done with the assumption that abnormalities in certain regions (e.g. the median nerve in

the distal forearm) will always be at the flexor retinaculum – particularly in uncomfortable and time consuming "inching" studies are not done.

Diffusion Tensor Imaging

From the earliest report on the use of DTI to image neural pathology (36), it has been clear that this technique has great potential for use in detecting inflammatory brain conditions. It is also proving to be promising for evaluation of stroke, dementia and diffuse axonal head injury. It is also being explored for evaluation of myelopathy in the cervical spinal cord. It is very demanding from the point of view of motion suppression, but increasing clinician experience with the special requirements is leading to steady advances in establishing the utility of the technique.

Conclusions

The introduction of imaging techniques capable of demonstrating the intrinsic signal of nerve as well as of preserving and displaying structural linear properties of neural tissue in general is progressively transforming all of neuro-imaging even as it transforms our approach to diagnosis, treatment planning and surgical access. The next ten years will be an extremely exciting period for the various forms of neural tractography. It is reasonably expected that there will be a logarithmic expansion of the utilization of these techniques so that more than 5 million such imaging studies will probably be performed in the next ten years.

Many of the fundamental obstacles have been overcome and the advance of the power of imaging equipment and post-processing technology will similarly help drive these methods to the forefront of neurology and neurosurgery.

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Figure Legends

Figure 1 – The first Diffusion Tensor Imaging case. This image is primarily the work of Todd Richards and shows the use of spatial diffusion information to highlight a neural tract curving through brain. This is the brain of a long-tailed macaque monkey (*Macaca fascicularis*) imaged as part of an effort to improve the sensitivity of MRI for the early detection of encephalomyelitis. Reproduced from: Filler AG, Tsuruda JS, Richards TL, Howe FA: *Images, apparatus, algorithms and methods.* GB 9216383, UK Patent Office, 1992 and also: Filler AG, Tsuruda JS, Richards TL, Howe FA: *Image Neurography and Diffusion Anisotropy Imaging.* US 5,560,360, Unites States Patent Office, 1993 (18, 19) .

Figure 2 – Relations of a small C5 mass to brachial plexus elements. In many cases, by collecting images in planes that are perpendicular to the main longitudinal axis of the nerve elements of interest, it is possible to obtain extremely specific information about the location of a mass within the brachial plexus.

Figure 3 – Relations of brachial plexus elements to an axillary mass. Although schwannomas can be detected by various techniques, it is extremely valuable for the surgeon to have a method of determining the position of the nerve elements relative to the position of the mass. Bp – brachial plexus, sc – schwannoma.

Figure 4 – Upper trunk brachial plexus injury with denervation of C5 muscles. A) There is an apparent discontinuity of the C5 component of the upper trunk. The C6 component is swollen upstream of the injury and sharply narrowed and hyperintense. B) Coronal view and C) nerve perpendicular view showing severe denervation changes in supraspinatus and infraspinatus muscles. Bpi – brachial plexus injury, su – supraspinatus, in – infraspinatus, ss – scapular spine.

Figure 5 – Right and left side comparison of a patient suffering from right sided thoracic outlet syndrome. The image demonstrates several types of abnormality detectable by MR Neurography relative to the normal side. There is increased caliber and image intensity of nerve elements on the left and two sites of impingement. A sharp focal downward distortion at the lateral border of the scalene triangle and then a gently sloped upward distortion over the first rib. Sc – scalene border, 1st – first rib.

Figure 6 – Varying degrees of severity of brachial plexus entrapment in thoracic outlet syndromes. A) Linear plexus with short segment of mild irritative changes near the later border of the scalene triangle; B) Evidence of more restrictive fibrosis associated with narrowing and brightening of plexus elements near the scalene border – note linear plexus despite elevated shoulder; C) Short segment of marked hyperintensity with slight swelling; D) Severe multiple element abnormality with narrowed and swollen segments, and marked hyperintensity; E) Linear normal plexus with isolated focal impingement of C5 spinal nerve, just proximal to the

scalene triangle; F) Fibrous band causing sharp downward distortion of mid and lower trunk proximal to scalene triangle, with second sharp upward distortion of lower trunk near scalene insertion at the first rib; G) Moderate restrictive impingement of plexus at scalene triangle causing generalized distortion of the course of the plexus with short segment of focal hyperintensity; H) Patient presenting with severe pain, numbness and weakness from progressive thoracic outlet syndrome – multiple points of sharp nerve course distortion with edema and hyperintensity affecting multiple brachial plexus elements.

Figure 7 – Extraforaminal impingement of descending L5 spinal nerve by lateral marginal osteophyte distal to the foramen. Drg – dorsal root ganglion, lmo – lateral marginal osteophyte.

Figure 8 – Bilateral split sciatic nerve at piriformis muscle. Among the most important aspects of pre-operative planning in management of sciatic nerve entrapments in the pelvis is the identification of patients with a split sciatic nerve partly passing through the piriformis muscle. This image demonstrated the S1 spinal roots, spinal nerves, LS plexus, and split peroneal and tibial components of the sciatic nerve (arrows) as they are deviated by segments of the piriformis muscle bilaterally.

Figure 9 – Severe focal compression of the sciatic nerve at the sciatic notch. The nerve is flattened, hyperintense and expanded to more than twice its normal diameter. This is a post-operative result that occurred when only one of the two bipartite elements of the piriformis muscle was released in a patient with split nerve and split muscle. Differential retraction of the cut piriformis segment relative to the intact segment caused a severe mechanical impingement syndrome.

Figure 10 – Pudendal nerve entrapment between the ischial spine and the Alcock canal. In patients with unilateral pudendal entrapment in the Alcock canal, it is typical to see asymmetric swelling and hyperintensity affecting the pudendal neurovascular bundle. Note increased caliber and hyperintensity at the left pudendal nerve indicated by the left arrow. Figure reproduced with permission from: Filler AG: Diagnosis and management of pudendal nerve entrapment syndromes: impact of MR Neurography and open MR-guided injections. **Neurosurgery Quarterly** 18:1-6, 2008 (12).

