REVIEW

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Ultrasonography-guided Peripheral Nerve Blocks in Orthopedic Lower Extremity Surgery: A Narrative Review

Ortopedik Alt Ekstremite Cerrahilerinde Ultrasonografi Kılavuzluğunda Periferik Sinir Blokları: Anlatısal Derleme

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Abstract

In orthopedic lower extremity surgeries, peripheral nerve blocks have gained an important place in anesthesia practice, providing perioperative analgesia, reducing opioid consumption, and enabling early mobilization. During hip, knee, ankle, and foot surgeries, various nerve blocks targeting both motor and sensory functions are applied individually based on the anatomy of the surgical area and the patient's characteristics. Femoral nerve block, pericapsular nerve group block, and suprainguinal and infrainguinal fascia iliaca blocks are frequently preferred in hip and proximal femur interventions, while in knee surgeries, the combination of adductor canal block and interspace between the popliteal artery and the capsule of the posterior knee block stands out. In ankle and foot surgeries, adequate anesthesia and analgesia can be achieved by superficially blocking the tibial, peroneal, sural and saphenous nerves. Nerve blocks performed under ultrasonography guidance reduce the risk of failure due to anatomic variations and decrease complication rates. In this review, the main peripheral nerve blocks used in lower extremity orthopedic surgeries, their anatomical basis, indications, complications, and application techniques are evaluated in light of the current literature.

Keywords: Analgesia, lower extremity, orthopedic procedures, peripheral nerve block, postoperative pain management, ultrasound-guided regional anesthesia

Öz

Ortopedik alt ekstremite cerrahilerinde periferik sinir blokları, perioperatif analjezi sağlama, opioid tüketimini azaltma ve erken mobilizasyona olanak tanıma açısından anestezi pratiğinde önemli bir yer edinmiştir. Kalça, diz, ayak bileği ve ayak cerrahileri sırasında hem motor hem de duyu fonksiyonlarını hedefleyen çeşitli sinir blokları, cerrahi alanın anatomisine ve hastanın özelliklerine göre bireyselleştirilerek uygulanmaktadır. Femoral sinir bloğu, perikapsüler sinir grup bloğu ve suprainguinal ve infrainguinal fascia iliaca blokları kalça ve proksimal femur girişimlerinde sık tercih edilirken, diz cerrahilerinde adductor kanal bloğu ile popliteal arter ile posterior diz kapsülü arasındaki boşluk bloğunun kombinasyonu öne çıkmaktadır. Ayak bileği ve ayak cerrahilerinde ise tibial, peroneal, sural ve safen sinirlerin yüzeyel olarak bloke edilmesiyle etkili bir anestezi ve analjezi sağlanabilmektedir. Ultrasonografi kılavuzluğunda gerçekleştirilen sinir blokları, anatomik varyasyonlara bağlı başarısızlık riskini azaltmakta ve komplikasyon oranlarını düşürmektedir. Bu derlemede, alt ekstremite ortopedik cerrahilerinde kullanılan başlıca periferik sinir blokları; anatomik temelleri, endikasyonları, komplikasyonları ve uygulama teknikleri güncel literatür eşliğinde değerlendirilmektedir.

Anahtar kelimeler: Alt ekstremite, analjezi, ortopedik prosedürler, periferik sinir bloğu, postoperatif ağrı yönetimi, ultrason rehberliğinde rejyonal anestezi

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Introduction

Lower extremity surgeries constitute a significant part of orthopedic practice, encompassing a wide range of procedures, including hip, knee and ankle prostheses, ligament reconstructions, and fracture repairs. During these surgeries, both intraoperative and postoperative pain control are crucial for patient satisfaction, early mobilization, and the reduction of complications. Although general anesthesia and neuraxial blocks are frequently applied, both methods have various disadvantages. Although subarachnoid block and epidural anesthesia/analgesia are successfully applied, there are various problems in patients who are sensitive to sympathetic blockade or who are on anticoagulant use (1,2). Regional anesthesia, which holds an important place in orthopedic operations, has gained significance in recent years with the widespread adoption of ultrasonography (USG).

In recent years, with the widespread use of USG-guided regional anesthesia and techniques, both fascial plane blocks and peripheral nerve blocks (PNBs) can be applied safely and effectively. It has been reported that USG-guided blocks in abdominal operations contribute to postoperative analgesia as well as to mobilization and gastrointestinal functions (3,4). In orthopedic operations, techniques such as femoral nerve block, adductor canal block, sciatic nerve block, and posterior gluteal approaches are widely used to provide adequate anesthesia and analgesia in knee and hip surgeries. These blocks not only reduce postoperative pain but also contribute to lowering healthcare costs by shortening early rehabilitation and discharge times. Their role in multimodal analgesia approaches is particularly noteworthy, as they help in reducing opioid-induced side effects such as nausea, respiratory depression, and sedation. The increasing number of studies on the efficacy and safety of PNBs in lower extremity surgeries, as well as their growing application in both pediatric and adult patients, further underscores their importance (5-7).

In this review, the anatomical basis, technical features, indications, complications, and clinical results of PNBs, which are frequently performed under USG guidance in orthopedic lower extremity surgeries, will be discussed in the context of the current literature.

