



A Review of Current Denervation Techniques for Chronic Hip Pain: Anatomical and Technical Considerations

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Abstract

Purpose of Review Percutaneous radiofrequency (RF) denervation of articular sensory nerves of the hip joint is a minimally invasive neurotomy technique that can provide pain relief in patients with chronic hip pain. There has been an increase in the number of publications on RF denervation of the hip over the last few years although many questions remain regarding anatomical targets, technical aspects, selection criteria, and evidence for effectiveness.

Recent Findings For this updated review, publications were identified by searching MEDLINE and other medical literature databases from inception through November 30, 2018. Existing knowledge of hip joint innervation was reviewed and data on patient selection, prognostication of analgesic benefit from ablation by using local anesthetic blocks, current techniques of performing hip joint ablation, analgesic success, functional outcomes, and adverse effects were critically reviewed and analyzed.

Summary Sensory denervation of the anterior hip joint using RF current is a viable treatment option for management of chronic hip pain after conservative methods fails to do so. We have synthesized knowledge from papers on techniques of ablation and from recently elaborated anatomical details. We also provide suggestions regarding anticipated outcomes of the procedure. Our review of existing literature indicates evidence for analgesic benefits, improvement in function, and a low incidence of adverse effects of RF ablation of sensory innervation to the hip joint. Future research should focus on refining the technique of ablation and monitoring of long-term outcomes.

Keywords Hip joint pain · Articular nerve · Radiofrequency · Denervation · Ablation · Neurotomy

Introduction

Population prevalence of hip pain is 7 to 10% in persons over 45 years of age. [1] The most common cause of chronic hip pain with advancing age is osteoarthritis (OA) which is also associated with stiffness, restriction of mobility, atrophy of muscles, impaired ambulation, and instability of the joint. [2] Other important causes of chronic pain in the hip include rheumatoid arthritis, labral tears of the acetabulum, osteonecrosis, post-traumatic arthritis, chronic infectious coxarthrosis, avascular necrosis, and persistent postoperative pain following total hip arthroplasty (THA). [3] Conservative management strategies including education regarding activity and weight loss, physical therapy, assistive devices, and analgesics (acetaminophen, non-steroidal anti-inflammatory drugs, opioids) are often employed to provide pain relief in patients with chronic pain in the hip, but these interventions usually confer temporary benefits, often lack efficacy, and may have significant adverse effects. Minimally invasive interventional techniques (intra-articular injections with

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steroids, visco-supplementation, regenerative therapies) often fail to provide long-term pain relief. [4] Patients who fail to respond to conservative treatments usually undergo arthroplasty, but this is associated with a concerning failure rate (5 to 15%) [5–7], significant cost, morbidity including worsening of symptoms, mortality, and persistent post-surgical pain in 7 to 28% of patients. [8, 9]

“Hip pain” is difficult to define topographically. Potential pain generators include intra-articular and extra-articular structures—ligaments, labrum, cartilage, synovium, bone, bursae, tendons, and nerves. Patients with pain related to pathology in the hip joint present with pain in one or more of the following locations: groin, anterolateral thigh, gluteal region, and occasionally referred pain below the knee. Among the various locations, groin pain is by far the most common, and limitation of internal rotation on examination usually suggests intra-articular pathology. [10]

Methods

We conducted comprehensive, serial searches of the medical literature databases from inception through November 30, 2018, using a highly sensitive search strategy. [11] An experienced medical information specialist performed the searches in consultation with the authors of this review. The following databases were searched: EMBASE, MEDLINE, MEDLINE In-Process & Other Non-Indexed Citations (all using the OvidSP Platform) and Cochrane Database of Systematic Reviews. PROSPERO and Cochrane Central Register of Controlled Trials, Google Scholar (first 200 hits), proceedings of the major annual meetings of pain societies in the last 4 years, and the U.S. National Library of Medicine and Cochrane databases were also included. Each search was limited to studies on live or cadaveric human subjects using combinations of the following terms “pain,” “hip joint,” “innervation”, “ablation”, and “radiofrequency”. Only English language citations were reviewed here, independently by two authors P.K. and Y.H. and subsequently verified by A.B. All instances of disagreement were discussed between the authors to reach a consensus. A narrative approach to the review was agreed upon given the heterogeneous nature of available data.

Results

Our search yielded 16 publications that were published between 1993 and 2018, containing a total of 127 patients within the age range of 25 to 89 years, which described different RF modalities and outcomes for denervation of the hip joint [12–25, 26•, 27]. There were six case reports [12–17] and ten case series (seven retrospectively [18–24] and three prospective [25, 26•, 27] with no randomized controlled trials

identified. Five studies involving dissection of hip joints in cadavers to understand the innervation patterns were also identified in our search [28–31, 32••].

