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EXPERT OPINION

Peripheral Nerve Stimulation of the Shoulder: A Technical Primer

Sailesh Arulkumar[1], Elisa E Neuchat[2], Eric Ly[3], Austin Ingwei Ly[4], Kiana Fahimipour[5], Mehul J Desai[6,7]

[1]Department of Anesthesiology, SSM Health, St. Anthony's Hospital, Oklahoma City, OK, USA; [2]School of Medicine, Louisiana State University Health Sciences Center at Shreveport, Shreveport, LA, USA; [3]Department of Anesthesiology, Brown University, Rhode Island Hospital, Providence, RI, USA; [4]The University of Tennessee Health Science Center College of Medicine, Memphis, TN, USA; [5]Department of Anesthesiology; Louisiana State University Health Sciences Center at New Orleans, New Orleans, LA, USA; [6]International Spine Pain & Performance Center, Washington, DC, USA; [7]George Washington University School of Medicine and Health Sciences, Washington, DC, USA

Correspondence: Mehul J Desai, International Spine Pain and Performance Center, 2021 K Street NW Suite 615, Washington, DC, 20006, USA, Tel +1.202.808.8295, Fax +1.202.808.8296, Email drdesai@isppcenter.com

Abstract: Scapulalgia or shoulder pain accounts for 16% of all musculoskeletal complaints in the healthy adult population and becomes more common as we age. When this pain exceeds 3 months in duration, it is deemed to be chronic, and typically treated in an escalating manner. Spanning a continuum of conservative and non-conservative measures, chronic shoulder pain treatments range from rest and physical therapy to surgery. Since each patient presents with a unique spectrum of symptoms a customized treatment plan is often required. Over the lifetime of many of these patients, a variety of treatment options are required. One of these treatment options, peripheral nerve stimulation (PNS), is a minimally invasive procedure in which an electrical impulse is delivered through a percutaneously implanted, small caliber electrode to a peripheral nerve proximal to the lesion which interferes with the pain signals. Over the past several years, significant growth of PNS in the treatment of chronic neuropathic pain has been observed. However, the procedural techniques have not been well described. The foundation of long-term, minimally invasive percutaneous PNS in patients with chronic shoulder pain, and procedural techniques for stimulating the suprascapular and axillary nerves using fluoroscopy or ultrasonography will be described in this report.

Keywords: scapulalgia, shoulder pain, chronic pain, suprascapular nerve, axillary nerve, peripheral nerve stimulation

Introduction

Scapulalgia or shoulder pain affects 18–26% of adults[1] and leads to over 12 million office visits annually in the otherwise healthy adult population.[2,3] Shoulder pain is often persistent or intermittent and defined as chronic when the pain exceeds 3 months.[4] Initial treatments are often applied in an escalating manner and may include one or more of the following: rest, non-steroidal medications, and physical therapy. Subsequent treatments may include corticosteroid injections, transcutaneous electrical nerve stimulation, radiofrequency (RF) ablation or cooled RF, temporary or short-term peripheral nerve stimulation (PNS), opioid medications, cryoablation, long-term PNS, or surgery.[5] These therapies are often used in combination with varying results; however, we believe shoulder pain treatment should be tailored to the specific patient's needs.

Peripheral nerve stimulation was invented in the mid-1960s and has been approved for neuropathic pain.[6] Since then, the technique and indications have evolved, but the current definition of PNS is the minimally invasive placement of a small caliber electrode along the target peripheral nerve which delivers an electrical stimulus that interrupts the nerve firing affecting a reduction in pain.[7] The exact mechanism of PNS is not fully understood, but it is thought to work by activating inhibitory neurons in the spinal cord.[8] More recently, Lin et al postulated the effect of PNS both centrally and peripherally. The authors described effects via the inflammatory pathways, the autonomic nervous system, the endogenous pain inhibition pathways, and involvement of the cortical and subcortical areas.[9]

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Over the past several years, PNS has broadly split into two major categories: short-term, temporary stimulation and long-term stimulation. Theoretically, short-term temporary stimulation provides relief in some patients beyond the duration of stimulation, and while studies have demonstrated this to some extent,[10,11] durable consistent relief beyond 1 year has not been reported. Permanent but reversible PNS may provide more consistent patient benefit and durable results over the long-term. PNS for the treatment of shoulder pain is performed by stimulation of one or both of the suprascapular or axillary nerves.[10–26] The foundation of long-term, minimally invasive percutaneous PNS and its impact on chronic shoulder pain, patient selection, and procedural techniques for stimulating the suprascapular and axillary nerves using fluoroscopy or ultrasonography, and patient follow-up will be reviewed in this report.

