Original article

MR imaging of the pudendal nerve: a one-year experience on an outpatient basis

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Abstract: Magnetic resonance (MR) neurography was used on an outpatient basis in 56 men, 244 women; mean age 41 ±0.8 and 53±1.4 years, respectively; range, 22-84 years with various pelvic floor dysfunctions and in 25 consecutive patients (8 males, 17 females; mean age, 38 years; range, 29-48 years) with chronic pelvic pain of undetermined origin to evaluate the appearance of the pudendal nerve. Most commonly, a combination of fat-suppressed T2-W and short inversion time inversion recovery (STIR) imaging sequences allowed successful depiction of nerve course anatomy and localization of lesions at site of disease, entrapment or injuries. Key images for interpretation were obtained in the axial and coronal orthogonal and oblique planes. A major disadvantage of these conventional imaging techniques is their inability to distinguish nerve from vessels due to similar MR signal intensity. To improve visualization of nerves, the bright fluid signal suppression technique should be implemented.

Key words: MR-neurography; Pudendal nerve neuropathy; Fat suppression technique; Nerve-oriented MR imaging; Blood suppression MRI.

INTRODUCTION

Despite its first description as far as 1992 by Howe and Filler and various subsequent papers[1-4] with generation of great interest almost since its inception, the practical application of MR technique to imaging of peripheral nerves, also called “ MR-neurography”, is still today an often overlooked and underappreciated technique. This is unfortunate, since it can be highly accurate, easy to perform and successful in many situations where other imaging techniques yield ambiguous results. In particular, MR-neurography of the pudendal nerve can produce detailed pictures in a wide variety of pathologies including nerve-compression syndromes, small nerve tumors, degenerative disease, entrapments, adhesions, and trauma.[5-10] Radiologists becoming involved in this field will experience an increasing demand for these examinations as clinicians come to rely more heavily on imaging studies for diagnosis, and to select patients for appropriate therapies. The current study was undertaken to revitalize interest in the technique and to describe which elements of the pelvic floor anatomy can be consistently used as landmarks for identification of the pudendal nerve along its entire course. Also, a description of the technical principles, including scan planes and pulse sequences, will be offered using most of existing top quality conventional scanners for optimal depiction of MRI nerve characteristics.

MATERIALS AND METHODS

Study population. The standardized MRI series of the pelvis performed during a twelve months period (January-December 2013) with conventional 1.5 T MR scanner (Philips, Achieva model, The Netherland) were retrospectively reviewed for evidence of pudendal nerve characteristics. All examinations were performed and interpreted by the same observer (P V) in close cooperation with the technical staff (B M, B F, B M, C R, C A, DeT L, F N, G G, M M, M N, R M, R R, S MC, Z A) and trained nurses (G P, M G). Patients (56 males, 244 females; mean age 41 ±0.8 and 53±1.4 years, respectively; range, 22-84 years) were referred to the diagnostic centre (Iniziativa Medica spa, Monselice, Padova, Italy) to undergo the examination on an outpatient basis for a variety of pelvic floor dysfunctions occurring alone or in combination, including chronic constipation and obstructive defecation syndrome (41%), pelvic organ prolapse (63%), minor or major fecal incontinence (18%), anal sepsis and fistula-in-ano (24%), prior colorectal and urogynecological surgery such as STARR procedure, Delorme operation and TVT or TOT procedure (39%) and abnormal pelvic organ support system from obstetric trauma (71%), as documented by physical examination. A small group of 25 consecutive patients (8 males, 17 females ; mean age, 38 years; range, 29-48 years) with chronic pelvic pain of undetermined origin was also enrolled into the study to rule out pudendal neuropathy; informed consent forms were obtained from all patients to participate in this institutional board-approved study.