Etiologies of Hip Joint Pain

Osteoarthritis was the most frequent indication for denervation procedures on the articular branches of nerves innervating the hip joint although patients with other diagnoses also underwent this procedure (Table 1). Diagnosis of OA of the hip joint in studies included in this review was made after clinical examination (pain in the hip region exacerbated by walking, inability to sleep on the affected side, positive hip joint stress maneuvers) and radiological evaluation of the joint using Tonnis or Kellgren-Lawrence grading system. It should be noted the incidence of radiological evidence of hip OA is significantly higher (20 to 40%) than the prevalence of symptoms (10 to 30%) in published literature [33]. Ten of the papers in our review associated with significant hip pain as part of the clinical presentation provided radiologic (radiography, computed tomography, or magnetic resonance imaging) evidence of pathologies [12, 13, 15, 16, 20, 23–25, 26•, 27].

Anatomy of the Hip Joint

The hip joint is a complex diarthrodial “ball and socket” articulation connecting the pelvis and the femur and providing stability and multiplanar mobility. It is composed of osseous and ligamentous structures. More than 20 muscles and their accompanying neurovascular bundles span this joint [34]. The static stability of hip is conferred by the bony configuration and soft tissue attachments especially on the anterior surface of the hip capsule.

Innervation of the Hip Joint

Horner postulated that for peripheral joints to produce pain, three discrete systems of innervation are required: afferent nerves from the joint capsule, intraosseous innervation, and cutaneous afferents in the overlying skin that provide kinesthetic sensation. [35] Kim and Azuma showed that acetabular labrum is richly populated with Vater-Pacini, Golgi-Mazzoni, Ruffini, and Krause corpuscles more frequent in the anterosuperior and posterosuperior part of the labrum [36]. Most of these sensory nerve end organs are in the articular side of the labrum and have implications for denervation targets. These corpuscles observed are receptors of deep sensation, pressure, and temperature. Thus, the labrum may function to provide proprioceptive input, and a damaged labrum may also be a source of hip pain. Two histologic studies have also found free nerve endings (nociceptors and mechanoreceptors) in the ligamentum teres, suggesting the ligamentum

Table 1 Innervation of the hip joint capsule

Innervation of the quadrants in the anterior capsule				
	Superolateral	Superomedial	Inferolateral	Inferomedial
Femoral high nerves	++++	+++	+++	++
Femoral low nerves	+	+	++	+
Obturator high nerves			+	+++
Obturator low nerves			++	++
Accessory obturator nerve		++		+++
Innervation of the quadrants in the posterior capsule				
Nerve to quadratus femoris	Medial, Superior, and Inferior			
Sciatic nerve	? Lateral, Medial(unclear)			
Superior gluteal nerve	Lateral			
Inferior gluteal nerve	Inferior (unclear)			

“+” refers to the presence of nerves in relation to the quadrant of the capsule. The number of “+” simply refers to the predominance of the nerve supply

teres may be involved in transmitting somatosensory afferent signals that are part of the reflex system for protecting the hip joint [37, 38]. Kampa and colleagues reported the capsule is poorly innervated anterosuperiorly, and called this internervous plane the “safe zone” of capsule and the anterior aspect of hip joint capsule having the highest number of sensory nerve endings. [39]

Direct articular branches from nerves around the hip joint represent the primary innervation of the hip, while small accessory articular twigs arising from nerves within the substance of muscles surrounding the joint form a secondary innervation source. This is in agreement with Hilton’s law that states joints in the body are innervated by nerves supplying muscles across that joint, where after the most distal motor point is given off the muscle, the remaining nerve fibers are purely sensory [40].

Most pain in the hip joint however originates from the joint capsule, and these sensory nerves are referred to as articular nerves. The innervation of the capsule is complex receiving contributions from articular branches of the femoral, obturator, accessory obturator nerve, nerve to the quadratus femoris, superior gluteal, and perhaps the sciatic and inferior gluteal nerves [28–31, 32••, 40]. It is also important to recognize that almost all nerves to the hip joint are accompanied by blood vessels that perfuse the joint while also innervating these vessels [41]. In order to understand the best approach for abolishing sensory afferent traffic from the hip joint, a thorough understanding of the major innervation to the hip is synthesized here and in Table 1 with information from five anatomic studies of hip innervation obtained from dissections on cadavers [28–31, 32••].

Innervation of the Anterior Hip Joint Pattern of innervation of the anterior capsule of the hip joint is best described by dividing it into four quadrants: superolateral, inferolateral, superomedial, and inferomedial [32••, 42••].

- Superolateral and inferolateral quadrants: femoral nerve

The anterolateral region of the hip joint capsule is innervated by articular branches of the femoral nerve (FN) classified as high or low if originating superior or inferior to the inguinal ligament, respectively. The high femoral branches arise distal to the lateral border of the psoas muscle, travel within iliacus deep to the inguinal ligament before innervating the capsule. In addition to innervating the lateral quadrants, these nerves also supply the superomedial quadrant and sparingly innervate the inferomedial quadrant [32••, 42••]. Another anatomical paper describes the nerve branching from pectineus, ascended cephalad to enter the superomedial quadrant [43]. Perhaps this pattern of articular nerve innervation explains the referred pain from hip going to anterior knee in some patients [28–31, 32••, 44, 45]. In contrast, the low femoral branches which are fewer in number, pierce the iliopsoas to supply capsule directly, or course inferiorly before recurring to innervate all quadrants of the anterior hip joint capsule with the highest representation in the inferolateral quadrant. They can innervate the capsule exclusively, or they can provide mixed sensory and motor innervation [44, 45].