Figure 11 - Distal pudendal nerve neurographic image anatomy. The pudendal nerve in the Alcock canal (AC) runs along the medial aspect of the obturator internus muscle (OI) medial to the ischial tuberosity (IT). The rectal branch of the nerve (RB) is well seen in most imaging cases (Re = rectum). Figure reproduced with permission from: Filler AG: Diagnosis and management of pudendal nerve

entrapment syndromes: impact of MR Neurography and open MR-guided injections. **Neurosurgery Quarterly** 18:1-6, 2008 (12).

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Aaron G. Filler, MD, PhD is a co-inventor on patents that cover the use of MR Neurography and DTI imaging. He has received funding from NIH, The Wellcome Trust, and the Atkinson Morley's Research Foundation for scientific research related to the subject matter. His clinical neurosurgical practice employs these imaging techniques. He performs radiology interpretations on MR Neurography and DTI images. He is a shareholder in NeuroGrafix – a company that administers patent technology licenses under agreement from the University of Washington which owns the patent and which also manages image data transport for neural tract imaging although he has not received any funds from NeuroGrafix.

Authorship

Aaron Filler, MD, PhD, FRCS was the primary investigator in this research, conceived of the research plan, invented the technologies, carried out the clinical implementation, participated directly in the imaging and image interpretation process. He generated the text and figures personally and also assembled the manuscript.

Article Summary

It is now possible to use MRI scanning to provide detailed images of nerves as well as neural tracts in the brain. This greatly extends the capabilities of imaging to assist in the diagnosis of nearly every category of neurological disorder. The impact of nerve and neural tract imaging is now becoming clear as summary evaluation of the kinds of information these tests provides becomes available. In the future, imaging of nerves and neural tracts of the brain will play an increasingly important role in the diagnostic process and they promise to offer specific results in areas where current diagnostic methods have often been insufficient.

Figure 1

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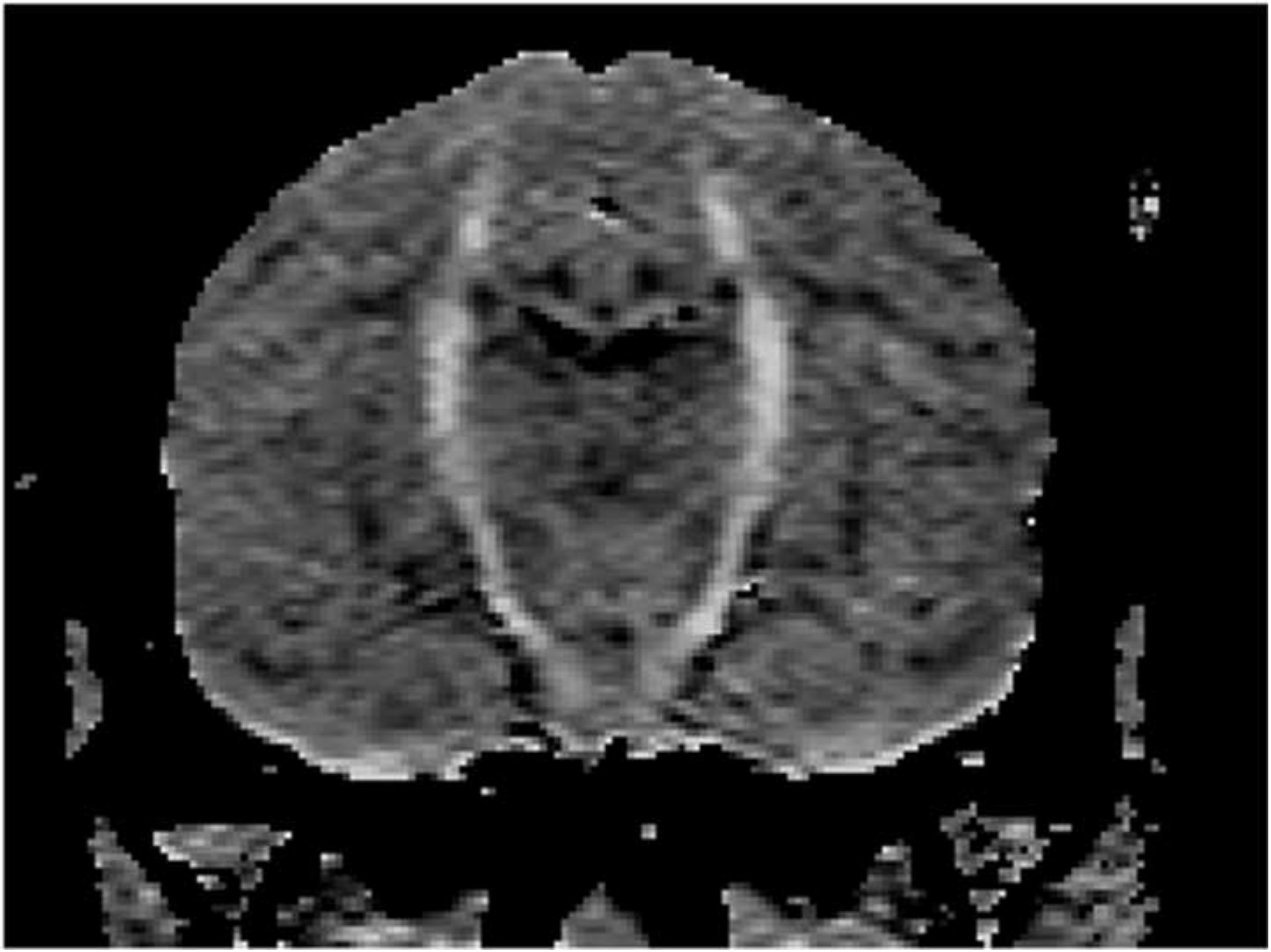