Imaging technique. Transverse, coronal, and sagittal TSE T2-weighted MRIs of the pelvic region were obtained at 1.5 T with a slice thickness of 4 mm and a slice gap of 1 mm using a XL TORSO coil wrapped around the patient’s pelvis. An anteroposterior frequency-encoding (right-to-left phase encoding) direction was used for the axial planes to prevent right-to-left chemical shift artifacts. With the subject in the supine position, the transverse image acquisition plane was perpendicular to the body axis. The coronal plane was perpendicular to the axial plane and parallel to the table. The sagittal plane was perpendicular to the coronal plane. In addition, oblique coronal images in the STIR pulse sequence were obtained taking the sacral promontory and the S1-3 vertebral bodies as reference, starting 0.5 cm dorsally to include the maximum gluteus muscle and ending 4 cm ventrally at the level of the arcuate ligament. Similarly, oblique axial TSE T2-W and STIR images were obtained parallel to the pubococcygeal line (PCL), starting at the anal verge up to the inferior margin of the symphysis pubis so as to include the clitoris anatomy (female).

Oblique sagittal STIR images were also acquired 3 cm laterally on the right or left to the midline taking the ischial anterior ramus as reference to visualize the neurovascular bundle along the Alcock’s canal course. In a few cases, the "black blood" pulse sequence technique was also experimentally used in an attempt to improve visualization of nerve structures. A complete summary of the technical setting for MR neurography of pudendal nerve at our institution is reported in Table 1.

Image analysis. Key images. In axial planes, 4 levels were chosen which represented consistent anatomic bony landmarks allowing identification of the course of the nerve down the pelvis after its origin in the sacral plexus, as follows: the region of the ischial margin and greater sciatic foramen (level I); the ischial spine and the roof of acetabular fossa (level II); the femoral head, neck, greater trochanter and acetabolum (level III); the ischial tuberosity, lesser trochanter, and symphysis pubis (level IV). In coronal planes, sections that lied parallel to the sacral promontory were taken at the level of the greater sciatic foramen, ischial spine and piriformis muscle (dorsally), and at the level of the symphysis pubis and arcuate ligament (ventrally). Also, midsagittal key images were analyzed to display the lumina of the organs and their relative positions with respect to the symphysis pubis (anteriorly) and to sacrococcygeal bony vertebrae (posteriorly); finally, sections parallel to the ischial rami, 2 cm on the right and on the left of the midline were obtained to depict the neurovascular bundle of the Alcock's canal.

RESULTS

With the method above described, an average number of a hundred and fifty images per patient were obtained which allowed detailed step-by-step analysis of the nerve course anatomy in the pelvis from all patients regardless of the symptom's presentation and pathology, as follows:

Axial images. T2-weighted images depicting each level of pudendal nerve course are shown in Figure 1 a,b,c,d.

At level I (a) the lumbosacral plexus is visualized just in front of the ventral aspect of the piriformis muscle which spans the aperture of the greater sciatic foramen; the nerve itself can be easily recognized as a number of "dark dots" against the hyperintense signal of the endopelvic fat. More laterally, a portion of the gluteal nerve can also be seen within the narrow fat recess bounded by the gluteus minimus muscle anteriorly and by gluteus medius muscle, posteriorly. Bony landmarks include the ischial margin and the ventral aspect of the sacrum. A section slightly lower than (a), at level II (b) shows the sciatic nerve still in close contact with the piriformis muscle as it exits the pelvis after overcoming the sacrospinous ligament. In this section the nerve is seen to assume a more elongated oval shape of low-intermediate signal intensity becoming almost iso-intense with the surrounding structures, making it more difficult to recognize. At level III (c) the nerve resumes both its vertical orientation and its dark dots appearance while descending into the narrow space between the posterior aspect of the inferior gemellus muscle and the anterior margin of the gluteal crease. More ventrally, the femoral nerve can be seen in close contact with the anterior aspect of the psoas muscle. Also visible at this level is the sacrotuberous ligament as a dark hypointense rectangular structure just in front of the gluteus maximus muscle. At level IV (d) the sciatic nerve descends through the narrow ischial tunnel between the posterior surface of the quadratus femoris muscle and the gluteus maximus muscle without contacting the obturator internus tendon. A modified axial oblique image taken at the same level is occasionally useful to display at best the distal branching area at the outlet of the Alcock's canal.