- Superomedial and Inferomedial quadrants: obturator and accessory obturator nerves

Articular branches of the obturator nerve (ON) innervate the superomedial region of the hip joint capsule and the pubofemoral ligament. Depending on the point of origin, the ON articular branches are categorized as high when these originates proximal to or within the obturator canal and low when these arise from the posterior branch of ON [32••]. Most high branches were single branches supplying consistently the inferomedial quadrant, while low branches traveled either directly or formed a fine plexus supplying both inferior medial and the

Table 2 Details of Studies Involving RF Treatments for Chronic Hip Pain

Study design	Author	Trial size range (years)	Diagnosis pain intensity	Articular nerves Imaging modality	Prognostic block	RF parameters	Outcome measures	Follow-up measures	Results
CS(P)	Kawaguchi 2001 [18]	n = 14 26–85 yrs	OA (8) Metastasis (2) PSPP post hip dislocation (4) Severe hip pain	ON (all patients) FN (5/14 patients) XR	IA injection and/or ON articular branch LA details not provided	Ablative 75–80 °C/90 s	Pain scores	11 months	<ul style="list-style-type: none"> 60% reduction in pain scores 11/14 patients had pain relief
	Rivera 2012 [19]	n = 18 age?	OA (16) PSPP Post THA(2) Severe hip pain	ON FN XR	3 cc of 0.1% ropivacaine	Ablative 90C-90s 22G cannula 5 mm tip	Pain scores Function (WOMAC score, Harris Hip score)	1,6 months	<ul style="list-style-type: none"> 33% reduction in pain scores (≥ 50% reduction in 8 patients) 16% reduction in WOMAC scores 34% improvement in Harris Hip score reductions in pain scores by 60% improvement in OHS reduction in use of analgesics reduction in pain scores by 60% improvement in OHS reduction in use of analgesics
CS (R)	Chye 2015 [20]	n = 15 66 yrs	OA Severe hip pain	FN ON XR	LA details not provided	PRF 42c-180 s ~ 2 cycles 22G cannula 10 mm tip	Pain scores OHS Analgesic requirements	1 week, 1, 3 months	<ul style="list-style-type: none"> pain relief in 14/15 patients
	Okada 1993 [21]	n = 15 > 60 yrs	OA, RA Osteonecrosis Chronic infectious coxarthrosis SN PSSP Post THA	FN ON SGN XR	LA details not provided	Ablative 80C-120 s	Pain scores JOA score	Days -12 months	<ul style="list-style-type: none"> reduction in pain scores by 60%
	Akatov 1997 [22]	n = 13 47–79 yrs	OA Not provided	ON XR	2–3 cc of 1% lidocaine	Ablative 80C-120 s	Function (range of motion)	3 years	<ul style="list-style-type: none"> Pain relief in 12/13 patients Increased range of motion in 9 patients
	Malik 2003 [23]	n = 4 49–70 yrs	Avascular necrosis (1) Metastases (1) Severe hip pain	FN ON XR	?cc bupivacaine	Ablative 75-80C-90s Another patient PRF 10 mm ~ 2 cycles	Function (ambulation, ADL)	1, 2 and 3 months	<ul style="list-style-type: none"> 30–70% reductions in pain scores Improvement in function (3/4 patients) Decrease use of analgesics
	Wu 2007 [24]	n = 2 48–72 yrs	Avascular necrosis PSPP Post THA Severe hip pain	FN ON XR	0.5–1 cc of 1% lidocaine	PRF 42c-120 s ~ 2 cycles 22G cannula 10 mm tip	Pain scores function (ambulation)	1, 2, 3 and 4 months	<ul style="list-style-type: none"> 50–80% reductions in pain scores Improvement in ambulation
	Cortinas-Saenz 2014 [25]	n = 3 33–79 yrs	Avascular necrosis severe hip pain	FN ON XR	?cc of 0.25% levobupivacaine	Ablative 90c-90s 22G cannula 10 mm tip	Pain scores	1,6 months	<ul style="list-style-type: none"> 50–80% reductions in pain scores reduction of analgesic dose 1 patient had permanent anesthesia of skin overlying hip joint >80% reduction in pain scores
	Kapurall 2018 [26•]	n = 23 27–73 yrs	Degenerative (18) PSPP Post THA(2) AVN(2) EDS(1) Severe hip pain	FN ON XR + US	2 blocks – 7 days apart 2 cc of 0.5% bupivacaine	Cooled 75C-180 s 17G cannula	Pain scores Opioid requirements	6 months	<ul style="list-style-type: none"> complex patients with opioids used for widespread pain >80% reduction in pain scores Larger denervated lesion Some underwent bilateral hip RF 1 case of transient neuritis

Table 2 (continued)