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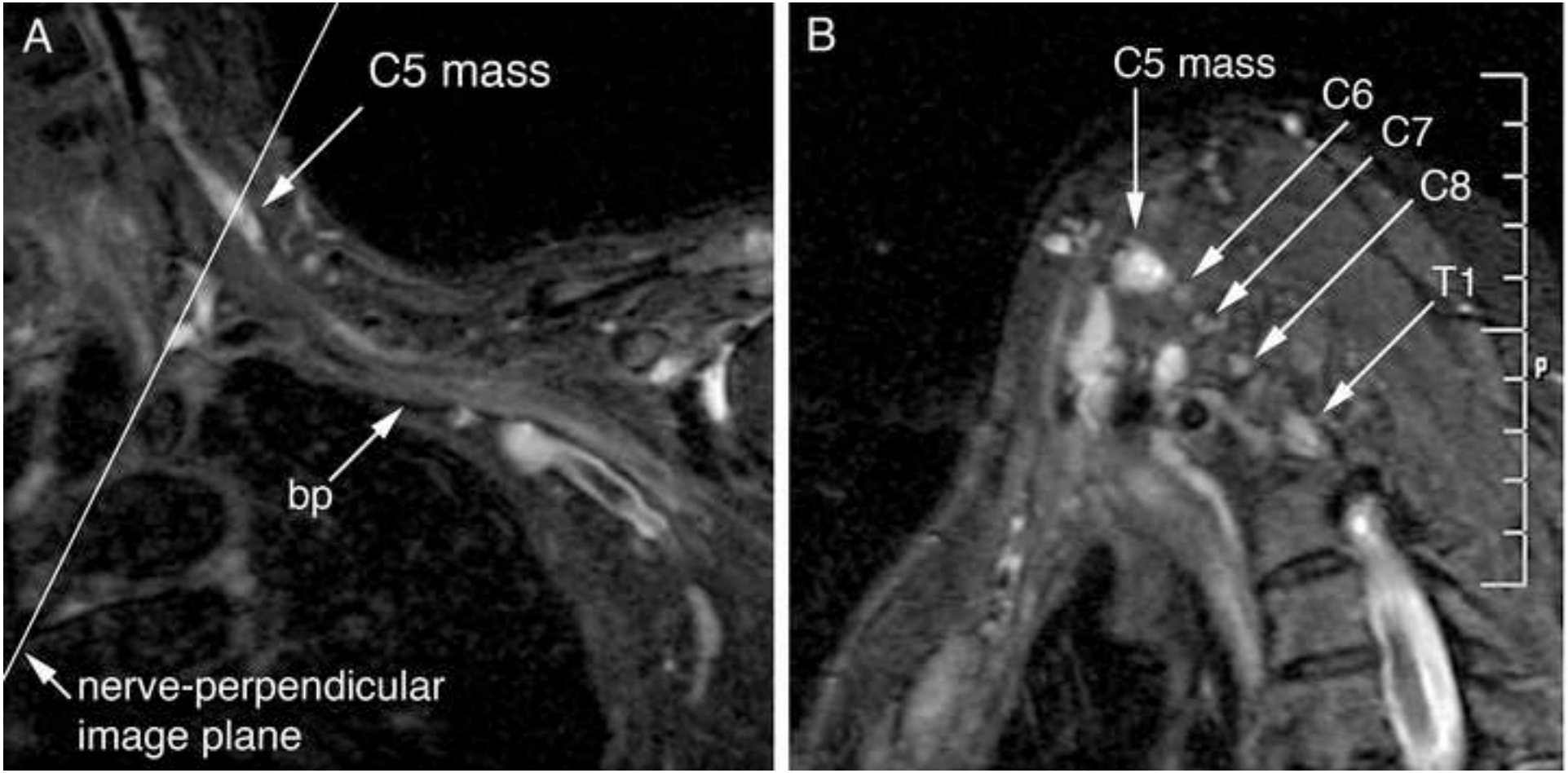

