Selective MR neurography–guided lumbosacral plexus perineural injections: techniques, targets, and territories

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Abstract

The T12 to S4 spinal nerves form the lumbosacral plexus in the retroperitoneum, providing sensory and motor innervation to the pelvis and lower extremities. The lumbosacral plexus has a wide range of anatomic variations and interchange of fibers between nerve anastomoses. Neuropathies of the lumbosacral plexus cause a broad spectrum of complex pelvic and lower extremity pain syndromes, which can be challenging to diagnose and treat successfully. In their workup, selective nerve blocks are employed to test the hypothesis that a lumbosacral plexus nerve contributes to a suspected pelvic and extremity pain syndrome, whereas therapeutic perineural injections aim to alleviate pain and paresthesia symptoms. While the sciatic and femoral nerves are large in caliber, the iliohypogastric and ilioinguinal, genitofemoral, lateral femoral cutaneous, anterior femoral cutaneous, posterior femoral cutaneous, obturator, and pudendal nerves are small, measuring a few millimeters in diameter and have a wide range of anatomic variants. Due to their minuteness, direct visualization of the smaller lumbosacral plexus branches can be difficult during selective nerve blocks, particularly in deeper pelvic locations or larger patients. In this setting, the high spatial and contrast resolution of interventional MR neurography guidance benefits nerve visualization and targeting, needle placement, and visualization of perineural injectant distribution, providing a highly accurate alternative to more commonly used ultrasonography, fluoroscopy, and computed tomography guidance for perineural injections. This article offers a practical guide for MR neurography–guided lumbosacral plexus perineural injections, including interventional setup, pulse sequence protocols, lumbosacral plexus MR neurography anatomy, anatomic variations, and injection targets.

Keywords Lumbosacral plexus · MRI guided · Nerve block · Neurography · Interventional MRI

Introduction

The T12 to S4 spinal nerves form the lumbosacral plexus. After exiting the spinal neural foramina, the lumbar and sacral spinal nerves form the lumbosacral plexus network in the lumbar and pelvic retroperitoneum (Table 1). The individual nerves formed by the network provide motor and sensory innervation to the pelvis and lower extremities. The lumbosacral plexus has a wide range of anatomic variations and interchange of fibers between nerve anastomoses. Neuropathies of the lumbosacral plexus cause a spectrum of complex pelvic and lower extremity pain syndromes, which can be challenging to diagnose clinically and treat successfully. In their workup, selective nerve blocks are employed to test the hypothesis that a lumbosacral plexus nerve contributes to a suspected pelvic and extremity pain syndrome, whereas therapeutic perineural injections aim to alleviate pain and paresthesia symptoms.

Selective perineural injections of the entire nerve are important for a valid pain response for diagnostic nerve blocks. Here, selectivity refers to solitary and complete anesthesia of the target nerve without concomitant blockage of surrounding nerves, for example, through the spread of local anesthetic or blocking a few but not all individual sub-branches in nerves with variant anatomic branching. Image

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Table 1 Lumbosacral plexus nerves

Lumbosacral plexus nerve	Spinal nerve contributions
Iliohypogastric nerve	L1 ($\pm$ T12 and T11)
Ilioinguinal nerve	L1 ($\pm$ T12 and T11)
Genitofemoral nerve	L1 and L2
Obturator nerve	L2 to L4
Femoral nerve and anterior femoral cutaneous nerve	L2 to L4
Lateral femoral cutaneous nerve	L2 and L3
Sciatic nerve	L4 to S3
Posterior femoral cutaneous nerve	S1 to S3
Pudendal nerve	S2 to S4
Superior gluteal nerve	L4 to S1
Inferior gluteal nerve	L4 to S1

Fig. 1 Interventional MRI suite. The interventional MRI suite includes a wide-bore 3.0 T MRI scanner (Magnetom Skyra, Siemens Healthcare), an MRI-conditional in-room monitor (white arrow) for scanner control and image display, and an interventional MRI coil (black arrow)

guidance is commonly employed to increase the selectivity and validity of diagnostic lumbosacral plexus nerve blocks. For the lumbosacral plexus, selective nerve blocks can often be achieved proximally in deeper retroperitoneal locations, where the individual nerves are further apart than in the pelvis and groin.

While the sciatic and femoral nerves are large in caliber, the iliohypogastric and ilioinguinal, genitofemoral, lateral femoral cutaneous, anterior femoral cutaneous, posterior femoral cutaneous, obturator, and pudendal are small, measuring a few millimeters in diameter and have a wide range of anatomic variants. Due to their minuteness, direct visualization of the smaller lumbosacral plexus branches can be difficult during selective nerve blocks, particularly in deeper pelvic locations or larger patients [1, 2]. In this setting, MR neurography guidance (interventional MR neurography) provides a highly accurate alternative to more commonly used ultrasonography, fluoroscopy, and computed tomography guidance for perineural injections. Interventional MR neurography combines diagnostic high-resolution MR neurography techniques and interventional procedure guidance [3]. Similar to diagnostic MR neurography, MR neurography image guidance provides high spatial and contrast resolution [4], which benefits the visualization of the small lumbosacral plexus nerves for mapping their course from the spinal origin to the periphery, identifying anatomic variations in the course, localizing focal nerve abnormalities, visualization of needle placement, monitoring perineural injections, and visualizing injectant without the use of contrast agents. Another advantage of interventional MR neurography is the absence of ionizing radiation.

This article offers a practical guide for MR neurography–guided lumbosacral plexus perineural injections, including interventional setup, pulse sequence protocols, lumbosacral plexus MR neurography anatomy, anatomic variations, and injection targets.

Interventional MR neurography technique

MR neurography–guided lumbosacral plexus nerve blocks can be performed with any clinical 1.5 T and 3.0 T wide-bore MRI scanners. However, 3.0 T field strength is beneficial because higher signal-to-noise ratios translate into higher spatial resolution, benefiting improved identification of smaller nerves, higher temporal resolution, and faster procedural image acquisition [5–7]. While new-generation 0.55 T scanners offer in-bore needle guidance for real-time MRI-guided interventions [8], the bores of most 1.5 and 3.0 T MRI scanners are too long for needle guidance inside the MRI bore. However, laser positioning systems of the MRI scanner and electronic table movements enable convenient in- and out-of-bore patient movements, similar to workflows with narrow-bore CT scanners.

The safety procedures and precautions are similar to diagnostic MR studies. MR neurography–guided injections must be performed with specially manufactured MR conditional needles, which are commercially available worldwide in the typically used size range. The MRI scanner should have a certified MR-compatible in-room monitor and mousepad through which the MRI scanner can be operated within the room (Fig. 1). MR neurography–guided perineural injections typically require a minimum of one operator and one technologist.

MR neurography–guided lumbosacral plexus injections may be performed in prone, supine, or individually adjusted oblique patient positions. Combining table coil elements and surface coils enables complete MR neurography visualization of the pelvis [3, 9], whereas using

surface coils only without table elements will result in a partial pelvic field-of-view. The choice of surface coil arrangement and patient positioning depends on the location of the target nerve and the patient body habitus.

At the beginning of a procedure, acquiring a large field-of-view non-fat-suppressed high-resolution proton density-weighted turbo spin echo pulse sequence using diagnostic 18- to 30-channel surface coils is useful for mapping the lumbosacral plexus nerves and target identification (Table 2, Sequence 1). The superior extent of this pulse sequence should be T12-L1 for upper lumbosacral plexus nerves and the iliac crest for lower lumbosacral plexus nerves. The inferior extent should include the entire pelvic floor for pelvic nerves and proximal thighs for lumbosacral plexus nerves extending to the site. Such a large field-of-view extended stack of planning images is advantageous for tracing nerves from their origin to the target territory, including recognizing anatomic variations, multiple branches, and differentiation from smaller vessels. Following the acquisition of the planning images, the diagnostic surface coil can be exchanged for an interventional flexible surface coil with a central opening suitable for sterile draping of the interventional site and passing through commercially available interventional needles (Fig. 1).

We typically use 20G and 22G MR conditional injection needles at 5 to 20 cm lengths, depending on patient size and depth of nerve location. Rapid turbo spin echo-based pulse sequences with an acquisition time of 1 to 4 s can be used for efficient needle visualization during placement and visualization of the injectant based on their intrinsic long T2 properties without the need for gadolinium contrast agents (Table 2, sequences 2–4). Conventional turbo spin echo and half-Fourier acquisition single-shot turbo spin echo imaging pulse sequences can be shortened to a few seconds of acquisition time by applying parallel imaging and long compacted echo trains [10–12]. Half-Fourier acquisition single-shot turbo spin echo imaging pulse sequences provide additional acceleration and inertia to patient motion, as all slice signals are acquired in a single echo train (Table 2). MRI conditional needles are light and typically stay in place at approximately 1-in. insertion depth during scanning. For more superficial nerve targets, needles may be supported with towels to stay in place during image acquisition.

Like MRI of metallic orthopedic implants, all interventional pulse sequences are optimized to visualize the metallic MR conditional needles using high receiver bandwidths [13]. While typically not needed when using modern MR conditional injection needles, rapid metal artifact reduction pulse sequences, such as compressed sensing SEMAC (Slice Encoding for Metal Artifact Correction), can be applied to reduce further metal artifacts [14, 15]. Experimental testing has demonstrated the safe use of combined axial needle paths and optimized interventional pulse sequences with minimized risk of needle heating [16, 17].