Study design	Author	Trial size range (years)	Diagnosis pain intensity	Articular nerves Imaging modality	Prognostic block	RF parameters	Outcome measures	Follow-up measures	Results
	Timirello 2018 [27]	n = 14 32-89 yrs	OA Severe hip pain	FN ON XR	1 cc of 0.5% ropivacaine	PRF 42C-300 s 18G cannula 10 mm tip Steroids post procedure	Pain scores OHS	1, 3, 6 and 12 months	<ul style="list-style-type: none"> > 50% improvement at end of 12 months in 9/14 patients two uncomplicated cases of femoral artery puncture
CR (5)	Fukui 2001 [12]	n = 1 59 yrs	Post infectious OA Severe hip pain	ON FN XR	3 cc of 1% lignocaine	Ablative 90c-120 s 22G cannula 4 mm tip	Pain scores Function (ambulation)	4,6,24 months	<ul style="list-style-type: none"> 80% reduction in pain scores at 6 months with gradual increase in pain by 2 yrs. but no severe pain improvement in ambulation ~ 90% and 20-50% reduction in pain scores after first and second procedures respectively return to baseline function after 1st treatment but moderate functional limitation after 2nd treatment
	Gupta 2014 [13]	n = 1 55 yrs	OA Severe hip pain	ON FN XR + US	LA details not provided Positive response to IA injections in the past	Ablative 80c-120 s-2 lesions 10 mm tip	Pain scores function (ADL) analgesic requirements	6 months	<ul style="list-style-type: none"> discontinuation of analgesics for 6 months after 1st treatment and for 4 months after 2nd treatment 80% reduction in pain scores
	Chaiban 2014 [14]	n = 1 80 yrs	PSPP ORIF Hip#	ON FN XR + US	LA details not provided	Ablative 80c-60 s 22G cannula 5 mm tip	Pain scores	3 months	<ul style="list-style-type: none"> 80% reduction in pain scores improvement in ambulation and quality of sleep
	Kasliwal 2014 [15]	n = 1 25 yrs	Avascular necrosis Severe hip pain	ON FN XR	3 cc of 0.1% lignocaine	Ablative 80c-90s ~ 2 lesions 22G cannula 4 mm tip	Pain scores function (ambulate, sleep)	6 months	<ul style="list-style-type: none"> >50% reduction in pain scores but increase in analgesic requirements improvement in ambulation reduction in pain scores by 80%
	Stone 2014 [16]	n = 1 79 yrs	Metastatic cancer Severe hip pain	ON FN LFCN XR + US	2% lidocaine clonidine triamcinolone	Ablative 80C-80s 21G Cannula 10 mm tip	Pain score function analgesic requirements	8 days	<ul style="list-style-type: none"> improvement in ambulation reduction in pain scores by 80%
	Kim 2017 [17]	n = 1 59 yrs	PSPP post THA Severe hip pain	FN US	3 cc of 0.5% bupivacaine	Cooled 60C-150 s 17G cannula	Pain scores	1, 6, 24 months	<ul style="list-style-type: none"> reduction in pain scores by 80%

ADL activities of daily living, CR case report, CS case series (retrospective/prospective), FN femoral nerve, hip# hip fracture, JOA Japan Orthopedic Association, IA intra-articular, LA local anesthetic, LFCN lateral femoral cutaneous nerve, OA osteoarthritis, OHS Oxford Hip Score, ON obturator nerve, OS observational study, ORIF open reduction and internal fixation, PSPP Post-Surgical Persistent Pain, PRF pulsed radiofrequency, RF radiofrequency, SGN superior gluteal nerve, SN sciatic nerve, THA total hip arthroplasty, US ultrasound, VAS Visual Analogue scale, WOMAC Western Ontario and McMaster Universities Osteoarthritis Index score, XR fluoroscopy, yrs years

inferolateral aspects of anterior hip capsule. The accessory obturator nerve (AON) is found to innervate the medial capsule with higher frequency (54%) than previously reported (8–29%) [32••, 42••, 46–50]. It is present as a single nerve formed by the branches from the lumbar plexus which courses deep to the psoas along its medial margin to pass over the iliopubic eminence before supplying the inferomedial quadrant and occasionally the superomedial quadrant [32••, 42••]

Innervation of the Posterior Hip Joint Fewer studies have investigated the presence of sensory nerve endings and mechanoreceptors on the posterior hip capsule. This part of the joint is considered to be an area of minimal innervation. The posterior capsular innervation is derived from the sciatic nerve, nerve to quadratus femoris, superior, and inferior gluteal nerves. The articular branches arising from these nerves are either short or enter the muscle early on in their course. Thus, attempting to ablate these nerves would pose a risk of muscle weakness. Further, the vascular supply to the hip joint is mostly from the posterior circulation of the epiphysis. This aspect is worthy of consideration if one were to target the nerves supplying the posterior capsular region [28, 29, 42••, 44, 51].