Coronal Images. T2-weighted coronal images that lie parallel to the table of the diagnostic unit at the level of the greater sciatic foramen (Figure 2a, b), show that in this orientation the section plane is roughly parallel to the fibers of distal lumbosacral spinal nerves. On the more posterior images the coccygeal part of the levator ani muscle is depicted on either side of the rectum; this section plane is ideal to display the anatomy of right and left nerve sacral roots as they exit the spine travelling in essentially linear fashion for evidence of any distortion, narrowing and focal hyperintensity, as well as regional impingement. A series of vascular and neural structures are seen along their fiber direction. At the level of the ischial spine (a), the iliococcygeus muscle and the sacrospinous/sacrotuberous ligament complex is seen. Other visible structures include the piriformis muscle which spans the space of the greater sciatic foramen, and a linear fascicle pattern of low intensity signal consistent with the sciatic nerve and its tibial and peroneal subdivision. On more anterior images (b), at the level of the urogenital diaphragm, the bladder base, urethra and distal vagina are seen. Even more ventrally, the arcuate ligament becomes visible just below the symphysis pubis.

Axial and Coronal oblique Images. Sections obtained in these planes with the STIR pulse sequence are needed to detect any abnormal hyperintense signal intensity from within the nerve while suppressing that of the surrounding fat. Most common findings observed in the patient group

TABLE 1. – Protocol for Pudendal nerve Imaging by Philips Achieva MR scanner (1.5 T) and XL TORSO coil.

Series 1 3 Plane Localizer	**Series 2 Sagittal**	**Series 3 Coronal**	**Series 4 Axial**	**Series 5 Oblique Axial**	**Series 6 Oblique Coronal**	**Series 7 Oblique Sagittal**
TR (ms)	4435	3649	4656	10259	5471	5471
TE (ms)	100	100	100	80	80	80
TI (ms)				170	170	170
BW	299,5	164	173	262	254	254
ETL	29	20	20	17	17	17
NEX	2	2	2	3	3	3
FOV (FH-RL-AP)	250*250*177	250*250*138	250*250*173	260*260*134	250*250*-112	250*250*112
Matrix	560 (256*246)	560 (264*270)	560 (264*270)	336 (192*181)	320 (160*153)	336 (160*153)
Slice/gap	3,70 – 0,13	3,5 – 0,35	3,5 – 0,35	3,5 - 1	3 - 0,5	3 – 0,5
Flip angle	90	90	90			
Pulse Sequence	FSE	FSE	FSE	BBDIR STIR	BBDIR STIR	STIR
Fold over direction	F → H	R → L	R → L	R → L	R → L	A → P