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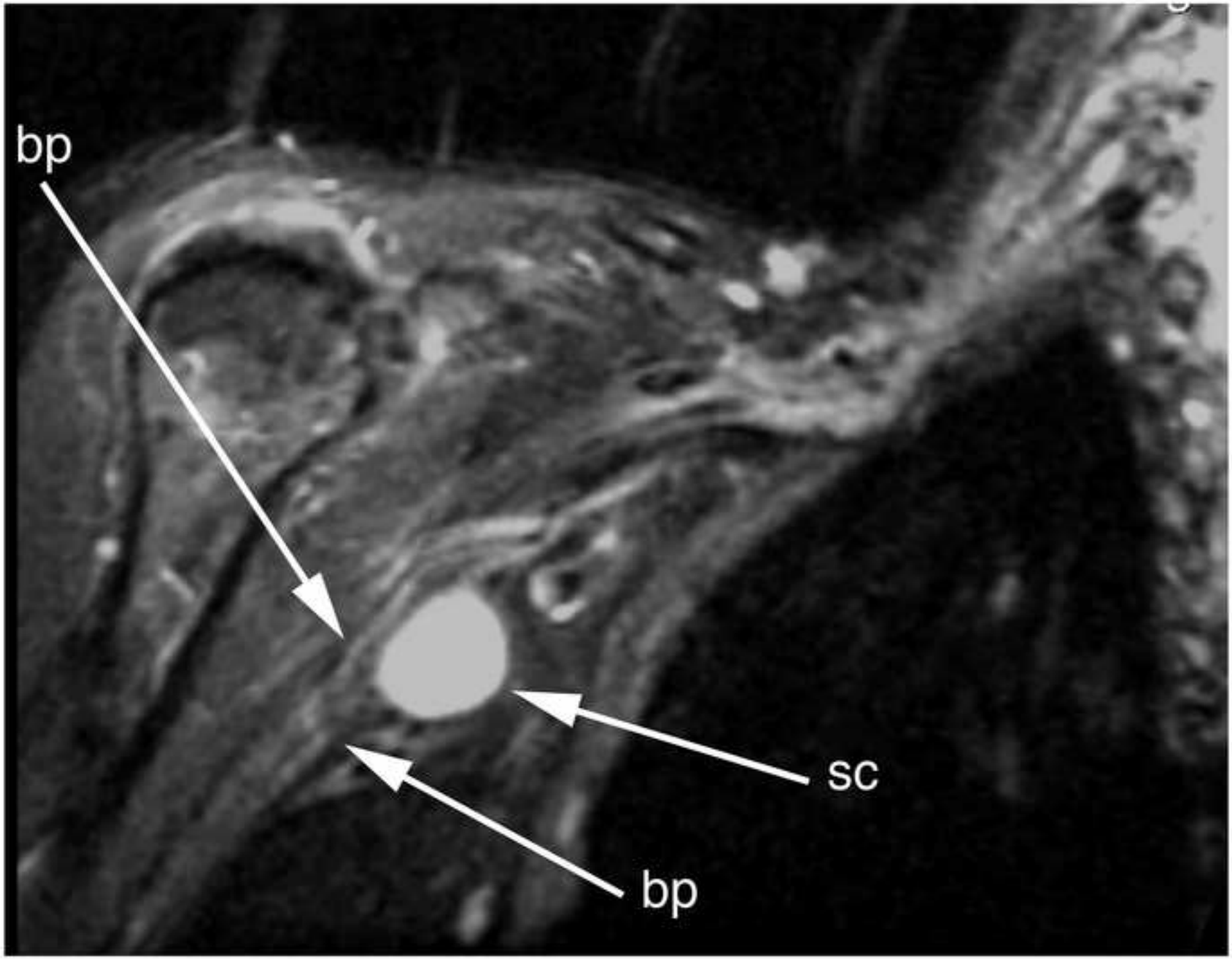

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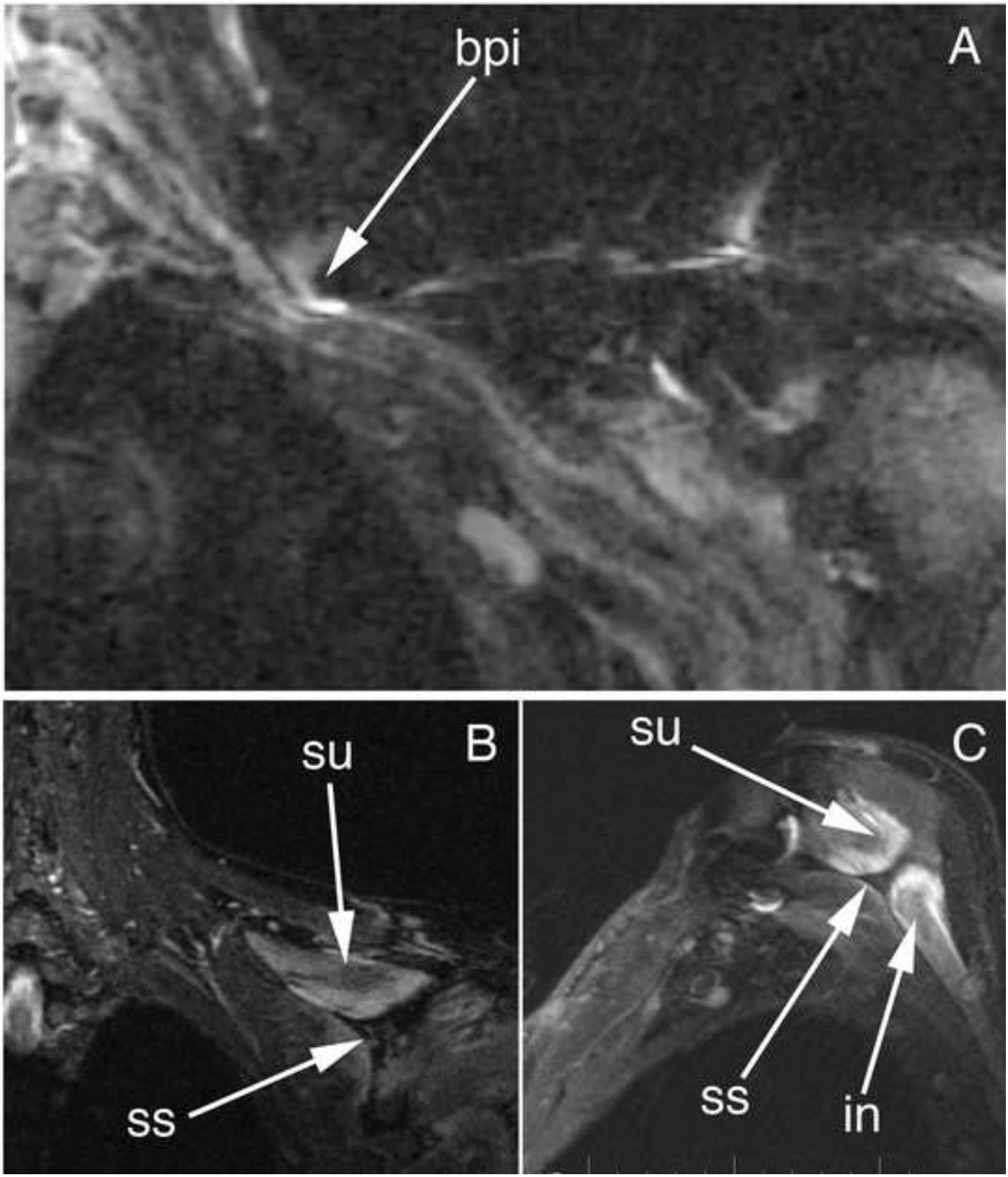