Method

A literature search was conducted in PubMed, Scopus, and Google Scholar databases for articles published between June 2015 and June 2025 using the keywords "ultrasound-guided", "peripheral nerve block", "lower extremity" and "orthopedic surgery". Randomized controlled trials, observational studies, cohort studies, systematic reviews, and meta-analyses were included in the review. Although no strict inclusion or exclusion criteria were adopted, articles were first evaluated based on their titles and abstracts, followed by an assessment of the full-text manuscripts. In addition, manual search strategies were employed, including screening the reference lists and cited articles in each database. References from key articles were then carefully examined to identify additional relevant sources. Case reports and studies not directly related to lower extremity orthopedic surgery were excluded. This narrative review adhered to the scale for the assessment of narrative review articles checklist to improve reporting quality (8).

PNBs in Hip and Femur Surgery

Anatomical Innervation

The innervation of the hip and femur region is provided by the contribution of multiple nerves originating from both the lumbar and sacral plexus. The anterior hip capsule is innervated mainly by the femoral nerve, the obturator nerve, and the accessory obturator nerve (9). The posterior hip capsule is innervated mainly by the superior gluteal nerve, the inferior gluteal nerve, the quadratus femoris nerve, and branches of the sciatic nerve (10). The femoral skin and periosteum are innervated by branches of the femoral nerve (such as the saphenous nerve) and the obturator nerve. Visceral pain fibers arriving at the hip joint can be transmitted through both somatic and autonomic pathways, which complicates postoperative analgesia. This anatomical diversity may necessitate the use of more than one nerve block or combined techniques to provide adequate analgesia in hip and femur surgeries (11).

Femoral Nerve Block

A femoral nerve block is a peripheral nerve block frequently used to provide adequate analgesia during orthopedic surgeries targeting the anterior region of the hip and femur, as well as the anterior aspect of the knee (12). The femoral nerve originates from the L2-L4 roots and passes through the iliopsoas muscle to reach the femoral triangle region just below the inguinal ligament. In this region, the nerve is located lateral to the femoral artery and can be easily identified with ultrasound guidance due to its superficial course. The block application is effective in reducing both intraoperative and postoperative pain in procedures such as total hip arthroplasty, femoral neck fracture operations, and knee arthroscopies (13). Ropivacaine (0.2-0.5%), bupivacaine (0.25-0.5%), and levobupivacaine (0.25-0.5%) are frequently used as local anesthetics. While 15-20 mL of local anesthetic is sufficient for a single-shot application, an infusion of 5-8 mL/hour with 0.2% ropivacaine is recommended in cases where a femoral nerve catheter is placed (14). The duration of the block varies depending on the agent used, but it lasts 12-18 hours for bupivacaine and levobupivacaine and approximately 8-12 hours for ropivacaine (15).

USG-guided Femoral Nerve Block Technique

The patient is placed in the supine position. A high-frequency (10-15 MHz) linear probe is placed transversely over the femoral artery, just below the inguinal ligament (Figure 1). In the USG image, the femoral artery appears as an anechoic circle, while the hyperechoic and triangular/oval-shaped femoral nerve is detected laterally (Figure 2). The blocking needle (22G, 50 mm, 80 mm, or 100 mm) is advanced from lateral to medial with an in-plane approach. The needle tip is placed just around the nerve, and local anesthetic is injected after aspiration. Homogeneous spread of the drug around the nerve is an indicator of effective blockade. Depending on the local anesthetic concentration used in the femoral nerve block, mobilization may be delayed due to weakness in the quadriceps muscle. Fall risk should be carefully assessed before initiating mobilization, particularly in elderly patients. Contraindications are infection in the area to be blocked, patient refusal, severe neuropathy, or nerve damage. Coagulopathy and the use of anticoagulants should be considered. Complications include intravascular injection and local anesthetic systemic toxicity (LAST), femoral nerve injury (injection with high pressure should be avoided), hematoma (especially in patients using anticoagulants), local infection, and loss of motor function (a postoperative mobilization plan should be considered).

Figure 1. Probe position for femoral nerve block

Fascia Iliaca Compartment Block (FICB)

The FICB is an effective and safe analgesia technique for both intraoperative and postoperative pain control in hip and femur fracture surgeries, targeting the femoral nerve, obturator nerve, and lateral femoral cutaneous nerve. The fascia iliaca is a fascial plane that covers the iliopsoas muscle and provides a potential space for nerves to course. This block aims to provide blockade of more than one nerve by spreading the local anesthetic to the compartment under the fascia iliaca. FICB is particularly suitable for elderly, polymorbid, and opioid-tolerant patients, making it one of the first-choice blocks (16).