Patient Selection

Patients with chronic shoulder pain are typically considered for PNS after they have exhausted a variety of conservative measures that include rest, non-steroidal anti-inflammatory medications, physical therapy, behavior modification, and corticosteroid injections.[27,28] Table 1 lists a number of shoulder pain etiologies amenable to PNS. In our experience, we found that patients with neuropathy and glenohumeral osteoarthritis are particularly good candidates with limited alternatives.

Relevant Anatomy

Suprascapular Nerve

To perform PNS, first identify key landmarks of the posterior scapular region and associated neurovascular structures. The suprascapular foramen, commonly referred to as the suprascapular notch, allows nerves and vasculature to continue from the base of the neck to the posterior scapular region. The suprascapular nerve typically traverses from anterior to posterior through the suprascapular notch with the artery and vein. The nerve runs deep to the rhomboid muscle superior to the scapula, through the suprascapular notch (inferior to the superior transverse scapular ligament), and inferior towards the spinoglenoid notch, which allows the nerve to reach the infraspinous fossa. The nerve branches as it courses through the spinoglenoid notch.

Axillary Nerve

The quadrangular space allows for communication between the axilla and posterior scapular region and is an important anatomical opening for the axillary nerve and the posterior circumflex humeral artery to pass anterior to posterior. It is bordered by the teres minor superiorly, the teres major inferiorly, the surgical neck of the humerus laterally, and the long head of the triceps brachii laterally.

Procedure

For PNS therapy, a trial procedure might be performed dependent on geographic or payer requirements. This may allow the clinician and patient to test the effectiveness of the stimulation prior to permanent implant. Before the procedure, the clinician should refer to the specific manufacturer's Instructions for Use. Patients with allergies to any components of the PNS implanted system would be contraindicated for treatment. Relative complications would include coagulopathies, or local infections near the lead implant access site. Implanting physicians should also review the 2017 Neurostimulation

Table 1 Non-Operative and Primary Patient Conditions Amenable to PNS

Posttraumatic or Postsurgical	Primary	Less Responsive Conditions
• Post partial or total shoulder replacement • Rotator cuff pathology – tendinopathy, partial tear, fully retracted tear • Severe or repeated shoulder dislocations • Brachial plexopathy	• Nerve entrapment or neuropathy • Glenohumeral osteoarthritis • Post-stroke shoulder pain • Iatrogenic injury • Parsonage-Turner syndrome	• Labral pathology • Acute rotator cuff pathology • Clavicular pathology

Note: Based on these studies.[10–26]

Appropriateness Consensus Committee recommendations, including those for infection prevention and management, as well as those for bleeding and coagulation management as they are useful in surgical management of PNS patients.[27,29,30]

Patient Preparations

Minimally invasive, percutaneous PNS requires a sterile surgical field. Suitable patient preparation including appropriate antiseptic skin preparation such as chlorhexidine or betadine should be utilized. Surgical draping to create a sterile field as well as the use of suction and electrocautery is recommended. A suitable positive pressure environment should be applied.[31]

There are several important considerations when positioning patients. Chief amongst those are patient comfort and safety, and appropriate access to the target nerves and internal pulse generator (IPG) implantation site or receiver position. Examples of patient positioning for access to the target nerves in the shoulder include prone, beach chair, and lateral semi-decubitus.

Target Nerves for PNS Therapy

The decision to stimulate the suprascapular nerve or the axillary nerve or both is typically based on several factors. With little data to guide this decision, pain location and underlying etiology are the primary drivers of decision-making. Posterior pain most commonly is addressed with suprascapular stimulation, whereas lateral pain may require axillary stimulation. Nerve block as a tool to map pain may be useful in the setting where pain is non-specific or does not follow a singular nerve path. Similarly, conditions such as glenohumeral osteoarthritis and post-stroke shoulder pain may benefit more from coupling a motor stimulation paradigm involving the axillary nerve in addition to suprascapular stimulation rather than stimulation of one nerve alone.

The Suprascapular Nerve

The suprascapular nerve is the lateral branch of the superior trunk of the brachial plexus and innervates the supraspinatus and infraspinatus muscles and is the target nerve for treatment of patients with pain from the posterior aspect of the shoulder (Figure 1). It also provides sensory innervation for the glenohumeral and acromioclavicular joints.