After successful needle placement adjacent to the target nerve, we typically inject 1–3 mL of 1% ropivacaine hydrochloride perineurally, depending on body habitus and perineural flow pattern [18]. The injection volume of 1 to

Table 2 Interventional 3 T MRI protocol for MR neurography–guided perineural injections

Number	1	2	3	4	5
Sequence type	Two-dimensional turbo spin echo	Two-dimensional turbo spin echo	Half-Fourier acquisition single-shot turbo spin-echo	Half-Fourier acquisition single-shot turbo spin-echo	Half-Fourier acquisition single-shot turbo spin-echo
Weighting	Intermediate	Intermediate	T2	T2	Short-tau inversion recovery (STIR)
Orientation	Axial	Axial and/or sagittal	Axial and/or sagittal	Axial and/or sagittal	Axial and/or sagittal
Repetition time (ms)	7110	2500	2290	3440	3660
Echo time (ms)	28	14	89	120	90
Inversion time (ms)	—	—	—	—	220
Echo train length	25	24	159	162	157
Slice thickness (mm)	2	2	4	3	4
Gap (mm)	0	0	0	0	0
Number of slices (average-This is dependent on body habitus to ensure adequate coverage)	51	5	1	3	3
Number of excitations	1	1	1	1	1
Field of view (mm)	350×252	350×252	350×317	350×328	350×328
Base resolution (pixel)	576	512	384	384	384
Phase resolution (%)	75	75	75	75	75
Receiver bandwidth (Hz)	300	490	480	305	205
Acquisition time	4 min 20 s	12 s	2 s	12 s	23 s

3 mL depends on the location, size of the target nerve, and the vicinity and risk of inadvertent spread to nearby nerves that could confound the pain response. For example, we use 1 mL for blocks of the small anterior femoral cutaneous nerve, whereas 3 mL for pudendal nerve blocks in Alcock's canal to achieve anterior spread along the intra-canalicular pudendal nerve. The high potency of 1% ropivacaine hydrochloride aids in complete nerve blocks with small injection volumes, which prevents the spread to and concomitant blocks of nearby nerves. Compared to bupivacaine hydrochloride, ropivacaine hydrochloride has a favorable neurotoxicity profile. Ropivacaine hydrochloride has a half-life of 1.5–4 h and a duration of action of up to 8–12 h, enabling a longer pain assessment period after the blocks. Rapid, highly T2-weighted HASTE pulse sequences are exquisitely well suited for visualizing the spread of injectants without the need for gadolinium contrast agents (Table 2). Particulate and non-particulate steroids may be added to the injections for therapeutic benefits.

In our experience, the complication rate of MRI-guided perineural injections is low. In performing over 2000 MRI-guided perineural injections over the past 10 years, we did not encounter a major complication requiring an elevated care level. Minor complications included small hematomas with less than 0.2% incidence and less than 0.1% vasovagal reactions. We did not observe injection-related infections. Fast pulse HASTE sequences, which can be acquired within one second, substantially limit motion artifacts, posing much less of a practical problem than diagnostic MRI. Needle placements and subsequent perineural injections have a high success rate of over 95%. MRI guidance is especially suitable for obese patients that fit the dimensions and limits of the MRI scanner, as adipose tissue produces high MRI signal on proton density and T2-weighted MR images, contrasting target nerves exquisitely well. MRI conditional injection needles are available in a broad range of widths and lengths of up to 20 cm, suitable for reaching any of the described nerve targets. Similar to CT guidance, a paucity of fatty tissues in very thin or cachectic patients may pose challenges in identifying certain nerves.

Patient selection

Common causes of lumbar plexus neuropathies include trauma (e.g., repetitive trauma such as seen from cycling, direct trauma, iatrogenic trauma during herniorrhaphy), post-surgical scarring, tumors, compression, adhesions, and congenital slings around the nerves. However, neuropathies are commonly idiopathic. Many patients present with normal MRI and MR neurography findings in which selective nerve blocks can be particularly useful in identifying a suspected nerve as a pain generator.

The clinical presentation can be grouped into predominantly motor, sensory, or mixed. Findings may be unilateral or bilateral, depending on the underlying cause. The decision for MR neurography–guided perineural injections is best made by a multidisciplinary team, including peripheral neurosurgeons, plastic surgeons, general surgeons, neurologists, anesthesiologists, radiologists, and others. Similarly, team reviews of the perineural blocks and pain response are useful for judging their validity and treatment decision-making [19].

Common indications for MR neurography–guided lumbosacral plexus injections include confirmation of the clinical diagnosis before more invasive treatments (e.g., surgical neurectomy), discrepancy between the location of abnormalities depicted on imaging with the clinical symptoms, allergy to iodinated contrast agents, normal MR Neurography findings despite patient-reported specific symptoms and findings confirmed on clinical examination, failure or partial response to conservative therapies, contraindications to surgery and more invasive procedures for pain management (e.g., neuromodulation), postoperative pain limiting recovery and rehabilitation, and contraindications or poor response to oral therapies [20, 21].

Contraindications to MR-guided lumbosacral plexus interventions include MRI contraindications. Relative contraindications include infections at the injection site or trajectory, allergy to any medications used for the procedures, anatomy-related issues precluding safe access to the region of interest, bleeding disorders, and coagulopathy [2, 22].

Pre- and post-procedural care

All MRI neurography–guided perineural injections are outpatient procedures. We admit all patients into pre-and post-anesthesia care units for the day, which provides a space for the procedure team to meet the patient, provide consent, observation, and, importantly, for pre- and post-procedure pain response assessments and documentation [3].

Unrelated to the image guidance technique used, perineural injections are best performed under local anesthesia only. Most MR neurography–guided perineural injections can be performed within 20 to 30 min of table time, similar to our CT-guided perineural nerve block times. We typically reserve a 1-h slot for an MRI-guided perineural injection. Intravenous sedation drugs may be used in select cases but may interfere with obtaining a valid pain response after a perineural injection block. We prefer performing the procedures with local anesthesia only, which is possible in greater than 90% and successful in greater than 95%. Preprocedural counseling of patients and a comprehensive informed consent process, using schematics and illustrations, is time

well spent to prepare patients appropriately for smooth procedures.

Before and after the procedure, symptom intensity may be quantified with the use of a standard 11-point numerical analog scale (NAS) ranging from 0/10 (no discomfort) to 10/10 (worst imaginable discomfort) after 5–15 min of performing typically aggravating tasks, including walking, sitting, climbing stairs, and hip motion. The location and extent of symptoms may be documented with "symptom maps" drawn on the patient's skin and then transcribed to a standardized anatomical illustration of the thigh for documentation and long-term storage [18].

Diagnostic nerve block principles

The main rationale for using MR neurography guidance is maximizing nerve block validity. The technical effectiveness of a nerve block is based on face validity, which confirms exclusive temporary anesthesia of the area innervated by the nerve. Due to anatomic variability and overlap of areas of innervation, accurate perineural drug delivery to the target structure and absent spread to nearby nerves is paramount. Small volumes of a highly potent local anesthetic, rather than large volume-type field blocks, aid in the exclusive anesthesia of the targeted nerve and avoid false-positive results by minimizing the risk of inadvertent concomitant blocks of nearby nerves. MR neurography–guided injections can directly visualize the nerve and injectant, and clinical assessment following the block adds face validity.

Exclusive, selective lumbosacral nerve blocks can be performed at multiple locations where the target nerve is sufficiently wide apart from other lumbosacral plexus nerves. Often, such locations are proximal in the retroperitoneum. Proximal blocks can have several advantages. Nerve blocks proximal to difficult-to-visualize anatomically variant branching patterns are less prone to incomplete nerve anesthesia than distal blocks, where blocking diverging branches is more challenging. Lastly, as the location of the pain-generating nerve insult or lesion can often not be determined with certainty, proximal nerve blocks are less likely

to produce aberrant pain responses due to blocks distal to a pain-generating nerve segment.

A second block and, optionally, a third block can be used to confirm the reliability of a derived pain response, especially for surgical treatment planning. Various protocols can be employed, including confirmatory blocks, comparative injections, placebo-controlled blocks, and target-control blocks (Table 3). The second and third injections should be performed after the effect of the preceding injection has worn off with certainty. For two-block regimens, the first injection may be performed in the morning and the second in the afternoon; however, we prefer to perform the injections on different days. Non-ionizing image guidance, such as MR neurography, benefits such extended testing protocols.

Face validity and reliability of test results build the foundation for obtaining conclusive pain response results. The accuracy of pelvic injection procedures can be maximized by committing to general testing principles, repetitive testing protocols, an interdisciplinary team approach with checks and balances in place, and meticulous image-guided technique techniques and documentation. MR neurography–guided injections can enhance the accuracy and efficacy of diagnostic and therapeutic lumbosacral plexus nerve blocks.

MR neurography–guided nerve blocks

Iliohypogastric and ilioinguinal nerves

The iliohypogastric and ilioinguinal nerves are part of the lumbar plexus, receiving major contributions from T12 and L1 spinal nerve segment nerves (Table 1). After piercing the psoas muscles together, the iliohypogastric and ilioinguinal nerves often form a common trunk in the retroperitoneal fat, just anterior to the quadratus lumborum muscle, which is an excellent location for an exclusive combined nerve block. After splitting up again and extending laterally, each nerve enters between the transversus abdominis and internus oblique muscles at various locations [23]. Both nerves give motor branches to the transversus abdominis, internal and

Table 3 Diagnostic nerve block protocols to increase diagnostic validity

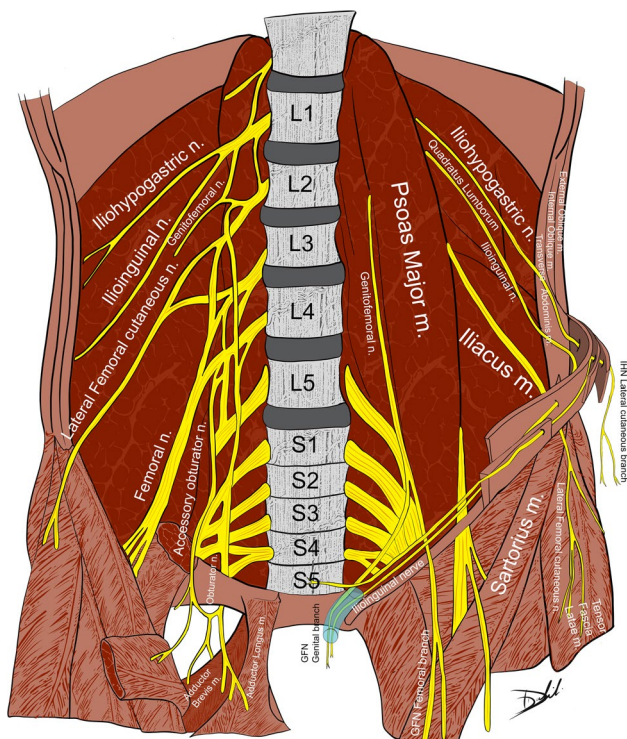| Type	Injectants
Confirmatory block	The same block with the same local anesthetic twice (e.g., preservative-free lidocaine and ropivacaine)
Comparative injections	One block with a short-acting anesthetic (e.g., preservative-free lidocaine) and the other block with a long-acting anesthetic (e.g., preservative-free ropivacaine)
Placebo-controlled block	One block with a placebo (sterile saline) and two blocks with a local anesthetic (e.g., preservative-free lidocaine and ropivacaine)
Target-controlled block	The same anesthetic three times (e.g., preservative-free lidocaine and ropivacaine), but different anatomic targets