There are two basic techniques in FICB: Infra-inguinal and supra-inguinal approaches. In the infra-inguinal approach, the block is performed just below the level of the inguinal ligament; in the supra-inguinal approach, the probe is placed proximal to the ligament and medial to the iliac crest. Ultrasound-guided supra-inguinal fascia iliaca

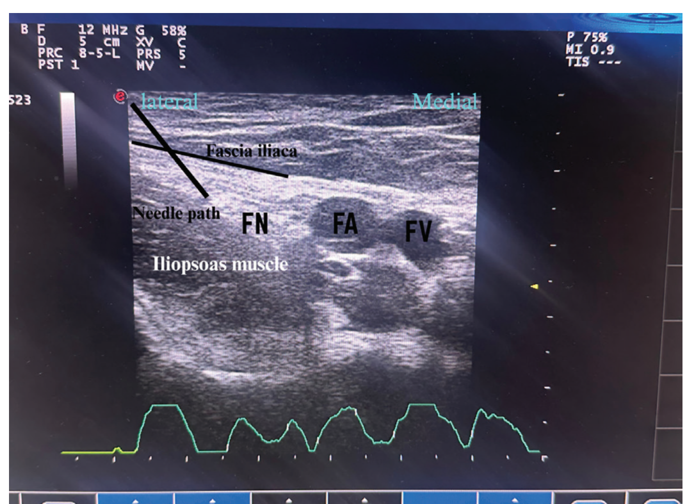

Figure 2. Femoral nerve block

Ultrasound image of femoral nerve block. The black line indicates needle trajectory. Local anesthetic is injected over the nerve. In the infrainguinal fascia iliaca block, local anesthetic is injected into the fascia iliaca under the inguinal ligament. FN: Femoral nerve, FA: Femoral artery, FV: Femoral vein block (SIFI) can include an obturator nerve block due to the more proximal spread of local anesthetic, providing more extensive analgesia. In the infra-inguinal fascia iliaca block, the high-frequency linear probe is placed 1-2 cm lateral to the femoral artery. The fascia iliaca is visualized as a structure extending between two hyperechoic lines and located above the iliopsoas muscle (Figure 2). The needle is advanced using an in-plane technique. After the needle tip is placed under the iliac fascia, 30-40 mL of local anesthetic (e.g., 0.25-0.5% ropivacaine, bupivacaine, or levobupivacaine) is slowly injected. In SIFI, the injection is made into the wide fascial plane over the iliacus muscle, medial to the iliac crest (Figure 3). The spread of the local anesthetic typically affects the lateral femoral cutaneous nerve first, followed by the femoral nerve, and then the obturator nerve, depending on the volume administered (Figure 4). The duration of analgesia varies depending on the agent used but can last 8-16 hours with ropivacaine and levobupivacaine and 12-18 hours with bupivacaine. It has been reported that SIFI reduces pain more effectively in the early postoperative period (3-8 hours) and achieves higher success rates in nerve blockade compared to the infra-inguinal fascia iliaca block (17). FICB is effective in postoperative analgesia for femur fractures or hip surgery operations, especially in elderly patients, due to its low risk of motor block, broad nerve coverage, and low complication rate.

Figure 3. Probe position for suprainguinal fascia iliaca block

Pericapsular Nerve Group (PENG) Block

The PENG block is a new nerve block, defined in 2018, that targets the nerves innervating the anterior capsule of the hip joint and largely preserves motor function. The block targets structures that sense the anterior capsule of the hip joint, such as the femoral nerve, the articular branch of the obturator nerve, and the accessory obturator nerve, if present. It has been reported to be effective and safe in reducing opioid requirements in the perioperative period, especially in elderly patients with hip fractures (18). It reduces the risk of delayed mobilization by affecting quadriceps muscle strength less than traditional femoral or fascia iliaca blocks. When performing a PENG block under USG guidance, the patient is placed in the supine position. The probe is placed in the transverse plane between the anterior inferior iliac spine and the superior pubic ramus. The iliopsoas muscle, femoral artery, and pectineus muscle are identified in the ultrasound image. The needle is advanced from lateral to medial with an in-plane approach. When it reaches the potential area between the iliopsoas muscle and the pubic ramus, the needle tip should stop before approaching the pectineus muscle (Figure 5). Usually, 20-30 mL of local anesthetic (e.g., 0.25-0.5% ropivacaine or bupivacaine) is injected. It should be observed that the local anesthetic spreads under the iliopsoas and reaches the pericapsular area where the nerves are located (18,19). The effect of the PENG block usually begins within 15-30 minutes and can last for 8-16 hours, depending on the agent used. Due to its ease of application in the supine position, low risk of

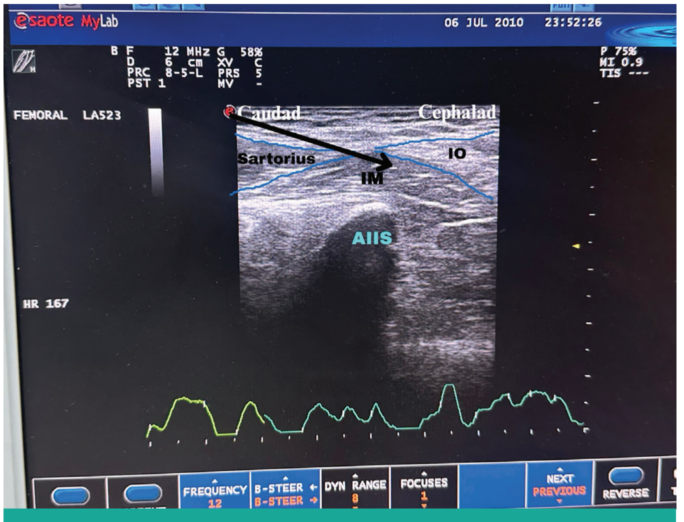

Figure 4. Ultrasound image of suprainguinal fascia iliaca block

The black line indicates needle trajectory. IO: Internal oblique muscle, IM: Iliacus muscle, AIIS: Anterior inferior iliac spine motor block, and wide coverage, it has become one of the preferred techniques, especially in elderly patients with hip fractures and those at high risk of falling. It can also be used in combination with other blocks (e.g., sciatic nerve block) in major surgeries, such as total hip arthroplasty (18,19).