Lead Implantation for PNS of the Suprascapular Nerve Using Fluoroscopy

Isolating the target location of the PNS lead placement should be considered prior to beginning,ie, at the suprascapular notch or spinoglenoid notch. Targeting the nerve at the suprascapular notch is the commonly described technique in the literature.[15,20,32] Typically, the patient should be in the prone position with the head in the contralateral position with arms adducted to their sides (Figure 2). A pillow is placed below the patient's chest to elevate the chest to create a safe environment for needle positioning. Drape and prepare the area to the midline, and below the scapula all the way across the deltoid to maximize options for IPG placement or receiver position. Optimized visualization to the suprascapular notch is typically achieved by adjusting the image intensifier 10–20 degrees cranial to expose the trajectory of the suprascapular notch and to expose the acromion and coracoid.

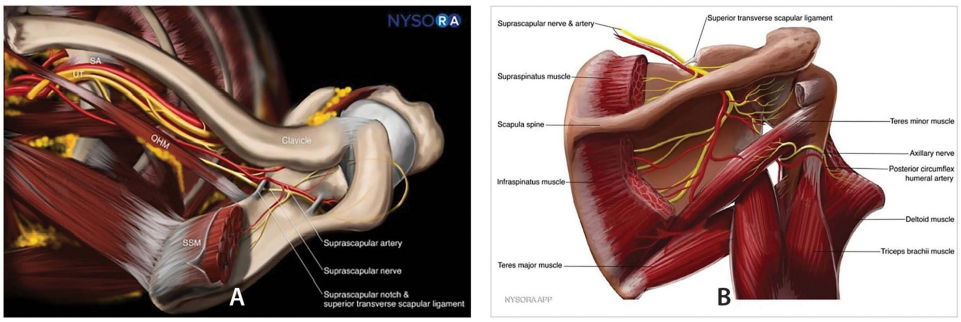

Figure 1 (**A**) Anterior view and (**B**) posterior view of the anatomy of the shoulder. Source: NYSORA.com. In compliance with ethical and academic standards, we acknowledge NYSORA, Inc. for granting permission to use the images in this article for educational purposes. All rights to these images remain with NYSORA, Inc.

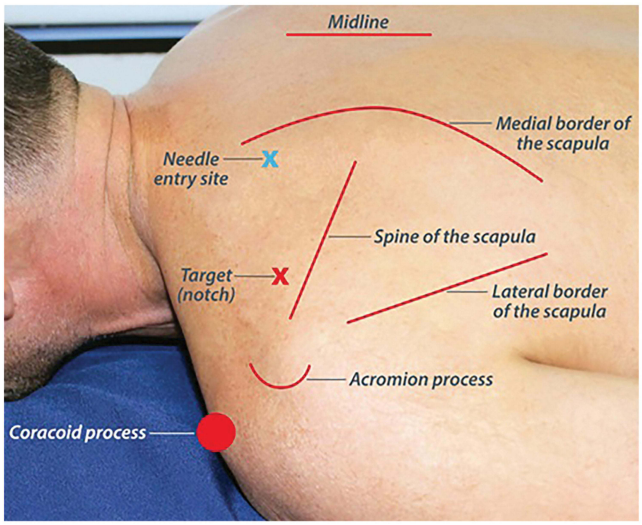

Figure 2 Patient positioning and external anatomical markers for accessing the suprascapular nerve. Figure courtesy of Nalu Medical. ©2024.

Using images of a needle outside of the body on fluoroscopy, map the lower, medial and lateral borders of the scapula to provide a reference point (Figure 3). The nerve target is just above the spine of the suprascapular notch. Administer local anesthesia at the area of needle insertion. It is advisable to avoid anesthetizing the entire target nerve for the purposes of testing intraoperatively and post-procedure. Puncture the skin with an insertion needle at the upper border of the scapula. Start coaxially and gradually turn towards the suprascapular notch. Moving medially to laterally, walk the insertion needle along the upper medial spine of the scapula toward the suprascapular notch. Maintain bony contact throughout, using intermittent fluoroscopic images to confirm the insertion needle trajectory. Stop advancement at the bony structure of the suprascapular notch. When the target area is reached, insert a PNS lead through the insertion needle and pull the needle back over the positioned lead to expose the electrodes for testing. Note that it is not necessary to touch the nerve with PNS as you are creating an electrical field. Generally, a distance of 0.5–3.0 cm away from the nerve is recommended and may be further dependent on the type of lead utilized as well as the area of the nerve stimulated. Lead technology and configuration differs and may affect the electrical field range.[33] If appropriate sensory and/or motor response is achieved completely remove the needle over the lead.