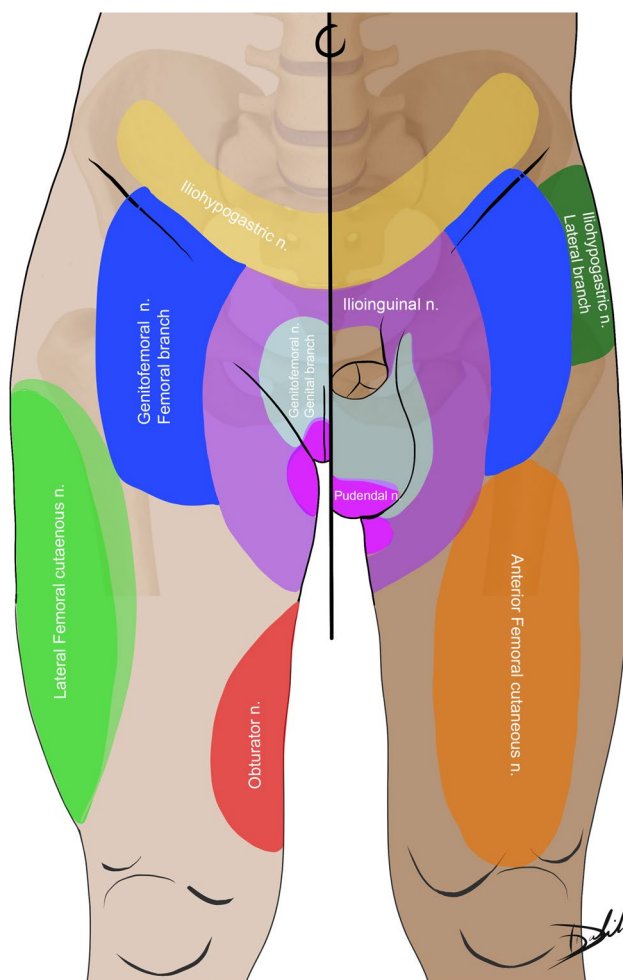external oblique musculature [23, 24], and terminate near the inguinal region.

The iliohypogastric nerve enters the anterior abdominal wall near the anterior iliac crest to innervate the skin overlying the lower abdominal wall, from the level of the umbilicus down to the pubic bone and extending to the upper part of the labia majora in females and the scrotum and penis in males (Figs. 2 and 4). The lateral branch of the iliohypogastric nerve innervates the lateral upper thigh and buttocks region (Figs. 3 and 4).

The ilioinguinal nerve enters the inguinal ring together with the genital branch of the genitofemoral nerve to innervate the skin overlying the lower abdomen (Fig. 2), just above the inguinal ligament, the base of the penis in males and the mons pubis and labia majora in females, and a small area of skin overlying the upper part of the inner thigh (Fig. 3).

Anatomical variability and overlap of sensory distribution have been recognized between the genitofemoral nerve (GFN) and ilioinguinal and Iliohypogastric nerves [24]. Four different types of cutaneous branching patterns were identified: type A, with a dominance of the genitofemoral nerve in the scrotal/labial and the ventromedial thigh region [24]. In type A, the ilioinguinal nerve gives no sensory contribution to these regions (44%). In type B, with a dominance of the ilioinguinal nerve, the
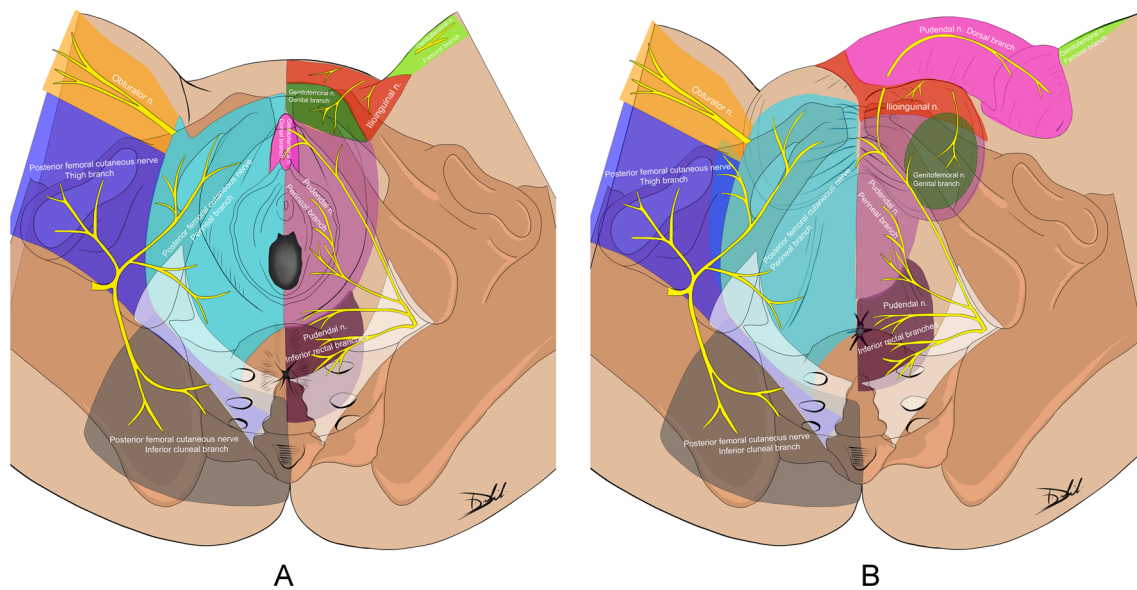

Fig. 3 Typical sensory distribution of the lumbosacral plexus nerves in men and women

genitofemoral nerve shares a branch with the ilioinguinal and gives motor fibers to the cremaster muscle in the inguinal canal but has no sensory branch to the groin (28%). In type C, there is noted dominance of the genitofemoral nerve; the ilioinguinal nerve has sensory branches to the mons pubis and inguinal crease together with an anterior proximal part of the root of the penis or labia majora. The nerve is found to share a branch with the Iliohypogastric nerve (20%). In type D, cutaneous branches emerge from both the ilioinguinal and the genitofemoral nerves. Additionally, the ilioinguinal nerve innervates the mons pubis and inguinal crease together with a very anterior proximal part of the root of the penis or labia majora (8%) [24]. Furthermore, such innervation patterns are only symmetrical in 40% of the population [24].

Clinically, presentations vary in location and size of symptomatic areas but often present with burning sensation along the inner upper thigh and lower parts of the anterior abdominal wall, base of the penis, labia, and perineum.

Fig. 2 Schematic demonstrating the anatomy of the lumbosacral plexus and its relationship to the surrounding structures

Fig. 4 Illustration of the perineal region sensory innervation through the ilioinguinal, obturator, genitofemoral, pudendal, and posterior femoral cutaneous nerves

Ilioinguinal and iliohypogastric blocks may be combined, as innervation patterns and symptoms overlap, and treatments often target both nerves. In the retroperitoneum, selective combined blocks can be performed anterior to the quadratus lumborum muscle using a posterior approach targeting the common trunk as it traverses laterally and caudally (Fig. 5).

Individual selective ilioinguinal and iliohypogastric blocks are more challenging and may only be possible in the retroperitoneum in a subset of patients where the nerves enter the oblique abdominal muscles separately and at different height levels. The iliohypogastric nerve can be blocked selectively, where it enters the oblique abdominal muscles more proximately and superiorly than the ilioinguinal nerve, using posterior, lateral oblique, or anterior oblique needle paths (Fig. 6). Similarly, the ilioinguinal nerve can be blocked selectively medial to the transverse abdominal muscle and distal to the entrance point of the iliohypogastric nerve.

Genitofemoral nerve

The genitofemoral nerve (L1–L2) pierces through the anterior psoas major fascia, typically at the L2-L3 level [3, 25]. Between L3/L4 and L4/L5, the GFN is constantly located anteromedially, whereas, between L4/L5 and S1, the GFN has a variable location either anteromedially or centrally on the psoas major muscle [3, 25]. The GFN splits into variable numbers of genital and femoral branches after it pierces the psoas fascia and crosses the ureters [23]. The genital branches descend over the inguinal vessels to enter the inguinal canal and the ilioinguinal nerve. The femoral branches descend under the inguinal ligament to the proximal thigh [23].

The genital branch supplies sensory innervation to the skin of the pubic region and the upper part of the anterior scrotum in men or the mons pubis and labia majora in women. The femoral branch innervates to the skin, overlying the femoral triangle over the anterior thigh bounded by the inguinal ligament, sartorius muscle, and adductor longus muscle. GFN provides motor function to the cremasteric muscle and is responsible for the cremasteric reflex [3, 9].

Genitofemoral neuralgia manifests variably with pain and paresthesia in the groin, scrotum, medial thigh, and femoral triangle medial aspect of the thigh [26]. The pain can be distributed anywhere along the path of the nerve or both branches. It is usually sharp, unilateral, and can occur in both men and women. In most cases, the compression of the nerve takes place during its course at and through the inguinal canal, most commonly after inguinal or femoral hernia surgery [27].

The traditional genitofemoral nerve block technique inferior to the inguinal ligament and lateral to the pubic tubercle or inside the inguinal canal carries a high risk for producing concomitant anesthesia of the ilioinguinal nerve, thereby resulting in a nonselective block [3, 9].