Psoas Compartment Block (Lumbar Plexus Block)

Psoas compartment block, also known as lumbar plexus block, is applied to block the nerves that innervate the anterior surface of the hip and thigh, such as the femoral nerve, obturator nerve, and lateral femoral cutaneous nerve, with a single injection at the lumbar plexus level. This block provides potent analgesia, especially in large-area orthopedic procedures such as total hip arthroplasty, revision hip surgeries, and femoral fracture fixations. Since it targets more proximal nerve fibers compared to more superficial blocks such as PENG or FICB, a more widespread block is achieved. However, since the application is performed in a deep, anatomically more complex area, the risk of complications is relatively higher (20,21).

In the psoas compartment block, which can be applied under ultrasound guidance or with a nerve stimulator, the patient is positioned in the lateral decubitus position, with the side to be treated facing upwards. A high-frequency or low-frequency (convex) probe is placed at the level of the L3 vertebra. The psoas major muscle is identified on the ultrasound image; hyperechoic nerve structures within the muscle are targeted. The needle is advanced with an in-plane technique, and the location can be confirmed by obtaining quadriceps contraction with nerve stimulation. Typically, 0.25-0.5% ropivacaine or bupivacaine is used, with a recommended volume of 20-30 mL. The duration of the block's effect varies depending on the agent used but can last up to 12-18 hours. However, due to the risks of complications such as epidural spread, retroperitoneal hematoma, and intravascular injection, this block should only be performed by experienced practitioners and with careful patient selection. This emphasis on careful patient selection and the involvement of experienced practitioners is crucial in ensuring the safety and effectiveness of the psoas compartment block (22).

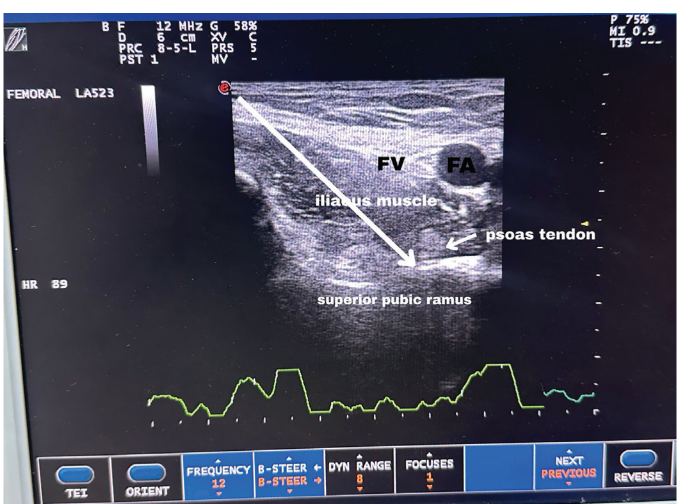

Figure 5. Ultrasound image of pericapsular nerve group block

The white line indicates needle trajectory. Local anesthetic is injected under the tendon of the psoas muscle. FA: Femoral artery, FV: Femoral vein

Sciatic Nerve Block

The sciatic nerve block, a highly effective peripheral block technique, targets the sciatic nerve. This nerve innervates the posterior region of the hip and lower extremity, the posterior aspect of the thigh, most of the leg, and the foot. It is commonly combined with a femoral nerve block, also known as a PENG block, in various surgeries, including hip surgeries, femoral shaft fracture fixations, procedures involving the posterior aspect of the knee, and foot surgeries. The sciatic nerve, originating from the lumbosacral plexus (L4-S3), can be blocked at different anatomical levels as it passes from the gluteal region to the posterior thigh. The subgluteal, parasacral, and popliteal approaches are preferred, with the subgluteal approach often chosen for its technical convenience and more superficial placement between the muscles (23).

When performing a subgluteal sciatic nerve block under USG guidance, the patient is placed in a lateral or prone position. A linear or low-frequency convex probe is placed transversely just proximal to the gluteal fold. On the USG image, the sciatic nerve is defined as a hyperechoic oval structure under the gluteus maximus muscle, between the adductor magnus and quadratus femoris muscles. The needle is advanced from lateral to medial with an in-plane technique. Usually, 0.25-0.5% ropivacaine, bupivacaine, or levobupivacaine is used; a volume of 15-25 mL is sufficient. The effect of the block typically begins 15-20 minutes after administration and can last for 12-18 hours. The most common complications are nerve trauma, hematoma, infection, and, rarely, ischemic neuropathy. Contraindications are active infection, coagulopathy, and traumatic deformation in the application area. High-volume injections should be avoided. It is crucial to apply low pressure and exercise caution during the injection to minimize the risk of nerve damage.