Lead Implantation for PNS of the Suprascapular Nerve Using Ultrasound

Identification of the suprascapular nerve can also be achieved using ultrasound for lead placement for innervation of the nerves supplying the shoulder.[20] The patient can be in a sitting position, prone, or in the lateral decubitus position

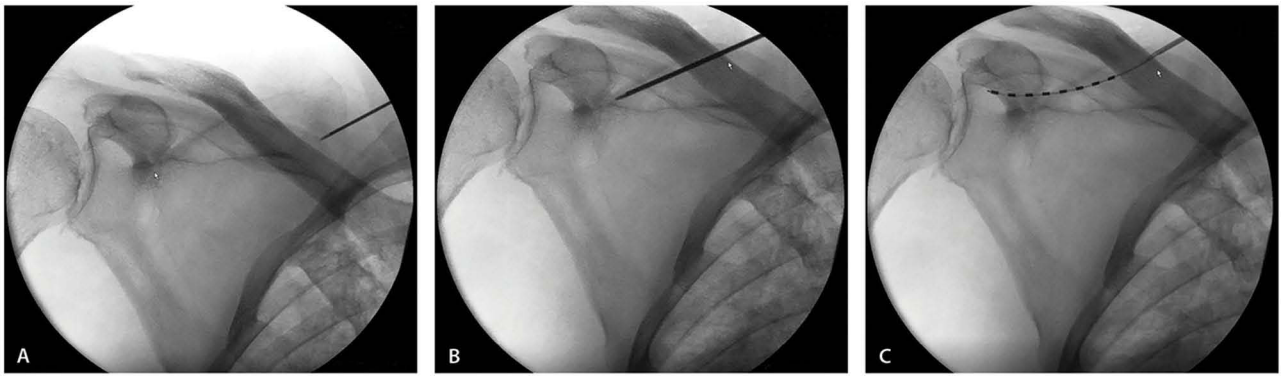

Figure 3 Accessing the suprascapular nerve using fluoroscopy. (**A**) needle entry site; (**B**) final needle placement; and (**C**) final lead placement. Figures courtesy of Nalu Medical. ©2024.

Figure 4 (**A**) Ultrasound transducer placement for accessing the suprascapular nerve; (**B**) Ultrasound image of the suprascapular nerve. Source: NYSORA.com. In compliance with ethical and academic standards, we acknowledge NYSORA, Inc. for granting permission to use the images in this article for educational purposes. All rights to these images remain with NYSORA, Inc.

(Figure 4A). A curved transducer is used for larger shoulders and a linear transducer is used for smaller shoulders. The ultrasound transducer is placed in the coronal plane over the supraspinatus muscle and then aimed to visualize the posterior part of the suprascapular spine and fossa.[20]

Identify the suprascapular notch. Mark the target location before prepping the patient. Since it is possible that the needle can enter the thoracic cavity, it is important to avoid targeting anteriorly. After identifying the suprascapular notch, the suprascapular nerve can be visualized below the transverse suprascapular ligament with the suprascapular artery above (Figure 4B). As with fluoroscopy, a medial-to-lateral approach is used for the insertion of the needle. For needle visualization and targeting adjacent to the nerve, an in-plane approach can be used.[20] Since the shoulder is a very mobile joint, considerations to prevent lead migration and ensuring that the lead does not cross the shoulder joint are needed.

The Axillary Nerve

PNS of the shoulder may include stimulation of the axillary nerve alone or in combination with the suprascapular nerve. The axillary nerve is a terminal branch of the C5 and C6 nerve roots at the level of the axilla and travels posteriorly and inferiorly to the subscapularis muscle, which is found in the quadrangular space with the posterior circumflex humeral artery. The axillary nerve leaves the quadrangular space and gives off an anterior branch that carries motor nerve fibers to the deltoid muscle and articular nerve fibers to the shoulder joint, and a posterior branch that carries motor nerve fibers to the teres minor muscle and articular nerve fibers to the skin over parts of the deltoid muscle.[34] The quadrangular space serves as an access point for the axillary nerve. While the axillary nerve may be targeted along its course from the brachial plexus to the posterior humerus, Mazzola and Spinner recommend the posterior humerus as the best location to target.[20]