- Posteromedial part: nerve to the quadratus femoris and sciatic nerve

The posteromedial superior and inferior regions of the hip joint capsule are innervated by the sciatic nerve and the articular branch of the nerve to the quadratus femoris. The nerve to the quadratus femoris is a branch from the sacral plexus and after exiting the greater sciatic foramen, it descends on the ischium anterior to the sciatic nerve and gives a few articular branches to the posterior hip joint capsule [28–31, 44]. The superior and middle branches curve upwards along the acetabular rim to supply the posterior joint capsule, while the inferior branches run directly along the upper border of the obturator externus where they are distributed to the posteroinferior region of the joint capsule and the ischio-femoral ligament [43]. The pattern of innervation of the hip joint from the sciatic nerve is unclear. The branch is seen to enter the capsule medially but the area of supply can overlap the lateral part supplied by the superior gluteal nerve [28, 29].

- Posterolateral part: superior gluteal nerve

The superior gluteal nerve originates directly from the sacral plexus. Articular branches of this nerve arise from its branches to gluteus minimus muscle and or the tensor fascia lata. These branches are small and accompany

blood vessels and innervate postero-lateral part of the hip joint capsule [28, 29].

- Posteroinferior part: inferior gluteal nerve or obturator nerve

There is no clear description in the existing literature regarding the location of the articular branches of the inferior gluteal nerve or branches of the obturator nerve supplying this part of the hip joint capsule [28, 29, 42••, 44, 51].

Anatomical Targets for Denervation of the Hip Using RF Ablation

It has been suggested that groin and medial thigh pain may be relieved by ablating articular branches of the obturator nerve whereas lateral thigh and trochanteric pain can be relieved by ablating articular branches of the femoral nerve, and gluteal pain can be relieved by blocking articular branches of nerves innervating the posterior hip joint (i.e., nerve to the quadratus femoris, superior and inferior gluteal nerves, sciatic nerve) (Fig. 1) [46, 52–54]. While application of radiofrequency denervation of the zygapophysial (facet) joint in the spine is a frequently performed procedure for chronic low back pain, papers on the denervation of articular branches of femoral, obturator, and accessory obturator nerve that supply nociceptive input to the anterior hip joint capsule have mostly been published only recently secondary to new appraisals on hip anatomy and innervation. The emergence of new equipment and techniques for RF ablation (e.g., cooled RF) has increased the spectrum of available treatments for reducing pain from the hip joint. [13, 26•, 44, 54–56]. The first description of RF neurotomy for hip pain was in 1997 by Akatov and Dreval [22]; they achieved pain control by destruction of articular branches of the obturator nerve. In 2001, Kawaguchi and colleagues reported their experience with radiofrequency neurotomy in 14 patients targeting articular branches of the obturator nerve in patients with pain in the groin and articular branches of the femoral nerve for pain in the trochanteric area. The authors reported that 86% of their patients had more than 50% reduction in pain scores between 1 and 11 months following RF ablation without any adverse events [18]. Other than the study by Okada and colleagues [21], all the clinical studies included in this review discuss the application of radiofrequency lesions to the anterior capsule. Posterior hip innervation needs further research to determine the frequency of nerve branches and their trajectories in relation to bony landmarks. It is in the context of choosing anatomic targets while balancing efficacy against safety, where the use of ablative or pulsed or cooled RF targeting articular sensory branches of major nerves innervating the hip joint has recently evolved.