Erector Spinae Plane (ESP) Block and Quadratus Lumborum (QLB) Block

The ESP block, an interfascial block technique introduced by Forero et al. (24), is gaining popularity. This technique involves injecting a local anesthetic into the deep plane of the erector spinae muscle group, located on the transverse processes of the thoracic or lumbar vertebrae. The local anesthetics are believed to provide both somatic and visceral analgesia via the dorsal rami, ventral rami, and rami communicantes. The ESP block, with its potential to provide comprehensive analgesia, has found applications in hip surgeries, pelvic fractures, spinal surgeries, and abdominal procedures. Notably, when applied at the L4-L5 level, it may spread to the lumbar plexus and sacral plexus (25).

The QLB block is a versatile and deeper variant of the transverse abdominis plane block (TAP block). It plays a pivotal role in controlling visceral and deep somatic pain, extending beyond the superficial analgesia achieved in abdominal surgeries. QLB can be performed using four techniques: Lateral (type 1), posterior (type 2), anterior/transmuscular (type 3), and intramuscular (type 4). Particularly in type 3 QLB, a local anesthetic can spread to the plane between the QLB and the psoas major muscle, creating an effective blockade on the lumbar plexus. QLB has been reported to help reduce opioid use, provide visceral analgesia, and offer long-term pain control in hip replacement surgeries and pelvic osteotomies (26).

Both blocks should be performed under USG guidance. In the ESP block, the patient is seated or positioned laterally. The vertebral transverse process is determined with a linear or convex probe. The needle is advanced under the muscle, on the transverse process, with the in-plane technique, and usually 20-30 mL of 0.25% bupivacaine or ropivacaine is injected (Figure 6). In QLB, the probe is placed on the lateral abdominal wall, under the ribs. Especially for type 3, the needle is directed to the plane between the QLB muscle and the psoas major. The duration of effect in both blocks can be up to 12-24 hours, depending on the local anesthetic agent. Complications are rare, but they carry risks such as pleural penetration, retroperitoneal hematoma, and infection, which require anatomical knowledge and skill in the use of USG guidance.

PNBs in Knee Surgery

Anatomical Innervation

The knee joint is innervated by a complex network of nerves originating from both the lumbar and sacral plexus. This innervation encompasses both somatic motor-sensory fibers and articular branches and is of great importance in planning postoperative analgesia. The anterior region of the knee joint is innervated mainly by branches of the femoral nerve (especially the saphenous nerve and vastus medialis), the lateral femoral cutaneous nerve, and the articular branch of the obturator nerve. The posterior capsule is mainly innervated by the terminal branches of the sciatic nerve, the tibial nerve, and the posterior obturator branch (27). The saphenous branch of the femoral nerve, in particular, has a wide sensory distribution in the medial and anteromedial skin regions of the knee and is one of the most frequently targeted nerves in knee surgery. However, the n. vastus medialis and obturator articular branches, which provide deep sensation in the anterior capsule, may not always be adequately blocked with conventional femoral nerve blocks. For effective control of the posterior pain component, techniques such as sciatic nerve block or, more specifically, interspace between the popliteal artery and capsule of the posterior knee (IPACK) block have been reported to be useful (28).

Saphenous Nerve Block

The saphenous nerve is the longest sensory branch of the femoral nerve. It provides extensive sensory innervation to the distal thigh and the anteromedial aspect of the knee, around the patella, and in the proximal tibia region. Since it does not contain motor fibers, it has become an important target for anesthesiologists who want to reduce pain in knee surgeries while preserving quadriceps function. It has

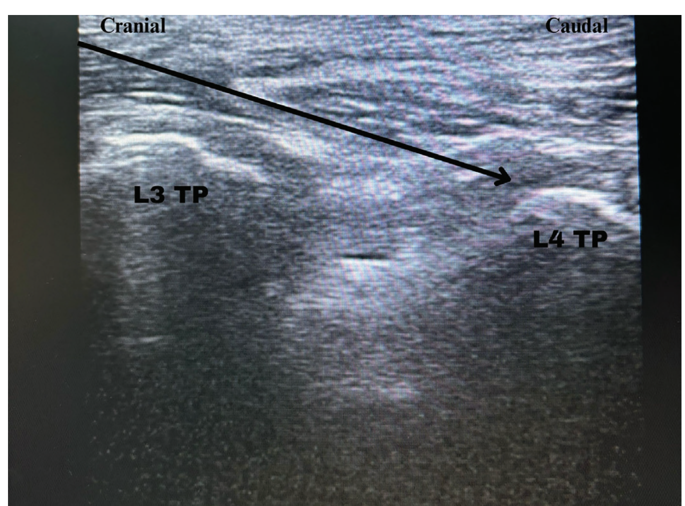

Figure 6. Ultrasound image of lumbar erector spinae plane block

The black line indicates needle trajectory. TP: Transverse process been reported that isolated saphenous nerve block provides adequate analgesia, especially in anteriorly focused knee procedures such as anterior cruciate ligament surgery, medial meniscus repair, and minimally invasive knee arthroscopies (29).