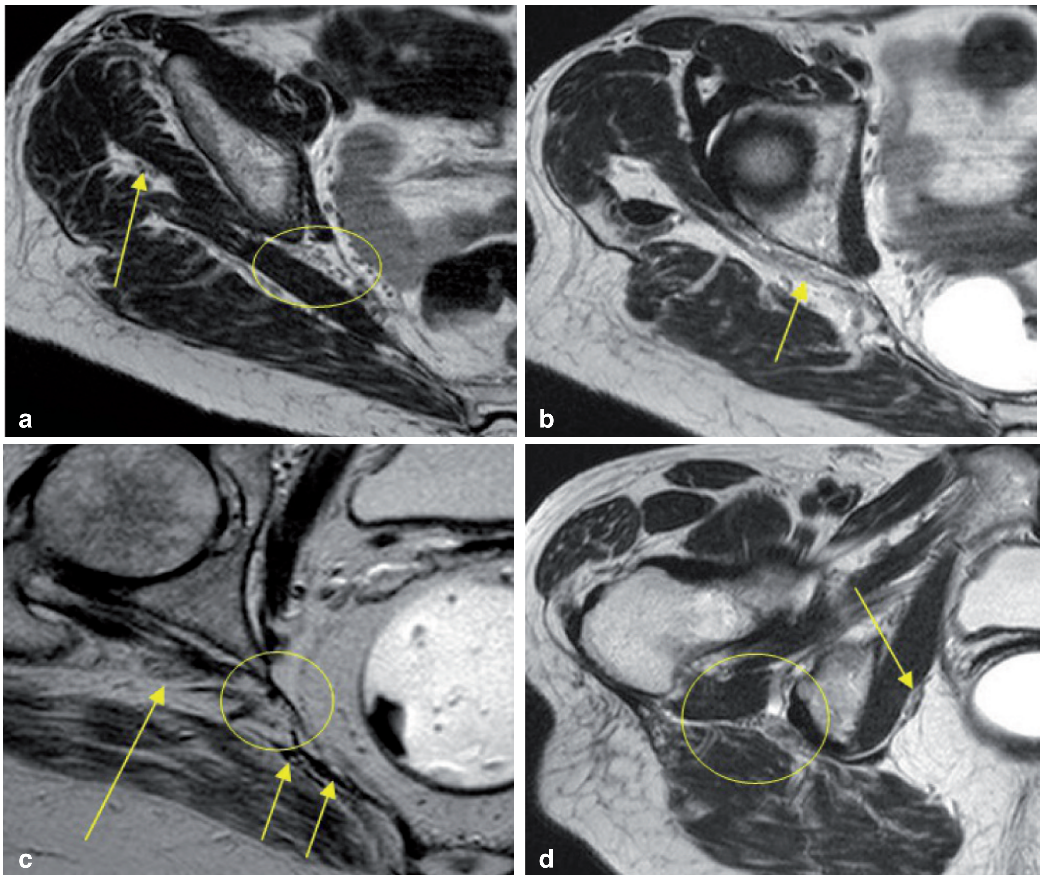


Figure 1. – Standard axial T2-W MR image (a) of the right half of the pelvis taken at the level of the ischial margin (level I) showing the "dark dots" appearance of the lumbosacral nerve (circle) just anteriorly to the piriformis muscle. The gluteal nerve (arrow) is also seen between the gluteus medius muscle, anteriorly and the gluteus maximus muscle, posteriorly. A section obtained at the level of the ischial spine (b) and greater sciatic foramen (level II) shows the nerve after exiting the pelvic cavity (arrow) as an indistinct, elongated dark structure almost iso-intense with the piriformis tendon. A section obtained at the level of the acetabulum (c) and head of femur (level III) shows the sciatic nerve (long arrow) as a more oval-shaped structure resuming its dark dots appearance. At this level the pudendal nerve reenters the pelvic cavity (circle) after encircling below the space between the sacrospinous and the sacrotuberous ligament (double short arrows). A section taken at the level of the ischial tuberosity (d) consistent with level IV shows the sciatic nerve travelling in its narrowest space (circle) between the quadratus femoris muscle and the gluteal crease. The neurovascular bundle in the Alcock's canal (arrow) is seen as a dark hypointense linear stripe just medial to the inner border of the obturator internus muscle.

with suspected or proven pudendal neuropathy included nerve image hyperintensity showing fascicular-level swelling or disruption, focal enlargement, mechanical distortion and kinking, entrapment within area of fibrofatty degeneration of adjacent muscles, and compression by prominent vessels (Figure 3). Unfortunately, however, the brightest structure in the STIR images was that of vessels with flowing blood and only prior identification of the nerve course anatomy by TSE T2-weighted sequences (Figure 4) allowed proper detection and location of nerve pathology in singular cases.

Sagittal Images. While midline sections were useful to display both the lumina of the organs and their relative positions, images taken approximately 2 cm right and left to the midline depicted at best the sacrotuberous ligament (Figure 5), the iliococcygeal muscle, the obturator internus muscle and the lateral extension of the perineal membrane. Sagittal oblique sections obtained parallel to the inferior ischiopubic rami on either side using the STIR pulse sequences are essential to depict the neurovascular bundle of the pudendal nerve contained in the sheath of the obturator fascia termed the pudendal canal (Figure 6).