The genitofemoral nerve is amenable to selective nerve block along its retroperitoneal course on the anterior surface of the psoas muscle [3, 9]. Anterior, lateral oblique (Fig. 7), and posterior (Fig. 8) needle paths can be used. For an anterior approach, the patient remains supine. This approach typically requires preprocedural bowel compression [3]. We
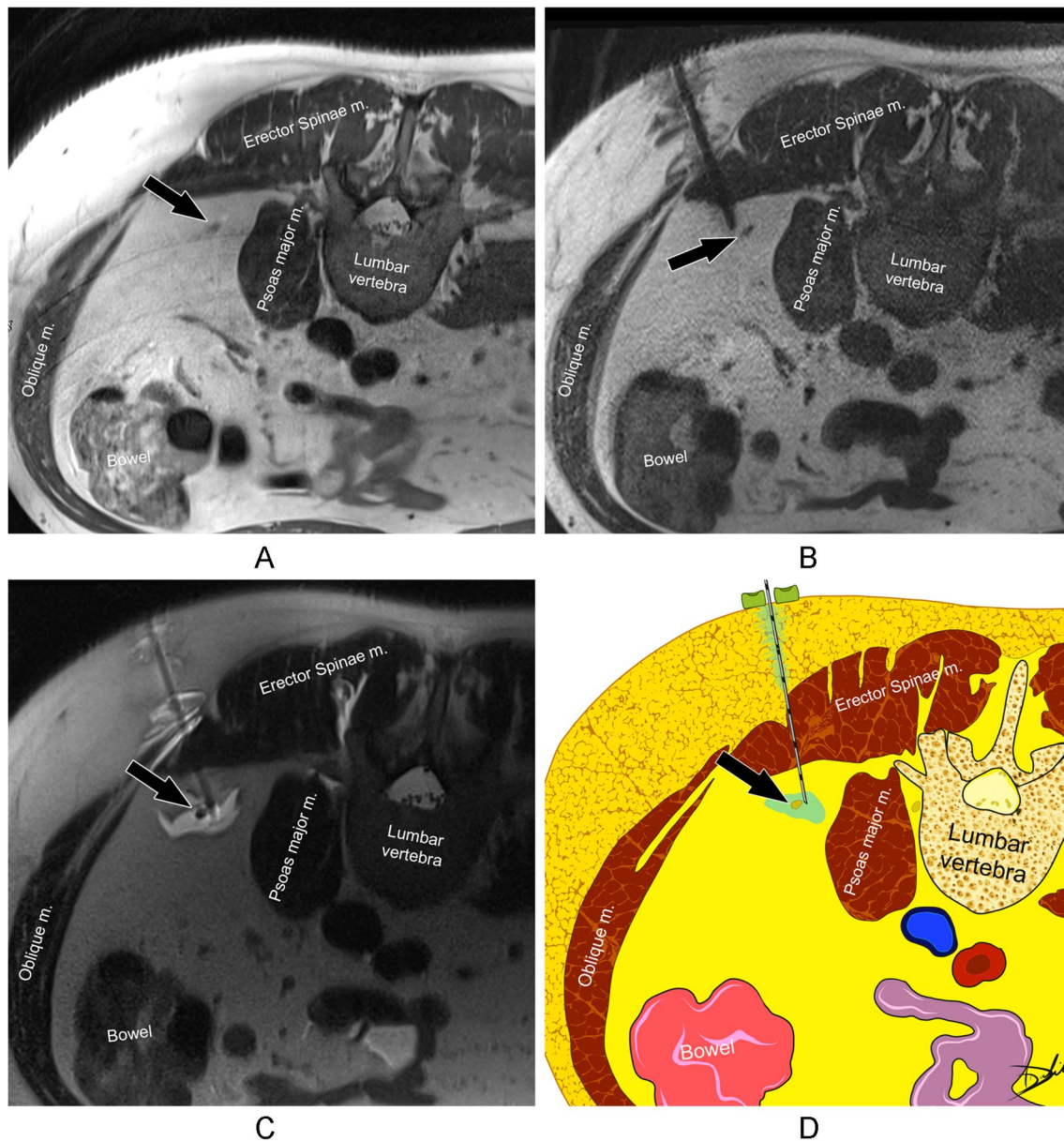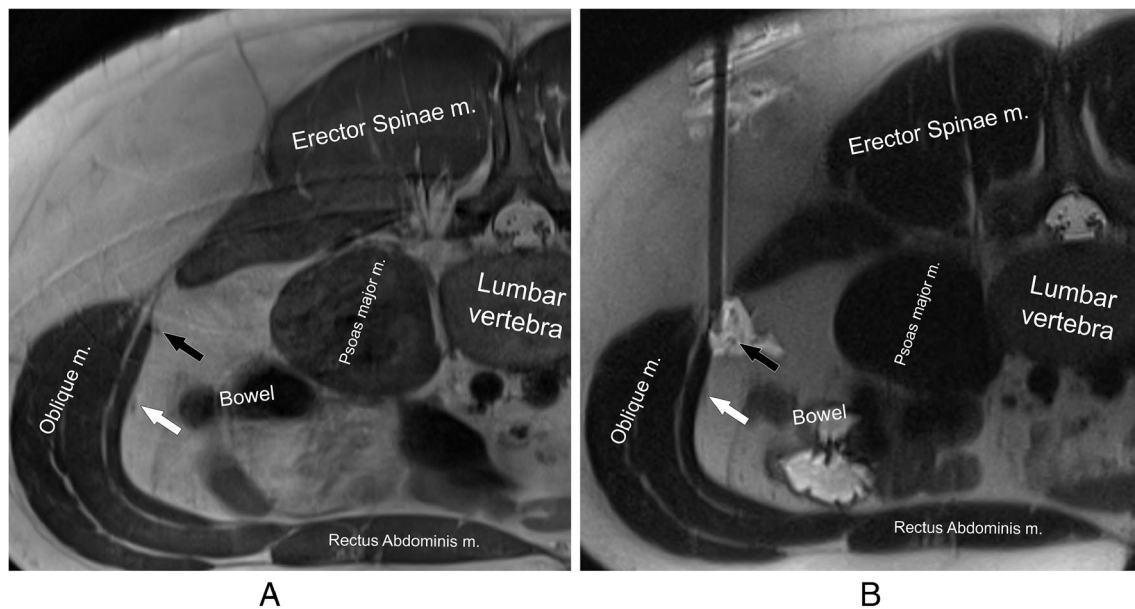
Fig. 5 Selective ilioinguinal-Iliohypogastric nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A** and **B**), axial T2-weight HASTE MR image (**C**) and illustration (**D**) through the left flank demonstrate the common trunk of the Ilioinguinal and Iliohypogastric nerves. Here the patient is positioned prone, and a posterolateral approach is undertaken, piercing the lateral aspect of the quadratus lumborum muscle, permitting selective blockade as the common trunk descends ventrally. The needle tip is demonstrated adjacent to the nerve, and following injection of 1 mL ropivacaine local anesthetic (**C** and **D**), the perineural distribution of the local anesthetic (bright signal intensity) is seen circumferential to the nerve. HASTE, half-Fourier acquisition single-shot turbo spin echo

are using a laxative regimen before the day of the procedure. A lateral oblique approach (Fig. 7) is performed with the patient in the anterior oblique position and is especially well-suited with concomitant ilioinguinal and iliohypogastric nerve blocks, as common ilioinguinal-iliohypogastric trunk blocks may be performed with the same needle trajectory. The posterior trans-psoas approach (Fig. 8) is performed with the patient in the prone position and is virtually always possible. We prefer verbal patients for this approach, as intraprocedural feedback is important for avoiding proximity to the femoral nerve within the psoas muscle. The best needle approach is chosen based on each patient's anatomy and optimal visualization of the genitofemoral nerve anterior to the psoas muscle and at a level where the genitofemoral nerve resides laterally to the gonadal vessels and ureter [3].

Fig. 6 Selective iliohypogastric nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A**) and axial T2-weight HASTE MR image (**B**) through the left flank demonstrate the iliohypogastric (black arrow) and ilioinguinal (white arrow) nerves in the retroperitoneum. With the patient prone position, the iliohypogastric nerve (black arrow) is selectively targeted for successful perineural injection through a posterior approach (**B**). There is no spread to the ilioinguinal nerve (white arrow in **B**)

Pudendal nerve

The S2-S4 spinal nerves form the pudendal nerve, which exits the pelvis through the greater sciatic foramen, formed by the piriformis muscle, greater sciatic notch, sacrotuberous ligament, and sacrospinous ligament. At the infrapiriformis foramen, the pudendal nerve travels with the inferior gluteal, sciatic, posterior femoral cutaneous, and sympathetic nerves, precluding selective pudendal nerve block at this level [28]. More distally in the subgluteal space, the pudendal nerve diverges medially, and the sciatic and posterior femoral cutaneous nerves laterally. The pudendal nerve curves around the ischiofemoral spine, between the sacrotuberous and sacrospinous ligaments, to enter the pudendal (Alcock's) canal [29, 30].

The pudendal nerve provides sensory innervation to the inferomedial buttocks area, perirectal area, perineum, and posterior scrotum. Motor supply is given to the bulbospongiosus and ischiocavernosus muscles, which play a major role in ejaculation, orgasm, and control of the external anal sphincter [30, 31].

Pudendal neuropathy presents with dysfunction in ejaculation, orgasm, and control of the external anal sphincter. Clinically, the diagnosis is challenging. In 2008, the Nantes criteria were validated as a reliable diagnostic tool for diagnosing pudendal nerve entrapment syndrome [32]. The five essential diagnostic criteria are (1) pain in the anatomical territory of the pudendal nerve, (2) worsened by sitting, (3) the patient is not woken at night by the pain, (4) no objective sensory loss on clinical examination, and (5) positive anesthetic pudendal nerve block. Other clinical criteria can further support the diagnosis of pudendal neuralgia. Electroneuromyography may confirm or refute the diagnosis of neuropathy but was found to have limited sensitivity and specificity in diagnosing pudendal nerve entrapment syndrome [33]. Exclusion criteria also included purely coccygeal, gluteal, or hypogastric pain, exclusively paroxysmal pain, exclusive pruritus, and presence of imaging abnormalities able to explain the symptoms [32].