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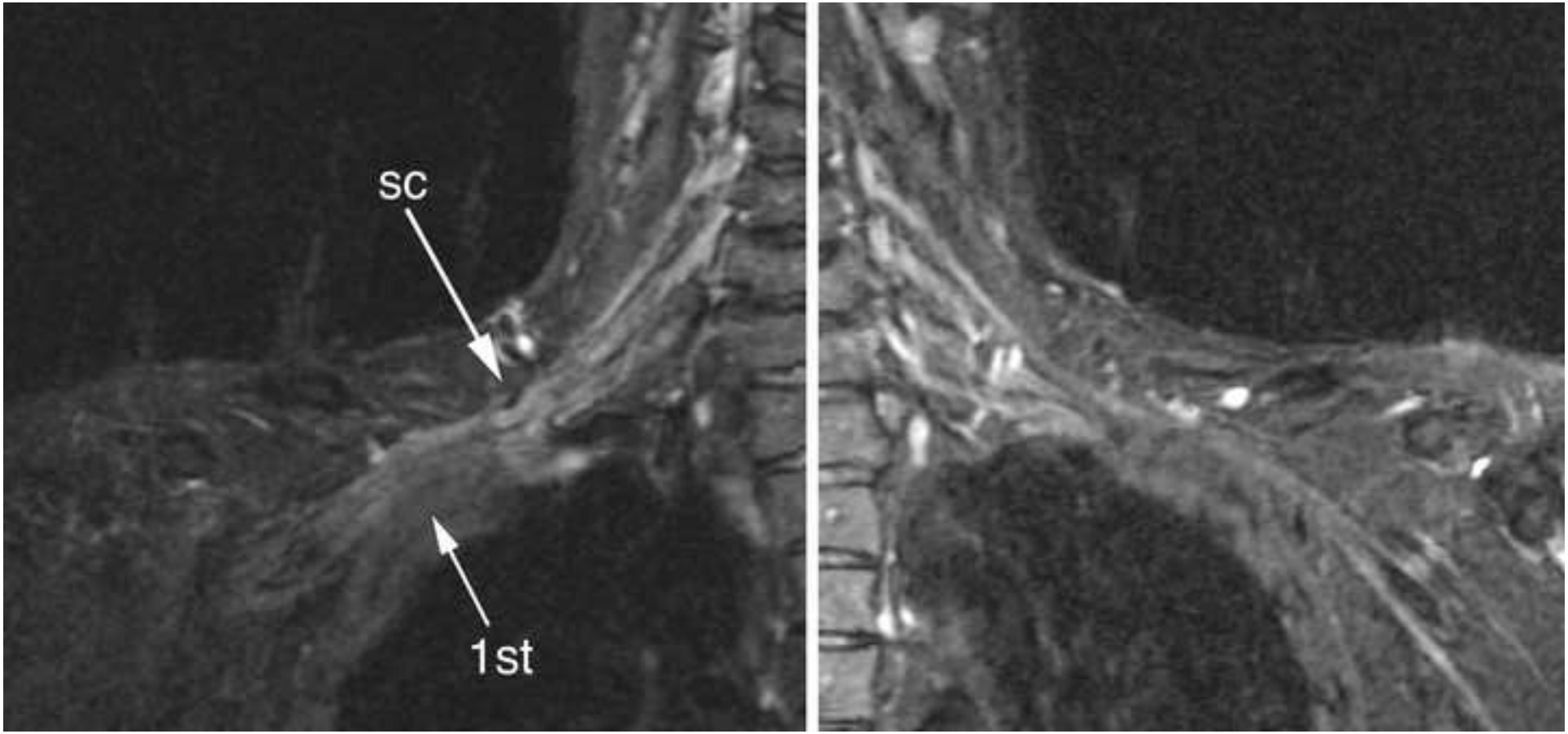