DISCUSSION

From the anatomical point of view,[11] nerves are known to be a mixture of different tissues, including protein-laden axoplasmic water, myelin, fatty interfascicular epineurium, and connective tissues. Magnetic resonance imaging (MRI), thanks to its inherent superior contrast and spatial resolution, provides a unique opportunity to examine the totality of soft tissue structures in the pelvis, including the pudendal nerve along its entire course. In the past, the practical application of MRI of peripheral nerves has been limited by technical difficulties in obtaining good image contrast between nerve and neighboring tissues. Recently, however , the identification of peripheral nerves such as the pudendal nerve has become technically possible in the T2-weighted neurography images which depict the low-protein endoneurial fluid that lies within the privileged space of the endoneurium, bathes the axons and has a bulk proximal to distal flow along the nerve. Clinically, direct imaging of the lumbar/sacral spinal nerves, proximal sciatic nerve and pudendal branches can help resolve the diagnosis in many disease status including degenerative disease, entrapments , adhesions in many patients with chronic pelvic pain syndromes. Obviously, of utmost importance for image interpretation is a reappraisal of pudendal nerve topographic anatomy[12,13] down the pelvis, as follows: the pudendal nerve originates in the sacral plexus from the ventral rami of the second, third and fourth sacral nerves immediately above the upper border of the sacrotuberous ligament and the ischiococcygeus muscle. From here, the nerve passes between the piriformis muscle and ischiococ-

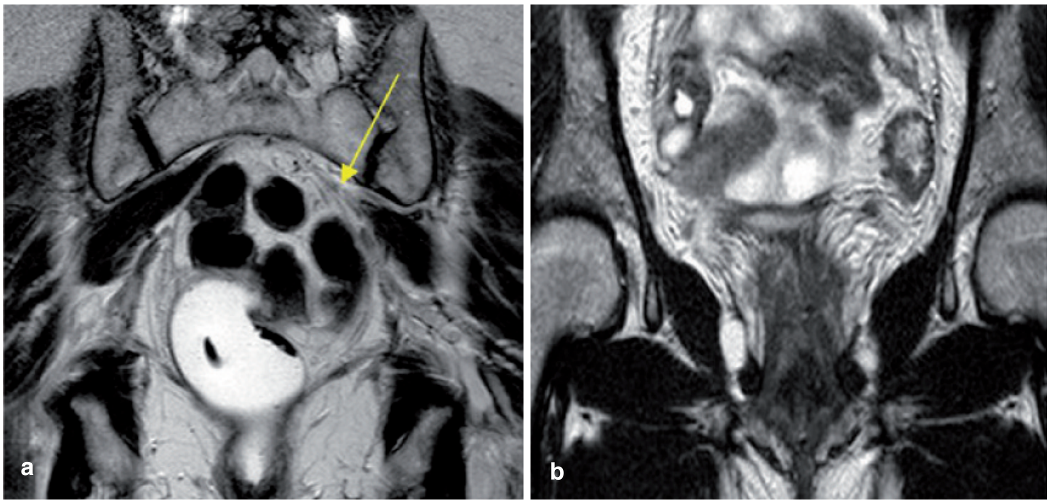


Figure 2. – Coronal T2-W MR image obtained in the posterior planes at the level of the greater sciatic foramen and sacral promontory (a): note the asymmetric hyperintense appearance of the left piriformis muscle (arrow) consistent with fibrofatty degenearation which was thought to be responsible for sciatic nerve and pudendal nerve entrapment syndrome in this 39-year old woman with history of intense bike activity. Coronal image obtained slightly anteriorly to a at the level of the acetabular fossa and obturator foramen (b) shows at best the appearance of the obturator internus and externus muscle and the pubococcygeal muscles on either side of the vagina, together with the structure of the perineal membrane.

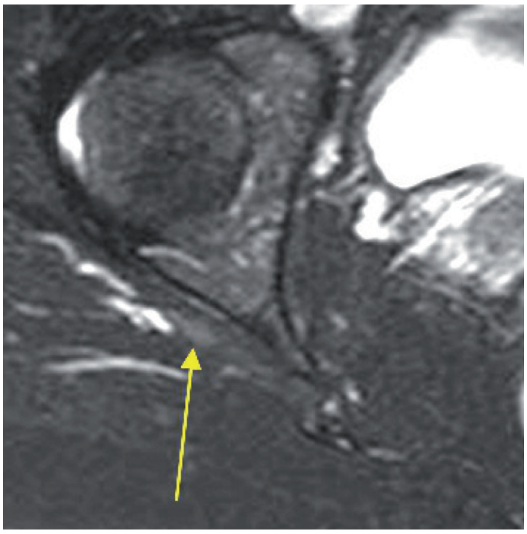


Figure 3. – Axial STIR MR image showing the close relationship of the sciatic nerve (arrow) with prominent hyperintense vessels: note that the flowing blood vessels are seen as the brightest structures in the image making the detection of nerve somewhat difficult.