A selective pudendal nerve block is best performed in the pudendal (Alcock's) canal (Fig. 9). Alcock's canal is cannulated by advancing the needle via a posterior approach through the or just next to the sacrospinous ligament at the entrance level of Alcock's canal (Fig. 4). The needle can be further advanced into Alcock's canal as the injectant distends it, which may add a hydrodissection component in the setting of adhesions. Care should be taken not to overfill the pudendal canal to avoid back-spill to the posterior femoral cutaneous nerve laterally in the gluteal space. Posterior femoral cutaneous neuropathy is
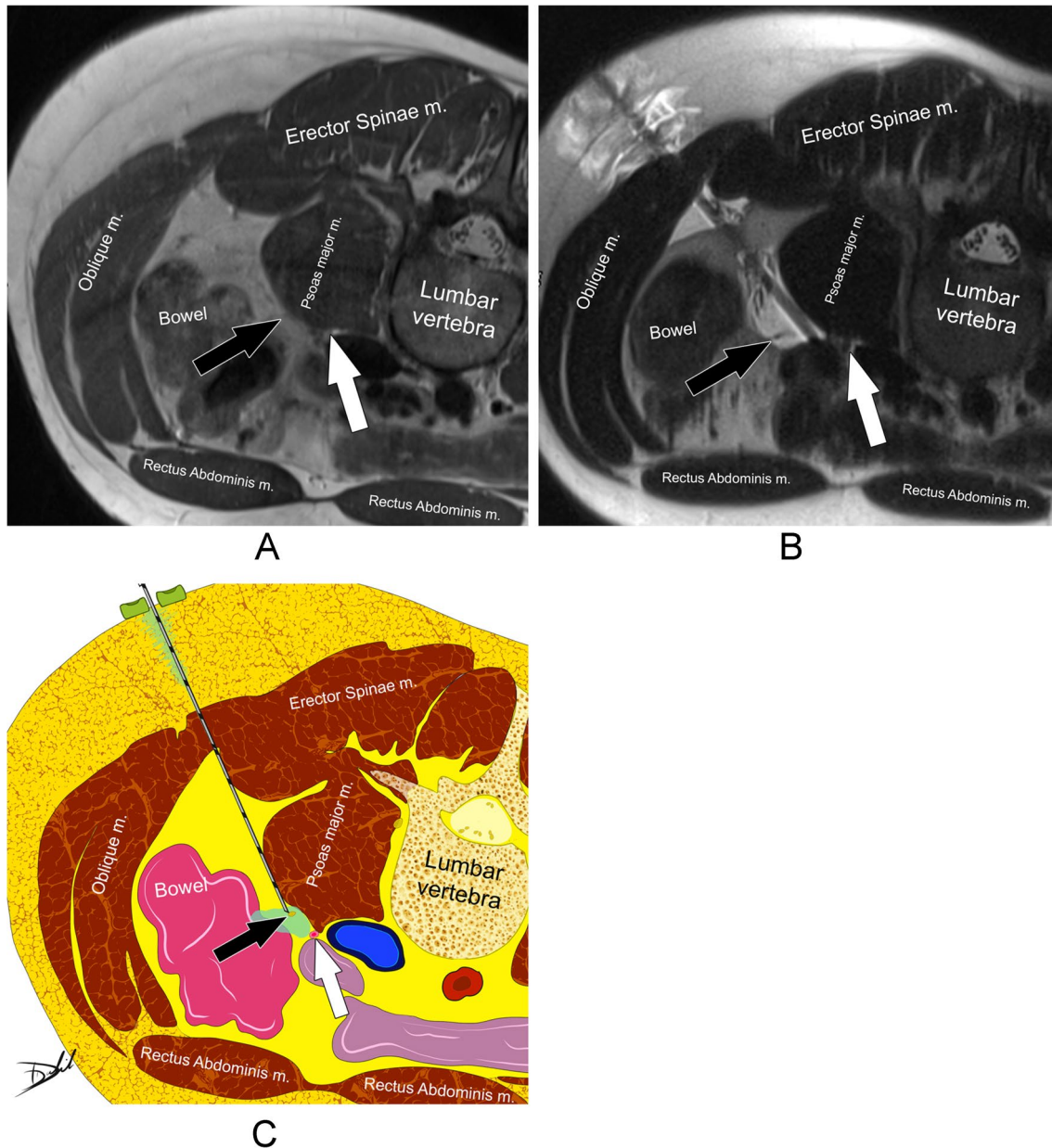
Fig. 7 Selective genitofemoral nerve block technique using a lateral oblique approach. Axial procedural proton-density-weighted turbo spin echo MR image (**A**), axial T2-weight HASTE MR image (**B**), and illustration through the left abdomen demonstrate the genitofemoral nerve (black arrows) anterior to the psoas major muscle. The white arrows demonstrate the medially located ureter. Using a lateral oblique approach through the oblique abdominal muscles, the needle is advanced anterior to the psoas muscle, to the genitofemoral nerve. The perineural distribution is demonstrated anterior to the psoas muscle following 3 mL ropivacaine local anesthetic. HASTE, half-Fourier acquisition single-shot turbo spin echo

the major differential diagnosis in pain due to co-innervation. Inadvertent spread invalidates a selective nerve block, producing an indifferent pain response [34].

Pudendal nerve blocks may be performed in the infrapiriformis foramen and at the ischial spine level. However, at either location, there is typically insufficient distance between the pudendal and posterior femoral cutaneous nerves at this level to ensure a selective block and valid pain response.

Posterior femoral cutaneous nerve

The posterior femoral cutaneous nerve arises from the anterior rami of S1–S3. The posterior femoral cutaneous
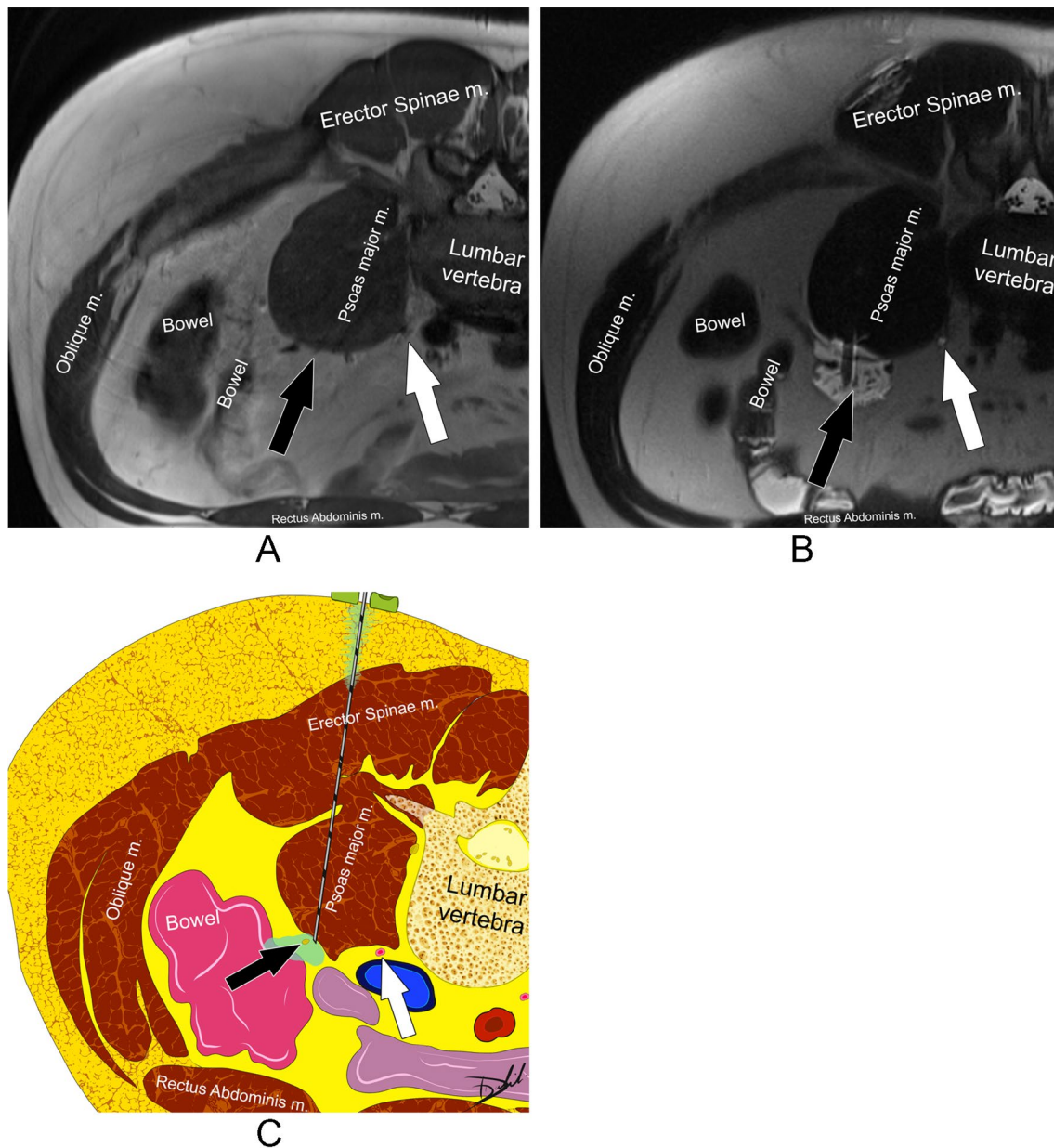
Fig. 8 Selective genitofemoral nerve block technique using the posterior trans-psoas approach. Axial procedural proton-density-weighted turbo spin echo MR image (**A**), axial T2-weight HASTE MR image (**B**), and illustration through the left abdomen demonstrate the genitofemoral nerve (black arrows) anterior to the psoas muscle (**C**). The white arrows demonstrate the mediately located ureter. Using a posterior trans-psoas muscle approach, the needle is advanced just beyond the anterior psoas muscle fascia to the genitofemoral nerve. The perineural distribution is demonstrated anterior to the psoas muscle following 3 mL ropivacaine local anesthetic. HASTE, half-Fourier acquisition single-shot turbo spin echo