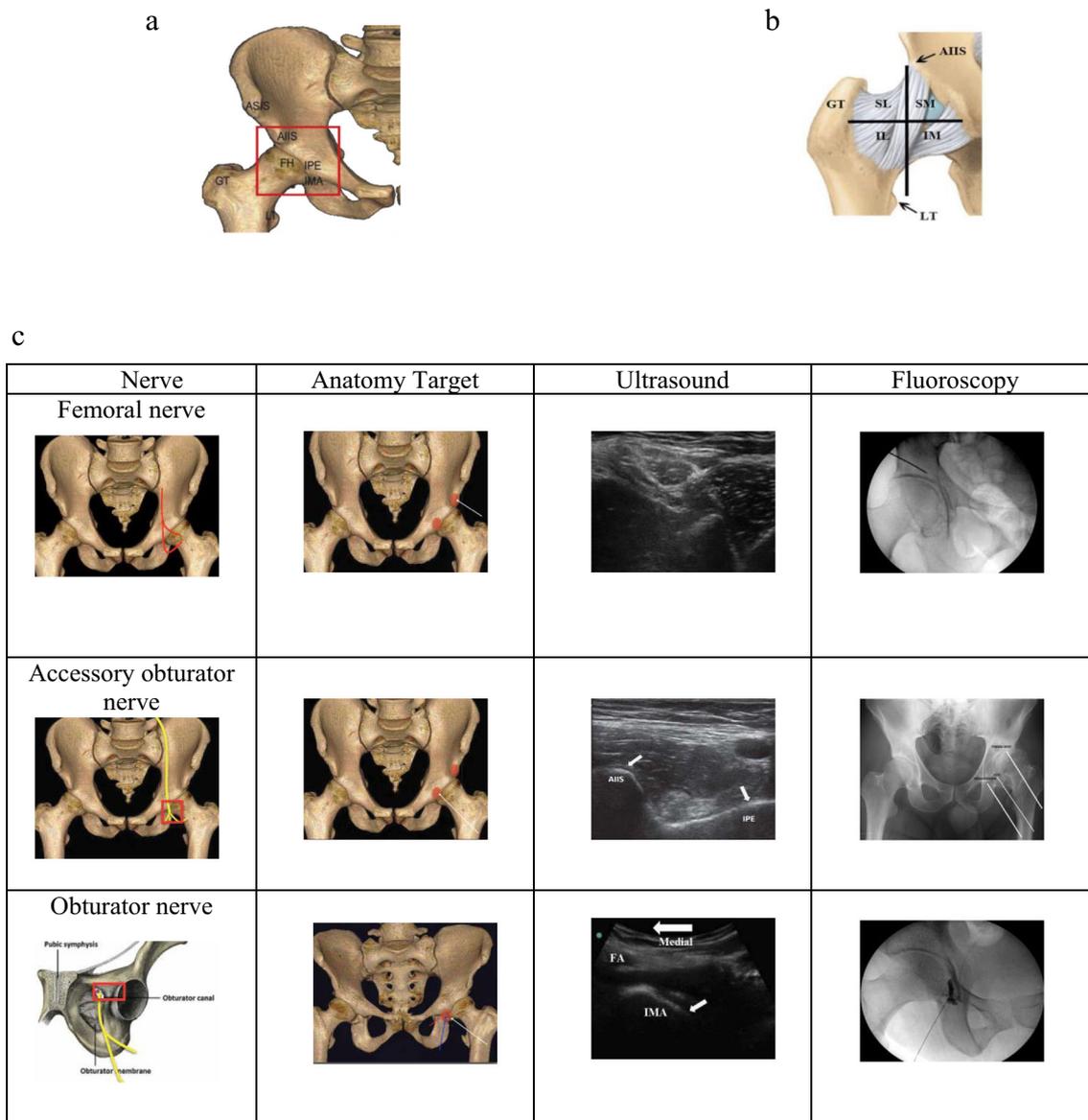


Fig. 1 Radiofrequency targets for denervating the hip joint . **A** Anatomy of the anterior hip joint **B** Anterior capsule of the hip **C** Targets for articular nerves innervating the anterior hip joint. The red rectangle in the pelvis skeleton shows the area of interest in **A** to **C**. AIIS: Anterior Inferior Iliac Spine; AON: Accessory Obturator nerve; ASIS: Anterior

Superior Iliac Spine; FH: Femoral Head; FA: Femoral artery; GT: Greater trochanter; IMA: Inferomedial acetabulum (Tear drop); IPE: Iliopubic eminence; IL: Inferolateral; IM: Inferomedial; LT: Lesser trochanter; SL: Superolateral; SM: Superomedial. Reproduced with permission from Philip Peng Educational Series

Technique for Performing RF Ablation

Imaging Modality and Interventional Landmarks

Although anatomic landmarks have been used in the past for blocking the obturator nerve and the nerve to quadratus femoris, fluoroscopy is considered mandatory for improving the accuracy of ablation of articular branches of nerves innervating the hip joint. All studies Table 2 except one [17] used fluoroscopy for positioning the RF cannulas, with four studies using a combination of fluoroscopy and ultrasound to avoid penetration of the femoral neurovascular bundle

[13, 14, 16, 26•] and one study employing ultrasound exclusively. [17] While femoral and accessory obturator nerves are accessed using a standard approach, three different cannula approaches for accessing the obturator nerve have been described. The anterolateral approach [26•] involves the use of both fluoroscopy and ultrasound for image guidance. This approach is potentially safer compared with the direct anterior approach [17–24] performed solely under fluoroscopy guidance, while the lesser reported anteromedial approach can be employed if both fluoroscopy and ultrasound are used [51]. In one paper, ultrasound was the only imaging modality used to guide placement of

a cooled RF cannula for ablating the articular branches of the femoral nerve [17].

A recent cadaveric study by Short and colleagues on the innervation of the anterior hip joint examined US landmarks for articular branches from the FN, ON, and AON [32••]. The main findings of this study were:

- Articular branches of the FN: High femoral branches that pass over the periosteal surface of the pubis were visualized on anteroposterior fluoroscopy at the superomedial aspect of acetabulum below the AIIS and near the anterolateral margin of the extra-articular portion of the hip joint. This bony region is easily visualized using ultrasound between a point immediately inferior and medial to the anterior inferior iliac spine (AIIS) up to a point midway between AIIS and the medial aspect of the iliopubic eminence [32••, 42••]. The entry point of the RF cannula corresponds to 1–2 cm lateral to the femoral artery pulse. Since these branches pass beneath the iliopsoas muscle, the effect of applying RF close to this muscle requires further examination. Low branches of the FN do not have reliable US visible landmarks [32••].
- Articular branches of the AON: The iliopubic eminence is a consistent landmark for AON which is easily visualized with ultrasound [25, 32••, 57–64].
- Articular branches of the ON: The most consistent sonographic landmark for the placement of the RF cannula to target the articular branches of the obturator nerve is the point immediately inferior to the “teardrop” silhouette seen on anteroposterior fluoroscopy [32••, 57]. This is the bony thickening of the inferomedial acetabulum corresponding to the junction between pubic and ischial bones often referred to as the “incisura” of the acetabulum [42••, 51, 57]. The lateral edge of the obturator foramen lies medial to this point with the acetabular wall situated laterally. A lateral cannula approach involves insertion of the RF cannula 2 cm lateral to this point below the level of the inguinal ligament, with the C-arm rotated ipsilateral 60–70° to the sagittal plane and 20° cephalad to the transverse plane, parallel to the course of the nerves [42••, 57]. It is advised to stay lateral to the teardrop to avoid the main obturator nerve that carries the motor innervation to the adductor muscles.