cygeus muscle and leaves the pelvis through the lower part of the greater sciatic foramen; then, it enters the gluteal region and joins the pudendal artery and vein, which both accompany the nerve for the remainder of its course. This neurovascular bundle then travels inferiorly and posteriorly in the fixed space between the sacrospinous (anterior) and the sacrotuberous (posterior) ligaments. At this point, the neurovascular bundle wraps around the posterior surface of the sacrospinous ligament and turns anteriorly and laterally re-entering the pelvis through the lesser sciatic foramen; the nerve then accompanies the internal pudendal vessels upwards and forwards along the lateral wall of the ischiorectal fossa, being contained in a sheath of the obturator fascia termed the pudendal canal (Alcock's canal). Three major branches are given off from the pudendal nerve, as follows: the first branch is the *levator branch* followed by the inferior anal nerve or rectal nerve. Its origin from the pudendal nerve is highly variable and may occur at the level of sacrospinous ligament, prior to entry into Alcock's canal, in the canal itself, or after it exits the canal. The rectal branch crosses the ischioanal fossa to innervate the external anal sphincter, the distal anal canal, and the circum-anal skin. The second branch is the *perineal nerve*, which runs inferiorly in the Alcock's canal. It divides into posterior labial/scrotal (sensory) branches and muscular (motor) branches. The posterior labial/scrotal branches travel in the lateral part of urogenital triangle and supply the skin of the labia majora or scrotum. In females, the posterior labial branches also supply sensory fibers to the skin of the lower vagina. Muscular branches of the perineal nerve supply the superficial transverse perineal muscle, bulbospongiosus, ischiocavernosus, deep transverse perineal muscle, sphincter urethrae and the anterior part of the external anal sphincter, and levator ani. The third branch, *dorsal clitoral/penile nerve*, emerges from underneath the inferior ramus of the pubic bone and penetrates into the urogenital membrane. It then turns sharply cephalad, travelling between the ischio cavernosus muscle and inferior margin of the inferior pubic ramus. The nerve then makes a very sharp anterior turn entering the clitoris. It is here where the nerve begins dividing into its smaller terminal branches.

From the technical point of view, the role of the radiologist is two-fold, as follows: (a) to visualize the nerve in areas of fixation, acute flexion and narrow canals; and (b) to render the nerve as the brightest object in the image. With regard to the first point, the present study confirms that clarification of the nerve course anatomy is based on proper acquisition and interpretation of a standard set of key images, namely those obtained with TSE T2-weighted pulse sequences in the axial plane (Table 2). Additional information come from coronal orthogonal planes combined with STIR images obtained in the oblique axial, coronal and sagittal planes. With the exception of STIR images obtained on both sides parallel to the ischial tuberosities and the anterior ischio-pubic ramus to improve visualization of the Alcock's canal, acquisition in the TSE T2-weighted sagittal plane was only occasionally found useful to clarify the relationship of the pudendal nerve with the sacrospinous ligament and gluteus maximum muscle.

With regard to the second point, the question is more difficult to deal with and some limitations do exist. More particularly, at MRI, it is possible, by applying a chemical-