nerve is a purely sensory nerve of the lumbosacral plexus, traveling in close proximity with the sciatic nerve through the infrapiriformis muscle and subgluteal space toward the posterior thigh. The posterior femoral cutaneous nerve was formerly known as the lesser sciatic nerve. The posterior femoral cutaneous nerve provides ischial tuberosity innervation through a small branch, perineal and inferomedial buttocks innervation through its perineal branch, inferolateral buttock area through the inferior cluneal nerves, and posterior thigh and popliteal and upper posterior thigh innervation through the major descending branch [29, 34–36].
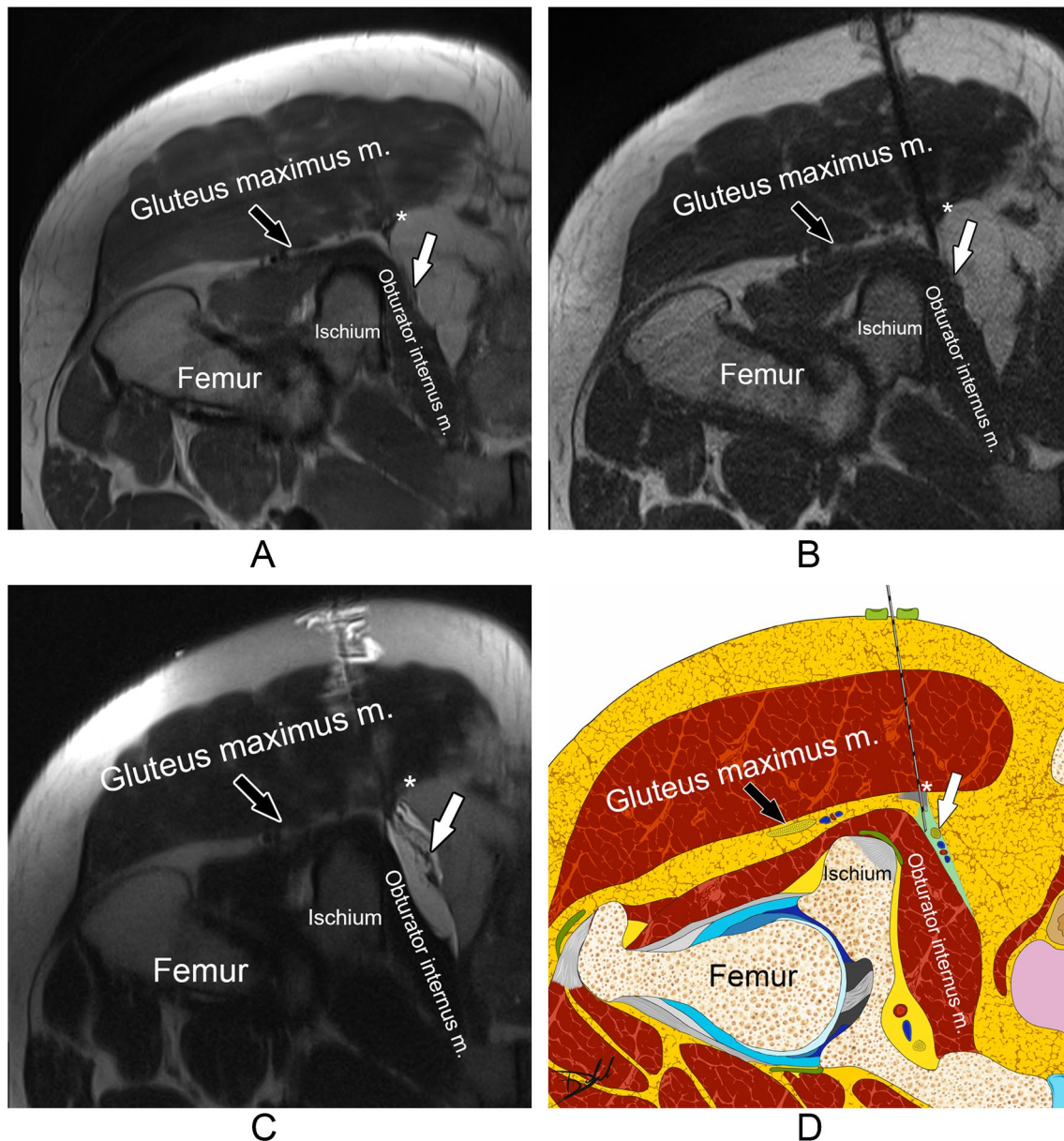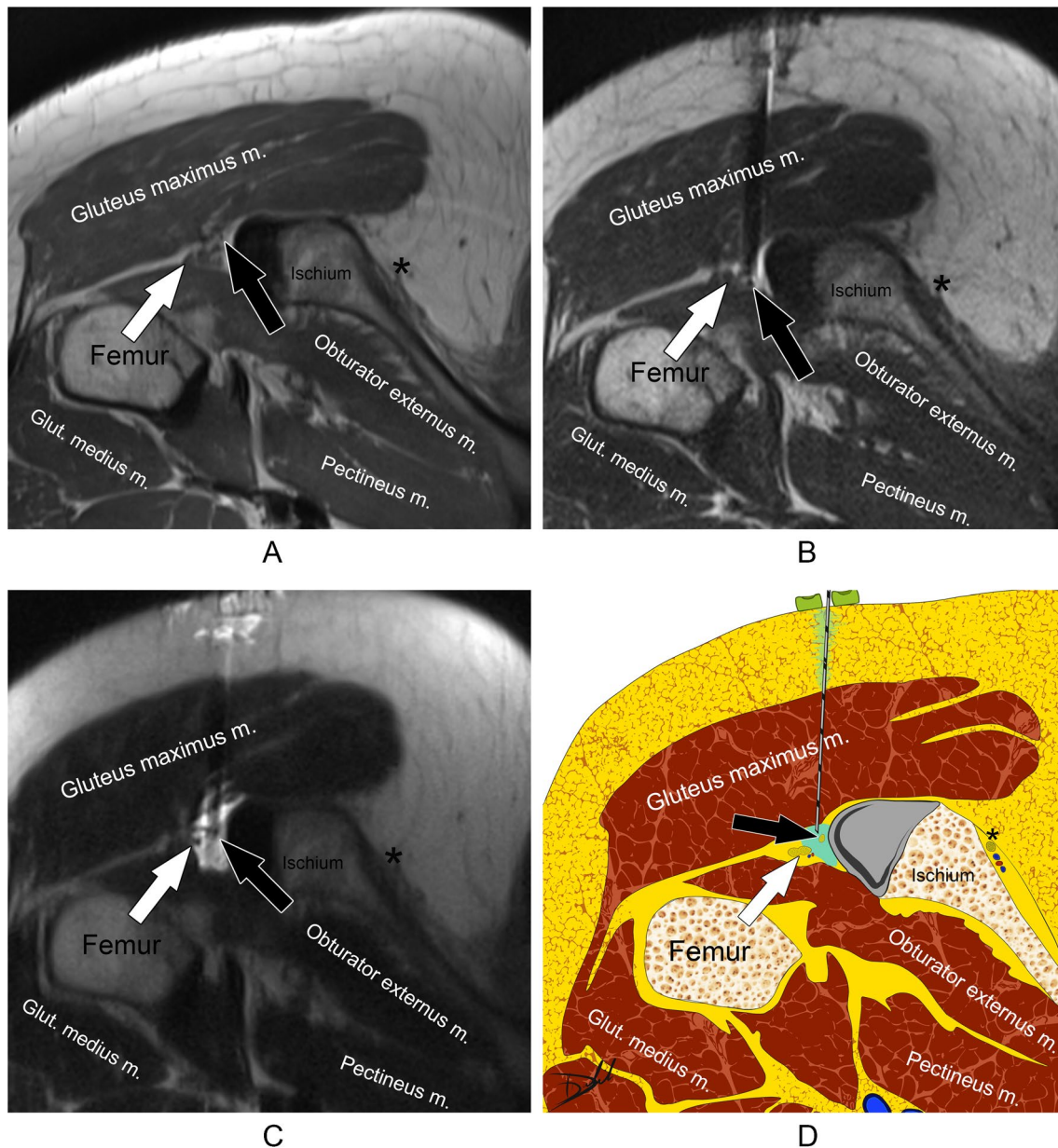
Fig. 9 Selective pudendal nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A** and **B**), axial T2-weight HASTE MR images (**C**), and illustration (**D**) through the left buttocks demonstrate the pudendal nerve (white arrows) within Alcock's canal. The posterior femoral cutaneous nerve (black arrows) is located laterally in the subgluteal space. Using a posterior approach through the sacrotuberous ligament (asterisks), the needle is advanced into the aperture of Alcock's canal. The injection of 3 mL ropivacaine local anesthetic result in distention of Alcock's canal and perineural pudendal distribution. HASTE, half-Fourier acquisition single-shot turbo spin echo

Depending on branch involvement, posterior femoral cutaneous neuropathy may manifest as pain and paresthesia in the skin over the inferior buttocks and perineum, posterior thigh, sitting ischial tuberosity pain, and posterior thigh and popliteal pain [35, 36]. Perineal branch posterior femoral cutaneous neuropathy is a major differential diagnosis of pudendal neuralgia due to co-innervation of the inferomedial buttocks and perineal region.

The main indication for posterior femoral cutaneous nerve blocks is differentiation from pudendal neuralgia. For this indication, selective posterior femoral cutaneous nerve blocks are qualified by non-concomitant pudendal nerve blocks. A concomitant sciatic nerve block is permissible and often unavoidable due to their intimate relationship, as the sensory innervation of the sciatic nerve is at and below the knee and, therefore, not confounding. The

Fig. 10 Posterior femoral cutaneous nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A** and **B**), axial T2-weight HASTE MR image (**C**), and illustration (**D**) through the left buttocks demonstrate the posterior femoral cutaneous nerve (black arrows) just lateral to the hamstrings tendon origin on the ischium and medial to the sciatic nerve (white arrows). Posterior femoral cutaneous nerve blockade is achieved by inserting the needle in a near-vertical orientation along the lateral margin of the hamstrings origin on the ischium bone. In patients with symptoms in the perineal area, the posterior femoral cutaneous nerve is usually targeted 2 cm below the ischial tuberosity. The needle tip is demonstrated adjacent to the posterior femoral cutaneous nerve. Following the injection of 1 mL ropivacaine local anesthetic, the perineural distribution of the local anesthetic (bright signal intensity) is demonstrated. HASTE, half-Fourier acquisition single-shot turbo spin echo

posterior femoral cutaneous nerve block is performed via a posterior approach at the level of the subgluteal space lateral to the ischial tuberosity, where the posterior femoral cutaneous nerve has diverged laterally and the pudendal nerve medially toward Alcock's canal. The small posterior femoral cutaneous nerve is typically located dorsal and medial to the sciatic nerve (Fig. 10).