Lead Implantation for PNS of the Axillary Nerve Using Fluoroscopy

The patient is positioned prone with arms adducted and a towel or pillow placed to bump up the affected shoulder. The fluoroscope is placed in the anterior-posterior position visualizing the junction of the head and neck of the humerus. The fluoroscopic target is just distal to the junction of the humeral head and neck such that the circumflex artery is avoided. The insertion needle is inserted with either a medial or lateral approach. First contact is made with the edge of the humeral neck, then with a shallow angle, walk the needle across the humerus just distal to the junction of the head and neck of the humerus. The final PNS lead location should be parallel to this junction.

Lead Implantation for PNS of the Axillary Nerve Using Ultrasound

For PNS lead placement using ultrasound, the patients should be in the same position as if using fluoroscopy; prone with arms adducted and a towel or pillow under the affected shoulder. The transducer is placed in a sagittal plane over the humeral head and neck (Figure 5A). The cross-sectional image should show the infraspinatus cranially, and the teres minor caudally (Figure 5B). The axillary nerve and circumflex artery are visualized at the inferior border of the terres minor. The cannula or needle is typically inserted from a caudal to cranial, in-plane approach although lateral to medial,

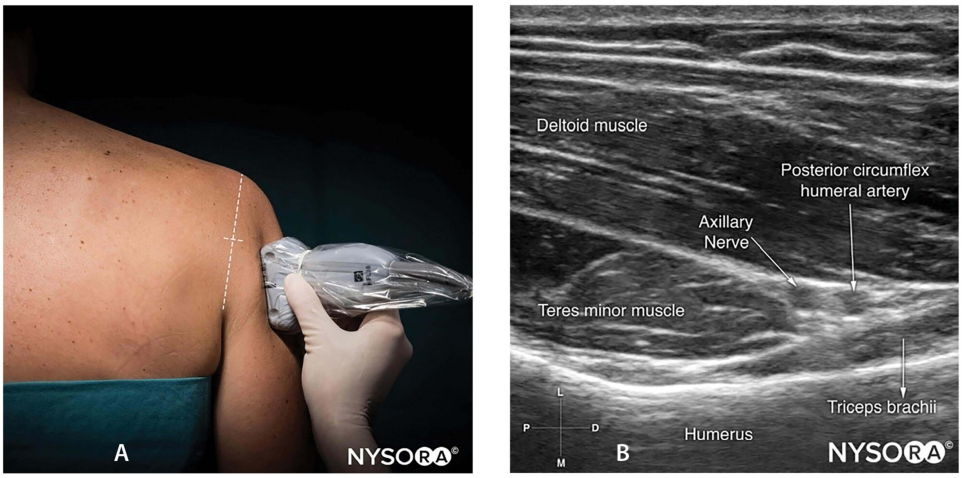

Figure 5 (**A**) Ultrasound transducer placement for accessing the axillary nerve; (**B**) Ultrasound image of the axillary nerve. Source: NYSORA.com. In compliance with ethical and academic standards, we acknowledge NYSORA, Inc. for granting permission to use the images in this article for educational purposes. All rights to these images remain with NYSORA, Inc.

or medial to lateral approaches as well as out-of-plane techniques have been described. The final PNS lead location should be at the junction of the head and neck of the humerus, in a parallel orientation to the trajectory of the axillary nerve.[20,32] Figure 6 shows a summary of the procedural steps for fluoroscopic and ultrasound imaging modalities for the suprascapular and axillary nerves.

Lead and Device Considerations

Single or Dual Lead Stimulation

Depending on the use case, a single or dual-lead configuration may be considered. When using dual leads, consider programming different stimulation paradigms for the suprascapular and axillary nerves. Dual leads may provide a broader area of therapy and also convey the benefit of therapy redundancy; if one lead is lost due to mechanical failure or migration, adequate pain relief may still be achieved with the remaining lead.