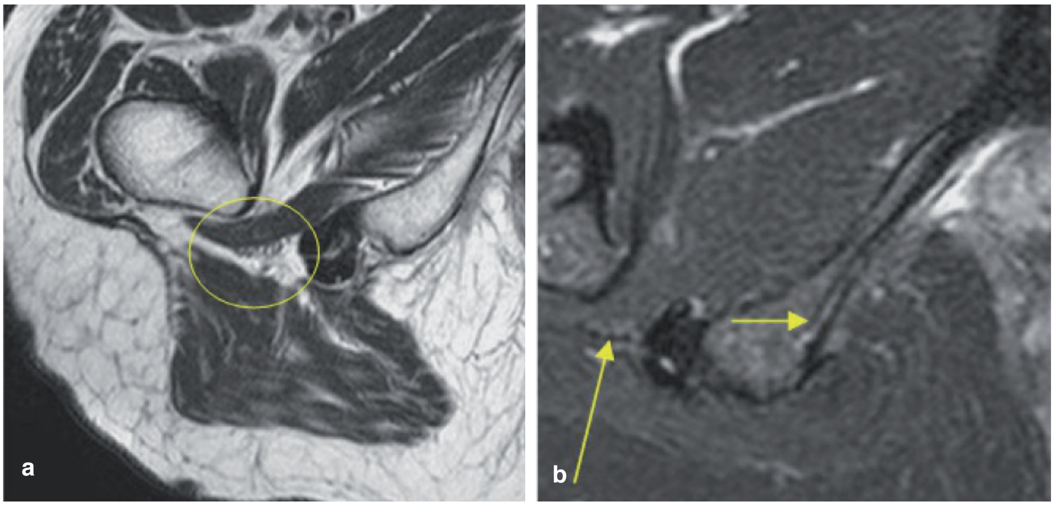


Figure 4. – The "dark dots" appearance of the sciatic nerve (a) in the preliminary "anatomic" axial T2-W images (circle) allows for adequate detection and interpretation of the slightly hyperintense fascicular pattern (long arrow) seen in the corresponding STIR images (b) which involves also the pudendal nerve in the Alcock's canal (short arrow).

shift selective pulse, to suppress much of fat signal around and from within nerves. Then, by selecting an appropriate echo time (around 90 milliseconds), a T2-weighting can be achieved resulting in suppression of fat signal, leaving most of the signal from the endoneurial fluid intact. Use of conventional (T2-weighted and STIR) neurography techniques, however, tends to leave vessel images bright too, making many small nerves that also appear in the images difficult to be distinguished. As such, in order to create the conditions that allow the generation of selective nerve images, a method should also be adopted to suppress bright fluid signal from flowing blood, also called *Black Blood techniques*,[14-16] whose effect has to do with replacement of blood in the imaging slice during the echo time (TE).

In order to obtain true black blood images ECG-gated double inversion recovery fast spin echo sequences have been reported. These employ a nonselective inversion pulse followed by a slice-selective pulse and fast spin echo readout after an inversion time TI. The inversion time is chosen to null the signal of blood, so that blood flowing into the imaging slice during TI appears dark due to the "wash-out" effect for flowing blood. Resulting images of this " signal nulling", in combination with a long "wash-in"/"wash-out" period, will display very dark blood enabling improved visualization of nerves. At our Institution this technique has not been fully implemented yet and needs more extensive research to be done before proper assessment of results.

Whatever the pulse sequence used, however, the radiologist must be aware of the anatomical basis for potential pudendal nerve compression in the following several locations along its course: as the first, the nerve can be compressed as it emerges from underneath the piriformis muscle; as the second, and most common, it may be compressed as it travels between the sacrospinous and sacrotuberous ligament; the third area of compression is Alcock's canal; the fourth is where the dorsal nerve of the clitoris/penis emerges from underneath the inferior ramus of the pubic bone and turns cephalad. Finally, compression can occur when the dorsal nerve of the clitoris/penis makes an anterior turn to enter the clitoris/penis. Identification of the presence or absence of pudendal bundle hyperintensity

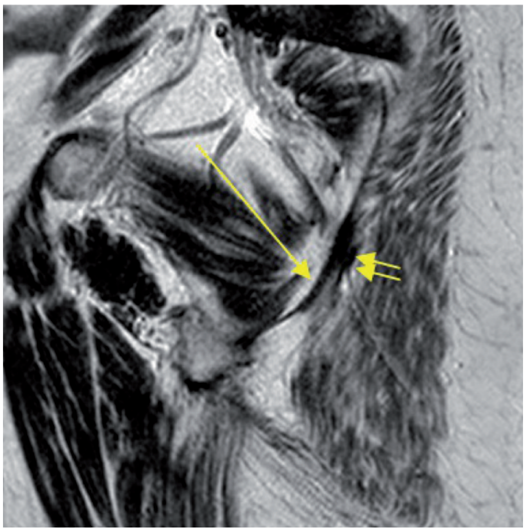


Figure 5. – Sagittal T2-W image taken almost 2 cm right of the midline at the level of the ischial spine, showing the sacrotuberous ligament (long arrow) encroaching the sacrospinous ligament (double short arrows). Note also the obturator internus muscle, anteriorly and the gluteus maximus muscle, posteriorly.