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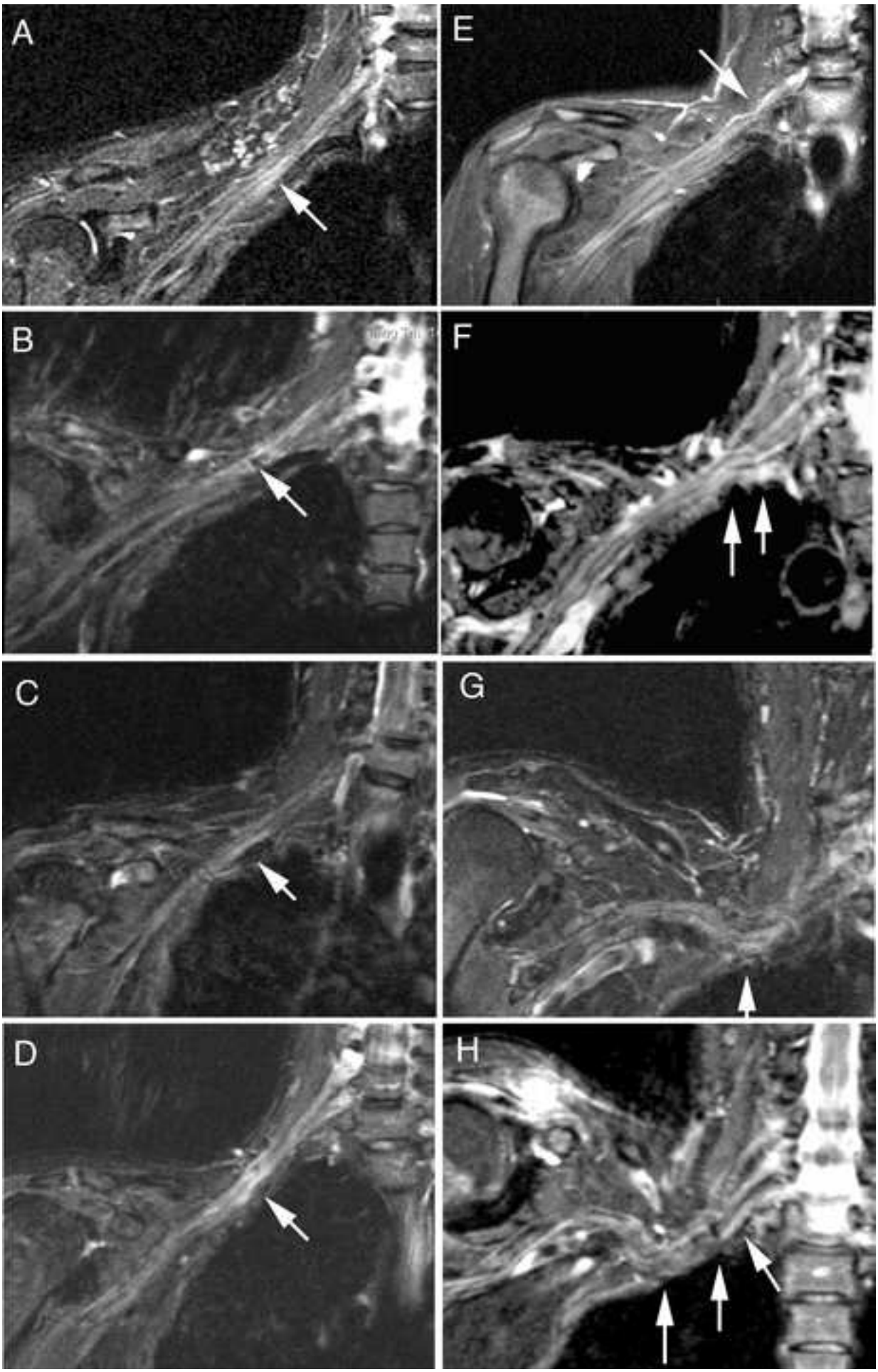

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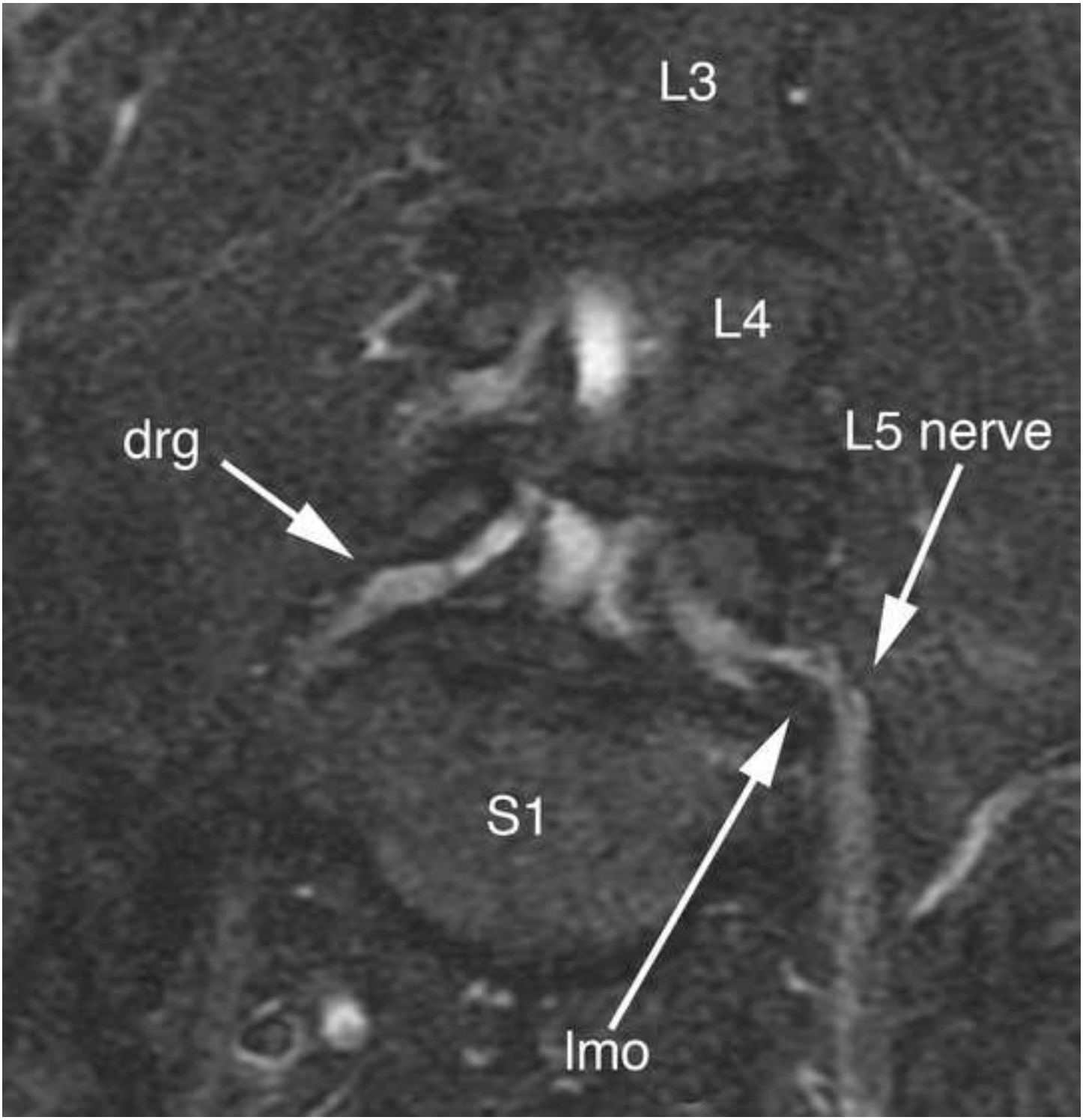