Diagnostic or Prognostic Blocks Prior to RF Lesioning

Diagnostic (or prognostic) blocks involving the administration of local anesthetics in the joint cavity [42••, 56] or adjacent to the articular branches innervating the hip joint are often performed, but their role in prognosticating success of RF ablation is unclear. The studies in our review employed a variety of paradigms for prognosticating success following RF ablation of the hip joint. Authors of three publications relied on analgesia following intra-

articular hip joint injections with local anesthetics as a selection criterion [13, 16, 18]. Ten out of 16 publications described prognostic articular branch blocks with local anesthetic volumes ranging between 0.5 and 3 ml. [12, 15–17, 19, 23–25, 26•, 27] There was also significant variability in the use and type of prognostic blocks prior to ablation in some of the publications included in our review, with three studies proceeding directly to ablation in absence of prognostic blocks [13, 14, 20].

Sensory and Motor Stimulation Prior to RF Lesioning to Improve Accuracy and Safety

The majority of publications included in our review described the use of sensory stimulation before RF lesioning to improve accuracy, [14–16, 19, 20, 24, 25, 26•, 27] with some reporting a check for absence of motor stimulation [14–16, 19, 25, 27] for improving safety. The lower threshold range for detecting sensory stimulation at 50 Hz was between 0.3 and 0.7 V, while the upper threshold range for ruling out motor stimulation at 2 Hz was between 0.9 and 3 V. The presence of paresthesias at the site of patients’ usual pain constituted a positive sensory test, whereas the absence of contraction of major muscle groups in the upper leg innervated by branches of the FN and ON was an acceptable motor test.

Details of Radiofrequency Technique and Lesion Characteristics

Most publications described the use of 21- or 22-gauge RF cannulas that were 10 cm in length and an active tip measuring 4–10 mm. The nature of the tip (curved or straight) was not specified. One publication described the use of multiple lesions [13]. Multiple and/or large lesions using 20G RF cannulas targeting the articular branches of femoral and obturator nerves may improve the probability of success because they can compensate for variability, effectively decreasing the margin of error. In our review of literature on techniques of RF ablation for hip joint pain, the use of bipolar lesioning was proposed in a cadaveric study [57], and the use of cooled RF was described in one study and a case report [17, 26•]. All publications used neuroablative temperatures (75–90 °C) for 1 to 3 min except for three articles, which employed two cycles of pulsed RF neuromodulation at a temperature of 42 C for 2 to 5 min [20, 24, 27]. Two publications described the use of “cooled” RF energy at 60 C for two - and-a-half minutes to 3 minutes through a 17-gauge cannula to ablate the articular branches of the FN, AON, and ON in a patient with persistent pain following total hip arthroplasty [17, 26•].

Pulsed RF Versus Ablative RF Versus Cooled RF

The mechanism of action of pulsed RF conferring analgesic benefit is not completely understood. Proposed mechanisms include electrical fields generated around sensory nerves reducing

afferent impulse conduction, enhanced descending inhibition, decrease in neuroglial activity, structural rearrangement of axonal membrane proteins, expression of neuron activation transcription factor 3, and some alterations in c-Fos gene expression [20, 24, 25, 26•, 28] which, in turn, encourages the formation of preprodynorphin, an RNA messenger resulting in increased production of endorphin which may confer a prolonged analgesic effect. Three studies reported the use of pulsed, non-ablative RF on the articular branches of the obturator and femoral nerves innervating the hip joint. [20, 24, 27] While pulsed RF requires perpendicular placement of the RF needle to the target that may increase the potential for neurovascular injury, inadvertent damage to the main femoral or obturator nerve stems in the RF field is less likely to result with pulsed RF as compared with ablative RF. Cooled RFA (C-RFA) involves lowering the temperature of the RF probe by internal cold irrigation, thus allowing a higher energy to produce a larger lesion. This avoids the requirement for repeated passes or repositions of the RF cannula near the femoral neurovascular bundle. This in turn may improve safety and comfort of the hip denervation procedure. [26•, 51, 58]

Most patients in the papers included in this review achieved good analgesic response and improvement in ambulation with ablative or pulsed RF or cooled RF lesion, but the duration varied from a few days up to 3 years. Because of the variability of the course and number of branches of the articular nerves innervating the hip joint, multiple/palisade lesions or a single large-size lesion delivered using an internally cooled electrode or a cannula with expandable tines is likely required for optimal results. Further clinical studies are required to examine the optimal type and configuration of lesions for denervating the hip joint. Although no studies have compared pulsed with conventional RF for hip pain, most case series included in our review employed conventional ablative RF.