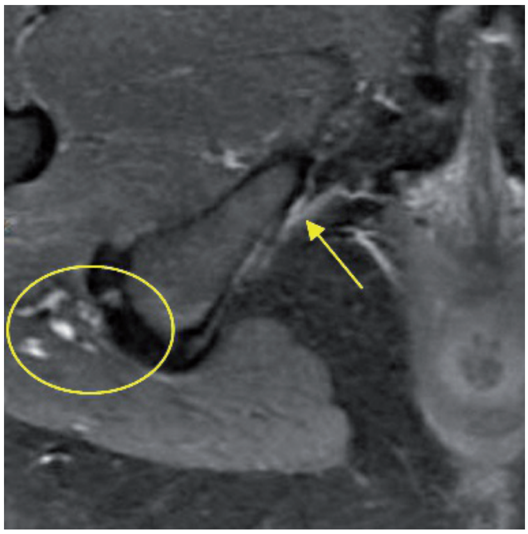
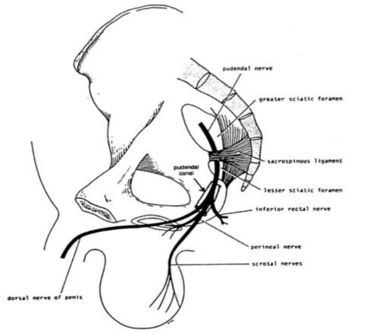


Figure 6. – Axial oblique STIR image showing at best the high signal intensity from the assons of the sciatic nerve in close contact with prominent vessels (circle) and clear hyperintensity along the pudendal nerve consistent with irritation and edema (arrow point at vessels).

TABLE 2. – Anatomic landmarks and pudendal nerve pathway reconstruction by level at axial MR imaging.



Level	Bone	Muscle	Tendon/ ligaments
I	Ischial margin Greater foramen sacrum	Gluteus minimus medium, maximus(*) piriformis	
II	Ischial spine Coccyx, roof of acetabular fossa	Coccygeus Obturator internus	Sacrospinous Sacrotuberous Piriformis
III	head, neck, trochanter of femur, acetabulum	Pettineus, gemellus obturator int/ext	Sacrotuberous
IV	Ischial tuberosity Symphysis pubis	Quadratus femoris	Anococcygeal Arcuate

Note (*) The gluteus maximus muscle is visible from level I to level IV

consistent with nerve irritation by the radiologist, however, is only one factor contributing to the success of the examination and to the development of a well-run outpatient imaging centre devoted to the diagnosis of pudendal nerve pathology. Of utmost importance is also a perfect training and cooperation with both the technical staff and booking service, together with efficient nursing. The latter aspect should be emphasized since much depends on the nurse in charge who is responsible for the coordination of patient movement within the diagnostic centre, administration of notes, and collection of prior reports; the nurses should understand the nature of the disease encountered, look after equipment and contrast materials to be administered, be able to position patients correctly and reassure them about the painfulness nature of the procedure explaining in advance the sequence of the examination. Finally, a strict feedback communication with the referring physician for further investigation requests will play a critical role in patient management.

CONCLUSION

MRI neurography is the direct imaging of nerves in the body using special modifications of standard MR technique to obtain a true detailed image of a nerve in which the resonance signal arises from the nerve itself rather than from surrounding tissues or from fat in the nerve lining. Because of the intraneural source of the image signal, the technique provides a medically useful set of information about the internal state of the nerve such as the presence of irritation, nerve swelling due to edema, compression, pinch or injury. A limitation of the technique is that structures close to the nerves, such as blood vessels, have similar signal intensity. In the case of sciatic nerve and pudendal nerve, various combinations of orthogonal and oblique sagittal, coronal and axial images together with fat-suppressed and blood-suppressed pulse sequences are recommended to detect and localize lesions to specific nerve roots or to more distal location. While image interpretation by the radiologist can be time consuming and precise localization of disease difficult, a more and more extensive use of the technique is highly desirable in order to change radically the diagnosis of pelvic floor dysfunction of neurological origin.

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