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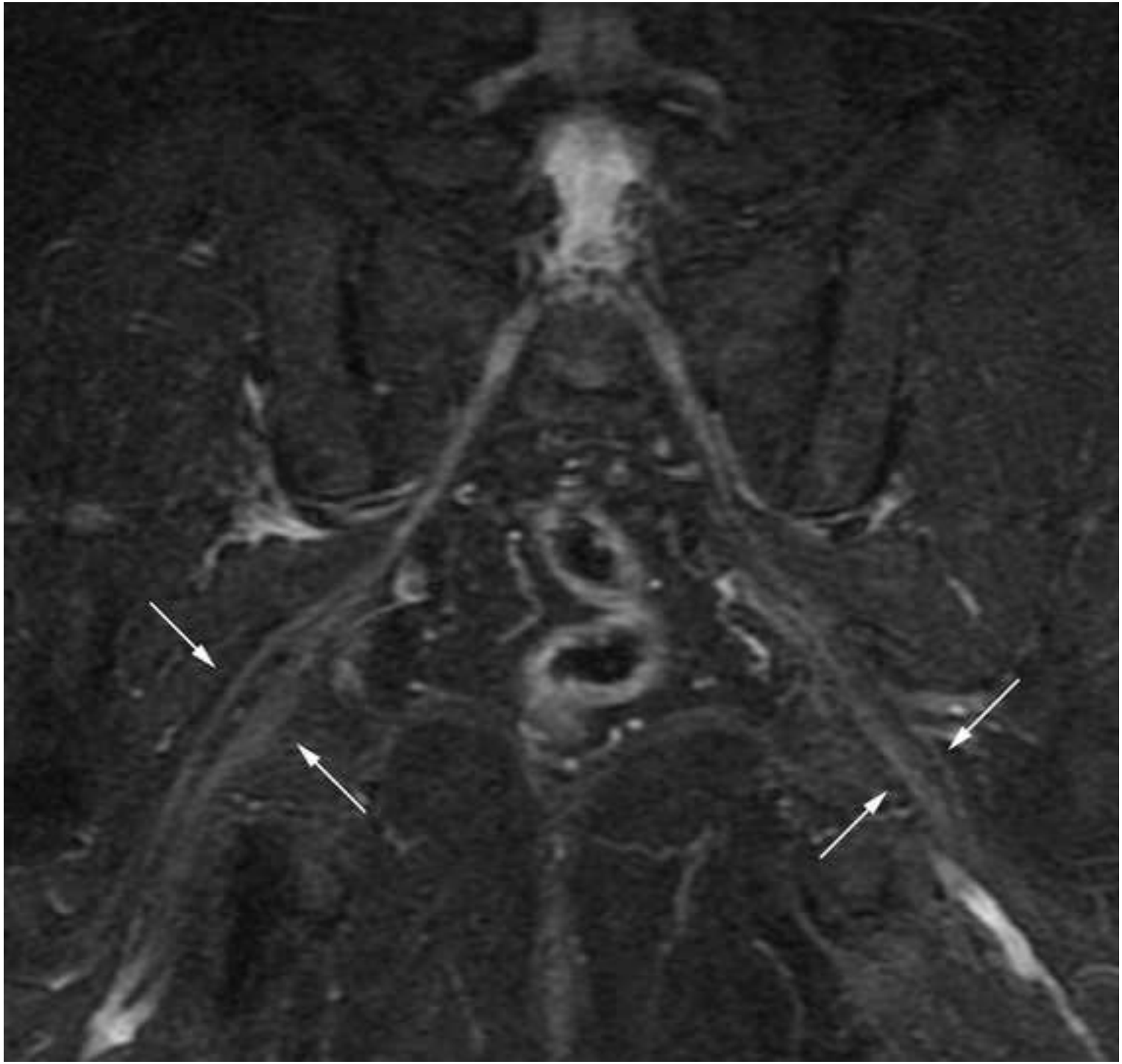