Role of Repeating Ablative Procedures for Hip Joint Denervation

Two individual case reports reported decreasing benefits with repeat ablations [12, 13] which is frequently the case with repeat procedure done for pain. [59, 60] However, based on the small case series evaluating serial RF ablation procedures of the lumbar and cervical facet joints, it is reasonable to hypothesize that majority of patients who undergo repeat denervation will experience comparable benefit [61–63] The current evidence does not allow us to draw firm conclusions about the effectiveness of repeat hip RF lesioning.

Outcomes of RF Ablation of the Hip Joint

Comprehensiveness in the reporting of analgesic and functional outcomes, and adverse effects varied across publications included in our review (Table 1).

Analgesic Outcomes

All 16 publications reported reduction in pain following RF procedures, but there was significant variation in the length of follow-up, which ranged from 8 days to 3 years. [12–25, 26•, 27] The degree of analgesic benefit varied with the reduction in pain scores ranging from 30 to over 90% from baseline scores. Some studies with serial follow-ups reported attrition of analgesic benefits with time [12, 13] with an inability to reproduce the benefits with repeat procedures, while one publication reported almost complete absence of pain 24 months after the ablation [17]. Reduction in requirement for analgesics by patients following the ablation procedures was described in almost all publications, but the reporting was subjective and inconsistent. The opioid use before and after RF ablation was quantified by Kapural and colleagues [26•], but the authors were unable to show reduction in opioid requirements, while most other studies did not provide data on analgesic use after the procedures. Most authors did not correlate analgesic success with the number of nerves ablated. Similar to publications on ablative RF lesioning, the four publications evaluating pulsed RF neuromodulation [18–20, 22] also reported analgesic benefits and subjective reduction in requirements for oral analgesics lasting for up to 3 to 4 months.

Functional Outcomes

Only a few studies included in this review used validated measures of hip function (e.g., Western Ontario and McMaster (WOMAC) Osteoarthritis Index, Harris Hip Score, Oxford Hip Score) [19] to assess the impact of RF ablation while the rest relied on subjective assessment of improvement in ambulation, sleep, and the ability to perform activities of daily living. In terms of the length of follow-up, two studies by Kapural et al. [26•] and Tinnarelli et al. [27] had long-term follow-up of six and 12 months respectively but overall there was a lack of data about long-term outcomes following sensory ablation of the hip joint. Monitoring outcomes is important because of concerns around the hip joint becoming insensate (essentially a Charcot joint) that may be susceptible to collapse.

Adverse Effects of RF Ablation of the Hip Joint

Adverse effects of RF procedures on innervation to the hip joint were reported in some publications which included loss of sensation in the cutaneous distribution of the FN and ON. [22, 23, 25] Hematomas in the inguinal area with use of a direct anterior approach for ablation of the articular branches of the obturator nerve were reported in one publication that resulted in the authors adopting the lateral

approach. [19] None of the publications described a systematic approach for evaluating adverse effects (e.g., examination of sensation and motor strength in dermatomal and myotomal distribution of the ablated nerves respectively, standardized questions, or pre-set, serial follow-ups).

Conclusions

Based on the papers included in our review, we propose the following indications for ablation of sensory nerve supply to the hip joint: arthroplasty is not appropriate because of risk of morbidity and mortality, or patient is not willing to undergo this procedure, or the wait time for arthroplasty is long [42••, 51, 64].

Complete ablation of the sensory supply to abolish hip pain is challenging due to gaps in knowledge about innervation patterns, the proximity of major nerves providing cutaneous sensation and motor innervation to the articular branches that supply hip joint and most of the studies focusing on treatment of anterior hip pain. Based on the available literature, we propose the following recommendations [42••, 51] with the caveat that these may change as more evidence is published.

- Target purely sensory distal afferent articular nerves where possible.
- Consider prognostic blocks with local anesthetics prior to RF ablation.
- Appropriate lesion parameters: choose a probe (needle gauge, length, expandable tines or non-tined), lesion modality (conventional, pulsed or Cooled RF), and appropriate parameters (ramp time, peak temperature, and treatment time) such that it maximizes nerve ablation target with minimal tissue injury to adjacent tissue.
- Ablation of nerves that have both sensory and motor components should be only performed where motor function loss is unimportant to avoid adverse clinical consequences. Alternatively, non-ablative pulsed RF can be considered.
- A frank discussion with patient about the long-term implications of developing an insensate joint.
- A lateral cannula insertion for the obturator branch or combined use of ultrasound and fluoroscopy modalities to avoid damaging neuro-vascular structures. Medial cannula insertion under ultrasound to target the ‘tear drop silhouette is another option.
- Defined landmarks to target articular innervations to posterior hip joint are yet to be established.
- Robust long-term data collection for pain and functional outcomes using validated scales.

Compliance with Ethical Standards

Conflict of Interest Pranab Kumar, Yasmine Hoydonckx, and Anuj Bhatia declare no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of major importance

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