The USG-guided saphenous nerve block is most commonly performed as an adductor canal block. With the patient in the supine position, a high-frequency linear probe is placed in the mid-thigh region. The femoral artery, sartorius muscle, vastus medialis, and adductor longus/magnus muscles are identified on USG. The saphenous nerve is typically identified as a small hyperechoic structure located laterally or posteromedially to the femoral artery (Figure 7). The block needle is advanced under the sartorius muscle with an in-plane technique, and blockade is achieved with 10-15 mL of 0.25% ropivacaine or bupivacaine. The spread of the local anesthetic around the artery in a ring shape indicates that the block is successful. Saphenous nerve block creates significantly less motor block compared to femoral nerve block, providing advantages in terms of early mobilization, a lower risk of falling, and rapid rehabilitation. Therefore, long-term infusion applications with adductor canal catheters have become widespread, especially in multimodal analgesia protocols. However, in interventions targeting the posteromedial aspect of the knee or the posterior capsule, a saphenous block alone may be insufficient. It should be combined with posterior techniques, such as an IPACK block, if necessary (30).

Popliteal Sciatic Nerve Block

The popliteal sciatic nerve block is an effective technique that aims to block the sciatic nerve at the level just before it divides into the tibial and peroneal branches. It is especially preferred in the posterior region of the knee, as well as in surgeries below the knee and interventions involving the ankle or foot. In knee surgeries, it is applied in combination with femoral or saphenous nerve blocks to control posterior capsular pain. The sciatic nerve divides into two as the tibial and common peroneal nerves in the popliteal fossa, and these branches course in a single sheath before diverging in the distal 1/3 of the thigh. This anatomical unity ensures that the block is effective at this level (31).

During the block application, the patient is usually placed in a prone or lateral position. Under USG guidance, a high-frequency linear probe is placed in the popliteal fossa on the posterior aspect of the thigh, approximately 5-10 cm proximal to the knee joint. The sciatic nerve is targeted at the point where the tibial and peroneal components are visualized as a combined hyperechoic oval structure (Figure 8). The needle is advanced from lateral to medial using an in-plane technique, and 20-30 mL of 0.25-0.5% ropivacaine, bupivacaine, or levobupivacaine is injected around the nerve sheath. The homogeneous spread of the local anesthetic surrounding the nerve is an indicator of the effective block. The duration of effect typically ranges from 12 to 24 hours. The popliteal block should be used with caution in patients planned for early mobilization, as it creates a motor block. However, in terms of providing

Figure 7. Ultrasound image of saphenous nerve block
The white line indicates needle trajectory. VM: Vastus medialis muscle, FA: Femoral artery, AL: Adductor longus muscle

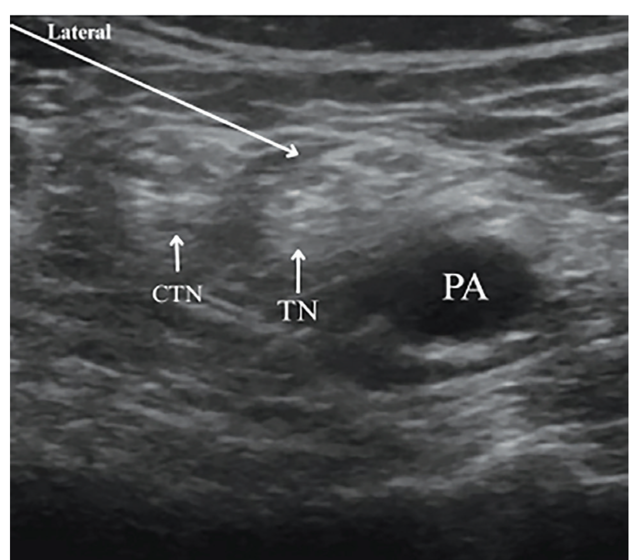

Figure 8. Ultrasound image of popliteal sciatic nerve block
The white line indicates needle trajectory. PA: Popliteal artery, TN: Tibial nerve

analgesia for the posterior capsule of the knee, it can be highly effective in commonly painful procedures, such as total knee arthroplasty, when combined with a saphenous nerve block. It has also been reported that it accelerates recovery by significantly reducing the need for opioids with long-term catheter applications (32).

IPACK Block

The IPACK block, a novel interfascial block technique, is designed to selectively block the nerve fibers innervating the posterior capsule of the knee while preserving motor functions. This unique approach targets structures such as the genicular branches of the tibial nerve, the articular extension of the posterior obturator nerve, and the popliteal plexus. It allows for early mobilization by providing adequate analgesia without causing motor block, particularly in controlling posterior knee pain that develops after total knee arthroplasty. When used in conjunction with the adductor canal block, it effectively blocks both the anterior and posterior knee capsules (33).

When performing an IPACK block under USG guidance, the patient is placed in the supine or lateral position, and a high-frequency linear or low-frequency convex probe is placed in the popliteal region of the knee. The potential space between the popliteal artery and the posterior aspect of the femur and tibia, located just posterior to the artery, is targeted (Figure 9). The needle is advanced in an in-plane technique, from medial to lateral or from lateral to medial.