Tunneling and Implantable Pulse Generator Placement

If using a PNS system that includes an IPG, surgical planning includes identifying a tunneling pathway and IPG placement. Like other surgical technical skills, with experience, most neuromodulators discover a preferred approach. Tunneling with a skill-specific tool or a needle may depend on personal preference, tunneling distance, depth, and location. Ascertaining tissue viability and potential obstacles to tunneling such as arteries, veins and nerves should be planned prior to surgery. In our experience, anesthetizing the tunneling track reduces post-surgical pain and allows for further trajectory planning and final confirmation of obstacles. An adequate depth of tunneling (ie below the dermis) should also be ensured so that erosion risk of the lead(s) is mitigated. The tunneling depth may vary based on patient body habitus.

Finally, IPG implantation or receiver position should be planned, and the location marked prior to surgery. Common locations for placement when targeting the nerves of the shoulder include infra-clavicular, flank, and peri-scapular and depend primarily on patient body habitus. Details of the types and programming of the available implantable pulse generator options are outside of the scope of this report.

Discussion

The majority of studies supporting the use of PNS in chronic shoulder pain are case series or case reports.[10–26] As reported by Mazzola and Spinner the use of PNS in chronic shoulder pain is applied to wide range of clinical conditions ranging from hemiplegic shoulder pain to adhesive capsulitis and glenohumeral osteoarthritis.[20] While most of these studies individually are either small or of modest quality, in aggregate they provide the foundation of further ongoing

Fluoroscopy		Ultrasound	
Patient Positioning			
Suprascapular	**Axillary**	**Suprascapular**	**Axillary**
Prone with head turned away from access location. Arms adducted. Bump under affected shoulder.	Prone with arms adducted. Bump under affected shoulder.	Sitting, prone, or lateral decubitus.	Prone with arms adducted. Bump under affected shoulder.
Imaging			
Tilt fluoroscope 10-20 degrees cranial to visualize the medial & lateral borders of the scapular and suprascapular notch.	AP fluoroscopy visualizing the head and neck of the humerus.	Place transducer in a coronal oblique orientation over the shoulder, parallel to the lateral 1/3 of the scapular spine to locate the suprascapular notch.	Place transducer in a sagittal plane over humeral head and neck. In cross section, the infraspinatus is seen cranially, and the terres minor seen caudally. The axillary nerve & circumflex artery are visualized at the inferior border of the terres minor.
Approach			
Insert needle at the upper medial border of the scapula. With a shallow angle, walk needle along the spine of scapula towards suprascapular notch.	Insert needle with either a medial or lateral approach. With a shallow angle, walk needle just distal to the junction of the head and neck of the humerus.	Insert needle in a shallow in-plane orientation, advancing medial to lateral until needle tip makes boney contact with the floor of the supraspinous fossa. Visualize the suprascapular nerve and artery.	Insert needle from caudal to cranial, lateral to medial, or medial to lateral approach in either in-plane or out-of-plane.
Final Lead Placement			
PNS lead placed in the supraspinous fossa in a perpendicular orientation to the suprascapular nerve.	PNS lead placed parallel to the junction of the head & neck of the humerus.	PNS lead placed in the supraspinatus fossa in a perpendicular orientation to the suprascapular nerve.	PNS lead placed at the junction of the head & neck of the humerus, in a parallel orientation to the axillary nerve.

Figure 6 Procedural considerations for peripheral nerve stimulation of the suprascapular and axillary nerves.

investigations into the clinical utility of this application. In the authors' experiences, PNS implantation targeting shoulder pain has commonly included the suprascapular nerve; however, PNS of both the suprascapular and axillary nerves can also be performed. Taking care to understand the anatomy pre-operatively and choosing a comfortable, reproducible approach is recommended. Whether ultrasound guidance or fluoroscopic imaging or a combination are used, anticipating these choices early is preferential. While generally safe, there are risks inherent to PNS implantation. These include more typical risks associated with neuromodulation such as infection, lead migration, erosion or skin breakdown, loss of efficacy, and bleeding but also include specific risks at the shoulder including pneumothorax. Surgical comorbidities and surgical technique should not be underestimated despite the miniaturization of these PNS technologies. Managing anticoagulants and infection risk is of paramount importance. Surgical skills and suture choice should be appropriate based on the needs of the patient and the specific surgery.

Limitations

This report describes the methods used for patient selection and procedural techniques that these authors have determined to work with good results in our clinical practice. Several implantable lead and pulse generator options are available, yet it is our opinion that the lead implant techniques described here can be applied generically.

Conclusion

Technical considerations for the application of PNS to chronic shoulder pain are specific to the nerves targeted and the imaging guidance chosen. As with many other neuromodulatory techniques, patient selection is paramount.

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