In patients with symptoms affecting the inferolateral buttock area, the inferior cluneal nerves are targeted at their take-off deep to the gluteus maximus muscle. In patients with symptoms in the posterior thighs, the distal portion of the posterior femoral cutaneous nerve is located between the gluteus maximus and the long head of the biceps femoris muscle [35].

Lateral femoral cutaneous nerve

The purely sensory lateral femoral cutaneous nerve arises from the posterior divisions of the L2 and L3 spinal nerves. The nerve emerges at the posterolateral border of the psoas major muscle and descends along the deep surface of the iliacus muscle deep to the anterior thigh. The nerve passes below or occasionally perforates the inguinal ligament to enter the thigh within a fibrous compartment just medial to the anterior superior iliac spine, passing over the sartorius deep to the fascia lata. The lateral femoral cutaneous nerve may be fused with the genitofemoral nerve in 2% of the population [37].

At least five variations of the lateral femoral cutaneous nerve course have been described [29, 38]: type A, superior to the ASIS, crossing the iliac crest (4%); type B, anterior to the anterior superior iliac spine and superficial to the origin of the sartorius muscle but within the substance of the inguinal ligament (27%); type C, medial to ASIS, at the tendinous origin of the sartorius muscle (23%); type D, medial to the origin of the sartorius muscle located in an interval between the tendon of the sartorius muscle and thickened fascia of the iliopsoas muscle deep to the inguinal ligament (26%); and type E, most medial and embedded in loose connective tissue, deep to the inguinal ligament, overlying the thin fascia of the iliopsoas muscle, and contributing to the femoral branch of the genitofemoral nerve (20%). There is also a wide variability of branching patterns, with up to 5 branches.

The lateral femoral cutaneous nerve supplies the skin on the anterior and lateral aspects of the thigh to the knee level. Lateral femoral cutaneous nerve entrapment presents with burning pain, dysesthesia (paresthesia and hypesthesia), or both in the anterolateral thigh extending to the anterior knee in some cases. Symptoms are often worse with prolonged standing and walking and alleviated by sitting down, though some report that sitting exaggerates the pain.

Owing to the proximity of the lateral femoral cutaneous nerve to the genitofemoral, ilioinguinal, and close proximity of nerves in the groin and the broad anatomic variation of the lateral femoral cutaneous nerve and the inguinal ligament, selective nerve blocks may be performed proximal to the inguinal ligament in the retroperitoneum. Anterior and anterolateral approaches above the anterior superior iliac spine may target the lateral femoral cutaneous nerve superficial to the iliacus muscle. Alternatively, a posterior approach may be used with the patient prone and a needle path through the quadratus lumborum to target the lateral femoral cutaneous nerve next to the psoas muscle (Fig. 11).

Anterior femoral cutaneous nerve

The anterior femoral cutaneous nerve arises from the lumbar plexus via the femoral nerve, which the posterior divisions of the anterior rami of spinal nerves L2-L4 form. Distal to the inguinal ligament, the anterior femoral cutaneous nerve separates from the femoral nerve at the level of the hip joint to course anteroinferiorly as a common trunk toward the anterior thigh [18], where it pierces through the fascia lata along the medial margin of the sartorius muscle and then subdivides into the medial branch — the medial femoral cutaneous nerve, and the intermediate branch — the intermediate femoral cutaneous nerve, thereby providing sensory innervation to the anteromedial and anterior thigh [18, 39].

The anterior femoral cutaneous nerve anastomoses with the lateral femoral cutaneous nerve, the infrapatellar branch of the saphenous nerve, and the obturator nerve from the subsartorial plexus, with overlapping sensory mapping with the adjacent lateral femoral cutaneous nerve, Iliohypogastric, ilioinguinal and genitofemoral nerves [34, 39].

Patients present with medial and anterior thigh pain extending to the knee, overlapping symptoms with the nerves mentioned above due to anatomical anastomosis. Due to clinical overlap in symptoms and territories, selective MR neurography–guided anterior femoral cutaneous nerve blocks are used in planning more invasive treatments to ensure appropriate patient selection and achieve better outcomes [19, 39].

Selective MR neurography–guided anterior femoral cutaneous nerve blocks are performed through an anterior approach with a short needle (Fig. 12). The small anterior femoral cutaneous nerve and its anatomic variations are best found by tracing its origin off the femoral nerve deep to and proximal to the myotendinous iliopsoas junction. The selective nerve block targeted is the common trunk of the anterior femoral cutaneous nerve just medial to the proximal sartorius muscle in the proximal thigh [18].

Obturator nerve

The obturator nerve of the lumbar plexus is formed through L2 to L4 anterior rami contributions. The obturator nerve descends in and emerges through the medial psoas to travel along the inner wall of the lesser pelvis through the
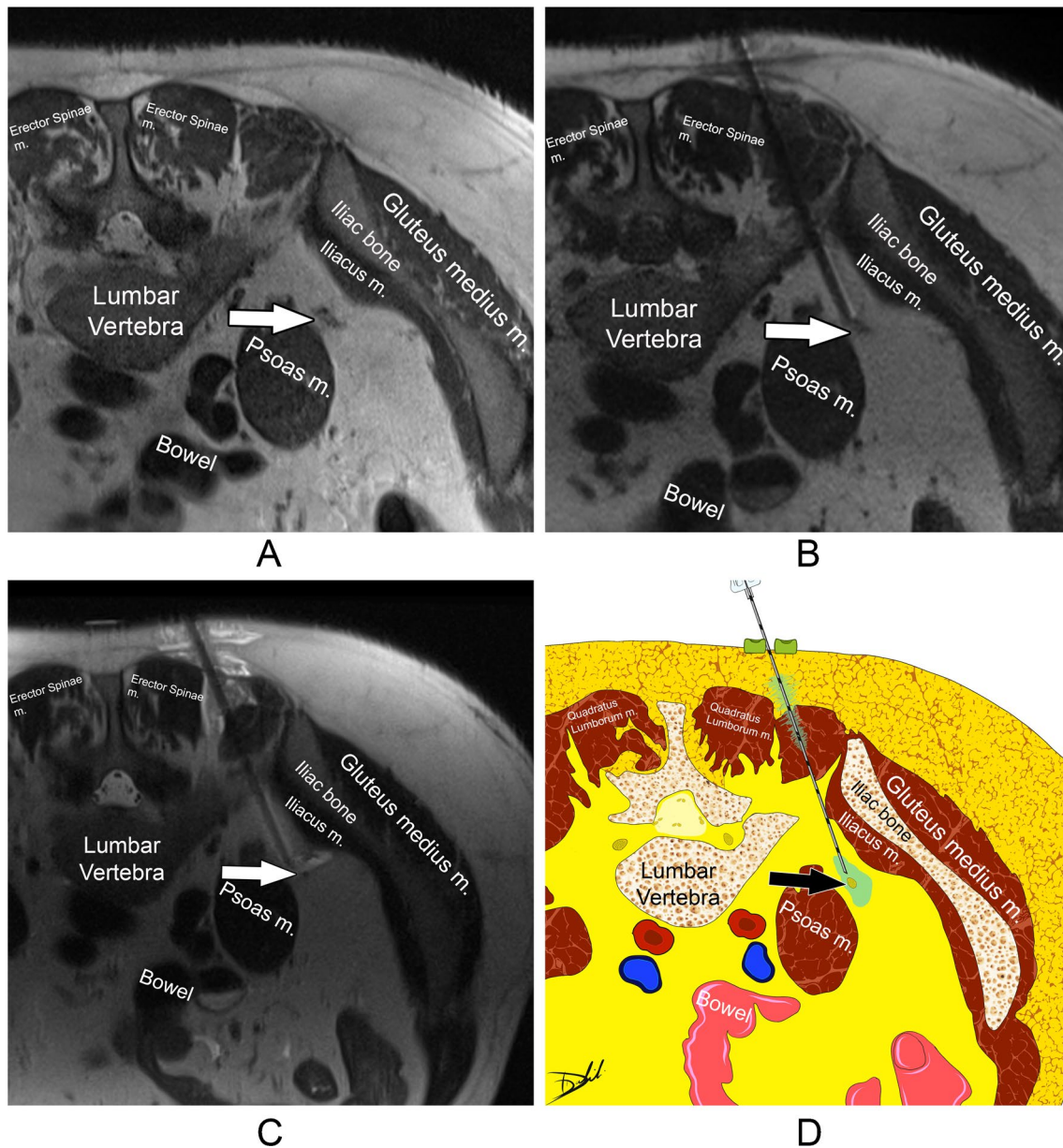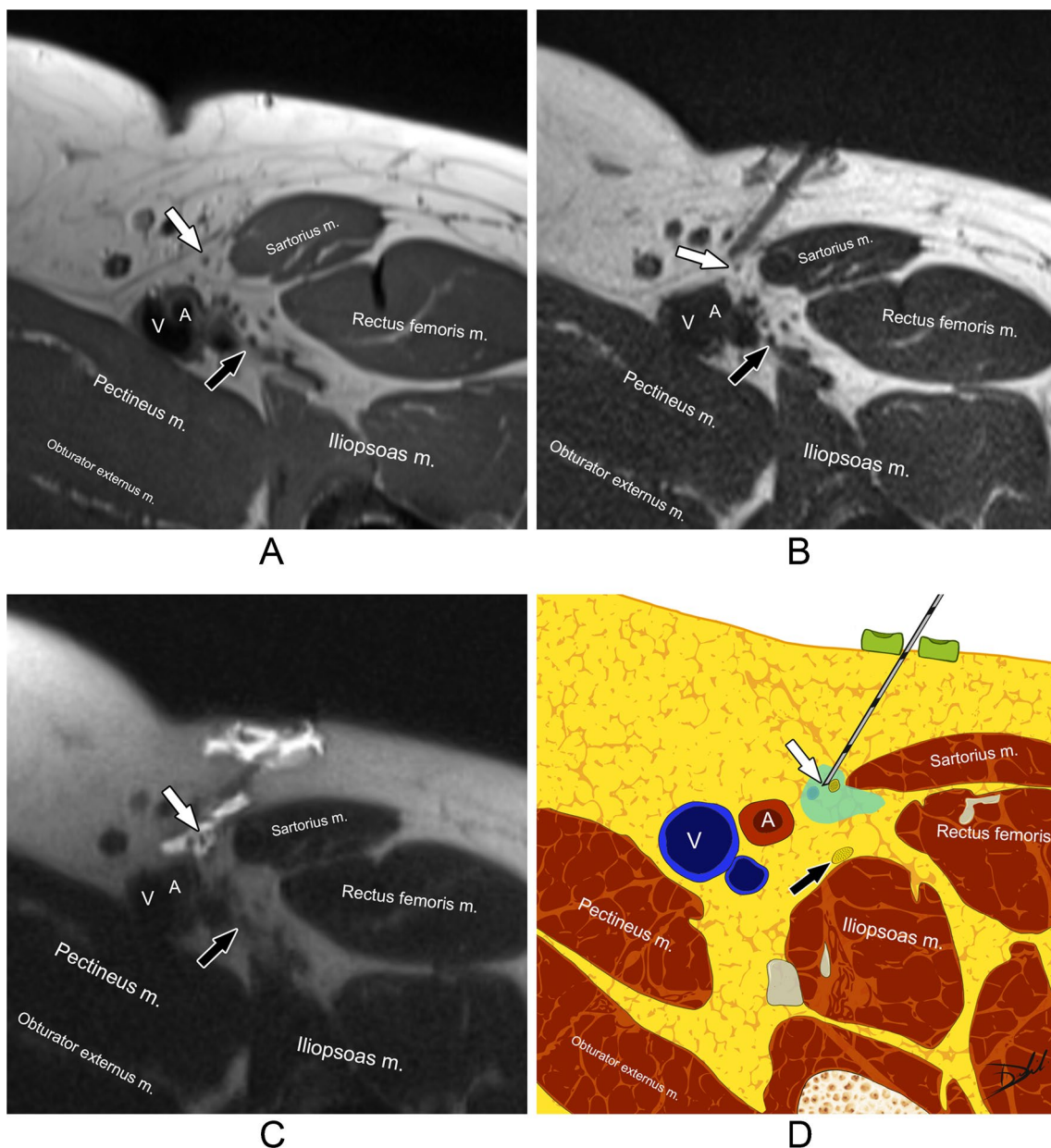
Fig. 11 Selective lateral femoral cutaneous nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A** and **B**), axial T2-weight HASTE MR image (**C**) and illustration (**D**) through the right flank demonstrate an abnormally enlarged lateral femoral cutaneous nerve (white arrow) just lateral to the psoas major muscle and medial to the iliacus muscle. With the patient prone, the lateral femoral cutaneous nerve is targeted through a posterior needle path. The needle tip is demonstrated adjacent to the lateral femoral cutaneous nerve. Following the injection of 2 mL ropivacaine local anesthetic, the perineural distribution of the local anesthetic (bright signal intensity) is demonstrated. HASTE, half-Fourier acquisition single-shot turbo spin echo