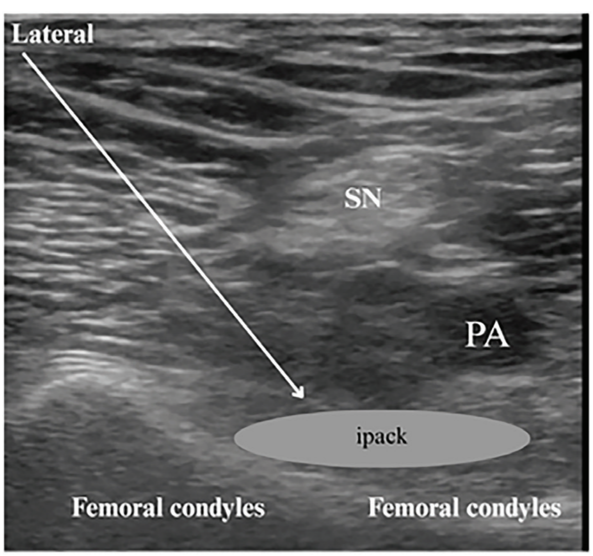

Figure 9. Ultrasound image of interspace between the popliteal artery and capsule of the posterior knee (IPACK) block

The white line indicates needle trajectory. PA: Popliteal artery, SN: Sciatic nerve

No nerve stimulation is required. Injection of 15-20 mL of 0.25% ropivacaine or bupivacaine is usually sufficient. The advantage of the block is that it targets only the posterior sensory branches without affecting the motor nerves, which provides adequate analgesia while minimizing the risk of falls. A well-executed IPACK block not only provides effective pain relief but also significantly reduces opioid requirements, thereby enhancing patient satisfaction and safety.

PNBs in Ankle and Foot Surgery

Anatomical Innervation

Branches of both the tibial and peroneal nerves, as well as other superficial nerves such as the sural and saphenous nerves, provide sensory innervation to the ankle and foot. This anatomical structure shows that complete sensory loss can be achieved by blocking the five primary peripheral nerves around the ankle. These nerves are the tibial nerve, deep peroneal nerve, superficial peroneal nerve, sural nerve, and saphenous nerve. The tibial nerve innervates the medial part of the sole and heel. It can be palpated at the ankle level, medial to the posterior tibial artery, in the retromalleolar region. The deep peroneal nerve is responsible for sensation in the first interdigital space on the dorsum of the foot. Its precise location, adjacent to the anterior tibial artery on the anterior surface of the ankle, is of utmost importance. The superficial peroneal nerve innervates the dorsolateral aspect of the foot; it is primarily located at the subcutaneous level and has a superficial distribution. The sural nerve supplies sensation to the outer side of the foot and the posterolateral aspect of the heel. Its location behind the lateral malleolus is a key point to remember. The saphenous nerve provides superficial sensory branches to the medial skin of the ankle and is an extension of the femoral nerve (34).

Ankle blocks are usually performed for surgical anesthesia (e.g., toe amputations, hallux valgus operations) or postoperative analgesia. Because these five nerves are superficial and easily accessible anatomically, ankle blocks are performed mainly by circumferential injection using anatomical landmarks without the use of USG guidance. However, the use of USG may be preferred, especially for the safe blockade of structures related to arteries, such as the tibial and deep peroneal nerves (35).

Ankle Block Techniques

Ankle block is a superficial and safe technique performed distally in lower extremity surgery. For the block to be successful, five major peripheral nerves—the tibial, deep peroneal, superficial peroneal, sural, and saphenous nerves—must be blocked separately. Since most of these nerves are superficial and easily identified by anatomic landmarks, ankle blocks are usually performed by subcutaneous injections directed at anatomic points without the need for ultrasound. However, the use of ultrasound may increase safety for structures adjacent to vessels, such as the tibial and deep peroneal nerves. The tibial nerve is located approximately 1-2 cm posterior to the medial malleolus, medial to the posterior tibial artery. Since the nerve courses deeply, it requires deep injection and careful aspiration. 5-8 mL of 0.5% ropivacaine or bupivacaine is sufficient. The deep peroneal nerve courses on the anterior aspect of the ankle, between the extensor hallucis longus tendon and the tibialis anterior tendon, next to the anterior tibial artery.

The nerve is quite superficial at this level; 3-5 mL of local anesthetic is sufficient. Since the superficial peroneal nerve usually spreads laterally in the subcutaneous tissue at the ankle level, it is blocked by a subcutaneous lateral annular injection spreading around the ankle.

The sural nerve is easily localized by palpation, posterior to the lateral malleolus, between the Achilles tendon and the mallear process. A superficial injection of 5 mL of local anesthetic is sufficient for this purpose. The saphenous nerve courses anterior to the medial malleolus, together with the saphenous vein, and usually runs subcutaneously along the medial ankle. Superficial injection of 3-5 mL is also applied here. Effective blockade of all nerves can usually be achieved with a total local anesthetic volume of 20-30 mL. Since the injections are performed near blood vessels, aspiration is essential before each injection. Surgical anesthesia can be achieved in the ankle and distal foot using this block technique; it is also an effective technique for postoperative analgesia, preserving motor functions to a large extent.

Complications of Peripheral Nerve Block

LAST

LAST is a potentially life-threatening complication that may result from intravascular injection of a local anesthetic or from the slow absorption of a high dose of local anesthetic administered perineurally. The clinical presentation and onset of LAST are highly variable, and symptoms may appear rapidly; however, in some cases, they may be delayed for 30 minutes or longer. Neurological toxicity signs usually occur first, followed by cardiac toxicity at higher concentrations. The manifestations of neurotoxicity are subjective and may include dizziness, altered mental status, perioral numbness, and tinnitus (36). These early symptoms can easily be overlooked if the patient is under sedation or general anesthesia. With rising plasma concentrations, muscle twitching and generalized tonic–clonic seizures develop. Ultimately, profound central nervous system depression may occur, leading to decreased consciousness and coma.