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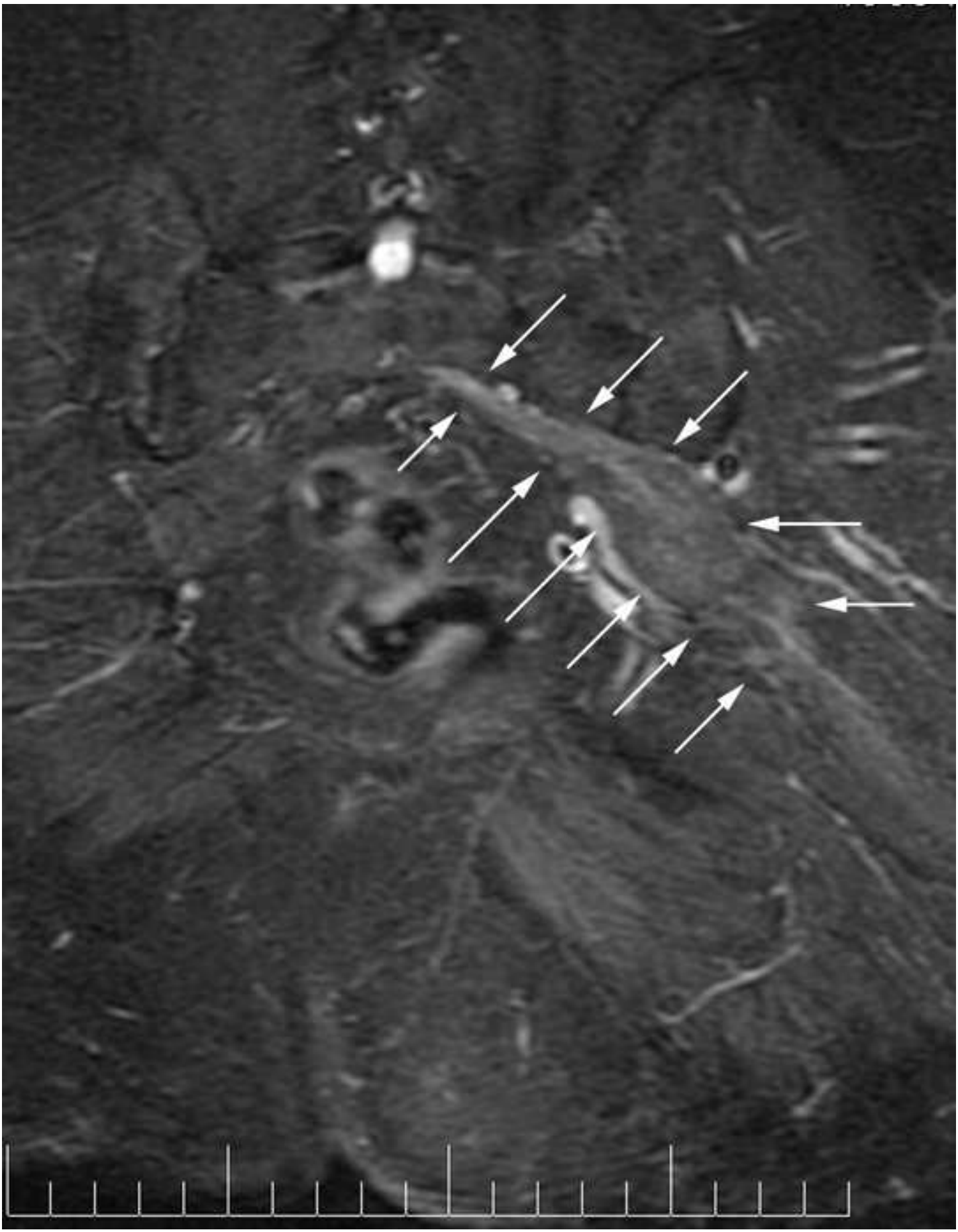

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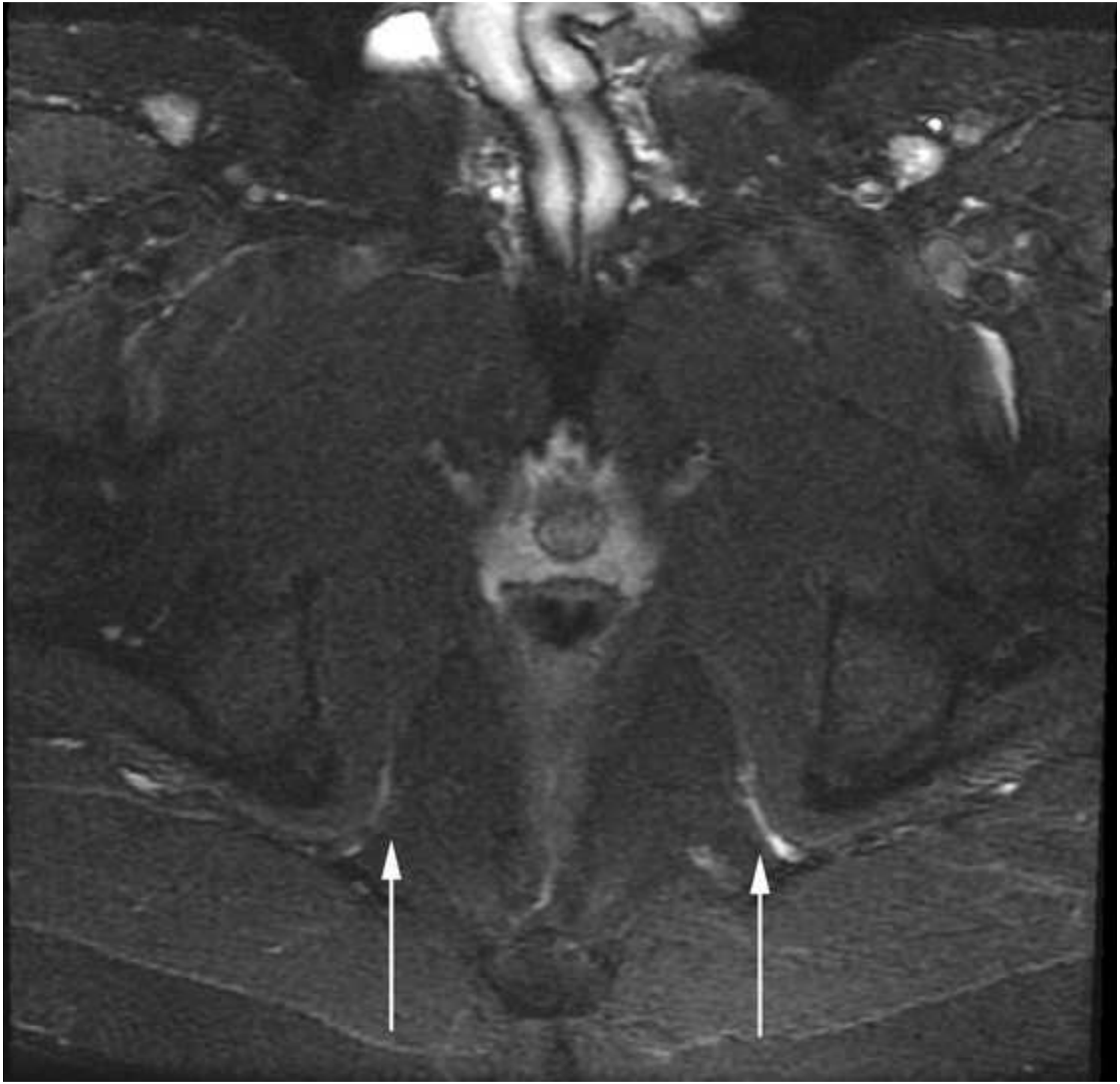

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