obturator canal to the anterior thigh. The obturator nerve then ramifies into anterior and posterior branches. The anterior branch provides motor innervation to the medial thigh muscles, including the adductor longus, adductor brevis, gracilis, and pectineus muscles. The posterior branch travels between the adductor brevis and magnus muscles supplying the adductor magnus and brevis, the obturator externus, and the adductor longus. The adductor brevis is the only muscle solely innervated by the obturator nerve. The sensory and motor branches are usually separated by

Fig. 12 Selective anterior femoral cutaneous nerve block technique Axial procedural proton-density-weighted turbo spin echo MR image (**A**) and HASTE image (**B**) through the left groin demonstrate the anterior femoral cutaneous nerve (white arrows) medial to the sartorius muscle belly. The black arrows indicate the deeper-located femoral nerve. Axial proton-density-weighted interventional turbo spin echo MR image (**B**) and illustration (D) demonstrate the needle tip adjacent to the anterior femoral cutaneous nerve (white arrows). The black arrow indicates the deeper-located femoral nerve. Axial T2-weight HASTE MR image (**C**) and illustration (**D**) following injection of 1 mL ropivacaine local anesthetic demonstrate the perineural distribution of the local anesthetic (bright signal intensity) around the nerve. The black arrow indicates the deeper-located femoral nerve. HASTE, half-Fourier acquisition single-shot turbo spin echo

some of the fibers of the obturator externus muscle. The obturator nerve supplies sensory innervation to the hip and knee joints and medial thigh [25, 40].

Obturator neuralgia presents with chronic hip pain and persistent hip adductor spasticity in patients with paraplegia, multiple sclerosis, cerebral palsy, and following strokes.

Selective obturator nerve blocks may be performed proximal to the obturator canal along the course medial to the lesser pelvis and inside the operator canal. For blocking
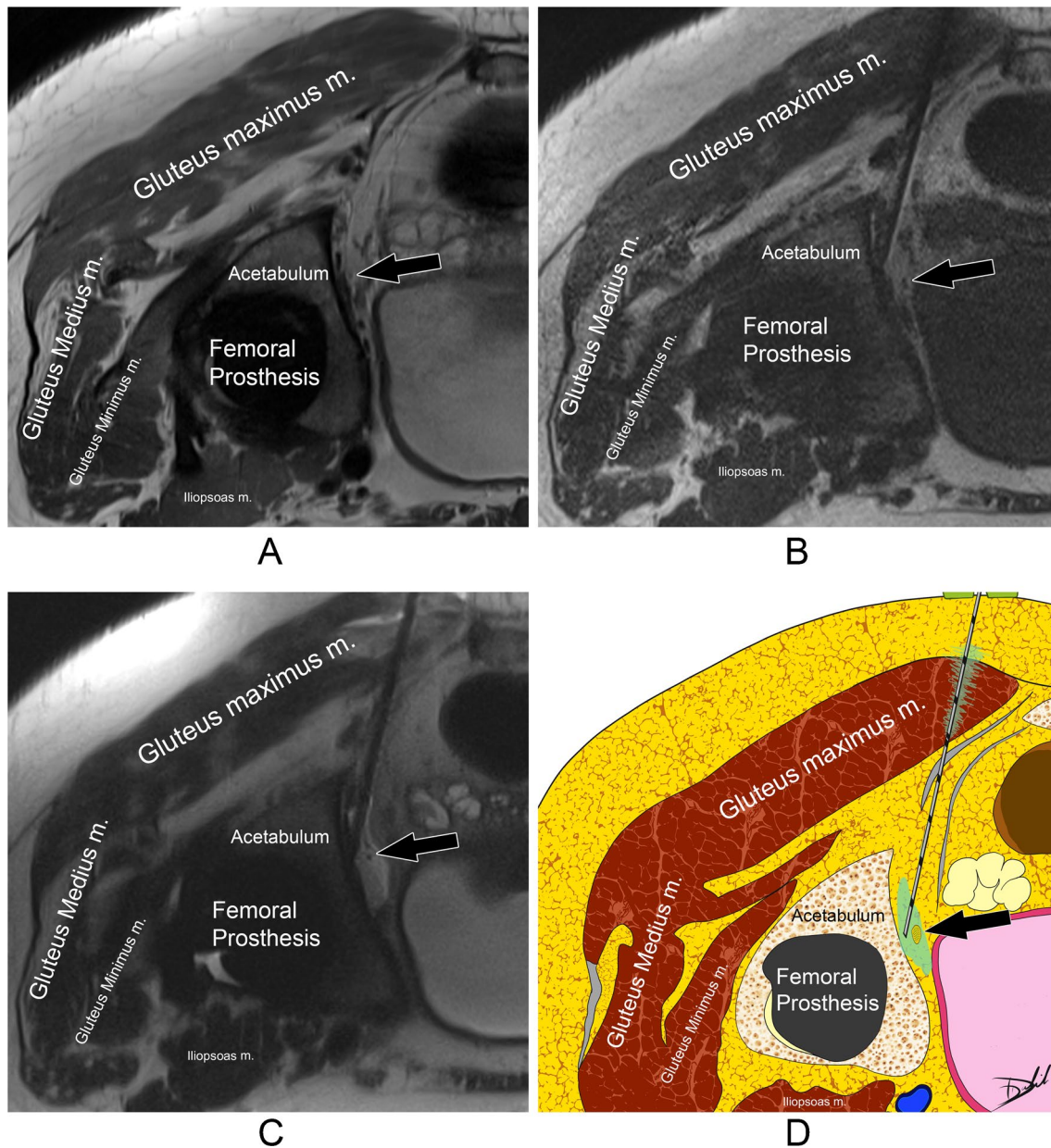
Fig. 13 Selective obturator nerve block technique. Axial procedural proton-density-weighted turbo spin echo MR images (**A** and **B**), axial T2-weighted HASTE MR image (**C**), and illustration (**D**) through the left hip demonstrate the obturator nerve (black arrow) just along the acetabular side wall. The patient is positioned in the prone position, and the nerve is targeted with a posterior approach lateral to the per- irectal fascia. The needle tip is demonstrated adjacent to the nerve. Following the injection of 2 mL ropivacaine local anesthetic (**C** and **D**), the perineural distribution of the local anesthetic (bright signal intensity) is demonstrated. HASTE, half-Fourier acquisition single-shot turbo spin echo

inside the obturator canal, a double angulated anterior needle path may be needed with mediolateral and inferosuperior trajectories to spare the inguinal canal and inguinal vessels and circumvent the pubic rami. For blocking the obturator nerve medial to the lesser pelvis, a posterior approach may be performed with the patient in the prone position, targeting the obturator nerve along the inner acetabular wall (Fig. 13).

Conclusion

MR neurography facilitates selective perineural injections of small lumbosacral plexus nerves, especially in locations that may be difficult to find with other image guidance modalities.

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