The treatment of LAST begins with early recognition of initial symptoms and the intensity of drug accumulation, followed by the urgent administration of intravenous Intralipid emulsion, even in the early stages of patient presentation. Intralipid should be administered as a weight-based bolus, immediately followed by continuous infusion (37). Bolus doses may be repeated, and if the patient remains hemodynamically unstable, the infusion rate can be doubled as indicated in current guidelines (38). The risk of LAST increases when large volumes of local anesthetics are administered simultaneously across multiple nerve distribution sites. Therefore, in PNBs, it is crucial to use the minimum effective dose of local anesthetic required.

Hematoma

During the performance of USG-guided PNBs, inadvertent puncture of surrounding vascular structures may lead to hematoma formation. It is important to avoid performing PNBs in anatomical regions where applying direct pressure to the puncture site is not feasible, as well as in patients with coagulation disorders. The vast majority of hematomas can be controlled by applying direct pressure to the needle puncture site; surgical decompression is rarely required.

Nerve injury

Although rare, nerve injuries may occur following PNBs. Most are transient, lasting from days to months. The incidence of major complications resulting in permanent nerve injury (lasting longer than six months) has been reported to range between 0.015% and 0.09% (39,40). The majority of nerve injuries are thought to occur secondary to intraneural injection. To minimize the likelihood of intrafascicular injection, the injection of local anesthetic should be discontinued if the patient reports paresthesia or if abnormally high resistance is encountered during injection. Under ultrasound guidance, the appropriate spread of the local anesthetic should always be confirmed. Pre-existing neuropathies (including diabetes) may predispose nerves to injury. In addition, nerve injury can also result from the direct neurotoxic effects of certain local anesthetics (41). Clinical manifestations of nerve injury are primarily sensory (pain, tingling, or paresthesia), but may also include any combination of sensory and motor deficits depending on the affected nerve and the severity of the injury. Most symptoms resolve within six months. If symptoms are severe or persistent, the patient should undergo further evaluation and diagnostic testing.

Block failure

Even in the hands of the most experienced, PNBs carry a risk of failure. Injection of local anesthetics outside the neurovascular sheath may prevent adequate spread to the target nerve. The level of expertise of the anesthesiologist performing the block has been reported to influence the success of the block (42). To maximize success rates, optimization of all patient-related variables is essential. Regardless of block type, patients with a body mass index (BMI) greater than 25 kg/m² have been shown to have a higher likelihood of receiving non-surgical anesthesia compared with those with lower BMI; moreover, block failure rates increase progressively with higher BMI (40). This is likely attributable to the greater difficulty in identifying anatomical landmarks in such patients. Advances in ultrasound guidance and its widespread clinical use have improved success rates, enhanced the quality of sensory blockade, and shortened procedural times by reducing the number of needle passes required to localize the target nerve. Prior to performing a nerve block, the risk of block failure should be discussed with the patient to ensure they are aware of this possibility. As part of this discussion, alternative analgesic strategies (such as alternative blocks, intravenous medications, or oral agents) should be reviewed if the block provides limited pain relief.

Infection

In single-dose PNBs, the risk of infection is considered negligible. The risk increases, however, in hospitalized critically ill patients, trauma patients, immunocompromised individuals, male patients, and when prophylactic antibiotics are not administered. For continuous blocks, the risk of infection can be minimized by removing the catheter within 48 to 72 hours after insertion.

Allergic reaction

The majority of adverse reactions to local anesthetics are non-allergic in nature. Nevertheless, mild allergic manifestations (such as erythema or rash) up to severe reactions progressing to anaphylaxis may occur. Medications and equipment required for symptomatic management should be readily available in locations where PNBs are performed.

Discussion

Ultrasound-guided PNBs are frequently employed for intraoperative anesthesia and postoperative analgesia in orthopedic lower extremity surgeries. In recent years, the description of various new blocks has led to an increase in the number of ultrasound-guided techniques performed (Table 1). In a meta-analysis evaluating the efficacy of the PENG block compared with placebo in total hip arthroplasty, the PENG block was found to significantly reduce early postoperative pain and opioid requirements, while prolonging the time to first opioid administration (43). Another study demonstrated that continuous PENG block provided superior analgesia compared with continuous FICB, better preserved quadriceps muscle strength, facilitated maintenance of motor function, promoted earlier mobilization, and reduced the need for additional analgesics (44). In contrast, a meta-analysis comparing femoral nerve block and FICB in geriatric patients with hip fractures reported no significant difference in opioid consumption within the first 24 hours; however, patients receiving femoral nerve block experienced a significantly lower incidence of side effects such as nausea, vomiting, and sedation (45).

When comparing postoperative analgesic strategies following total knee arthroplasty or traumatic knee surgery, combined and continuous block techniques (such as continuous adductor canal block combined with IPACK or genicular nerve block) have been shown to provide superior analgesia, lower opioid consumption, and improved functional recovery compared with single blocks (46). While a femoral nerve block initially demonstrates high analgesic efficacy, it may cause quadriceps muscle weakness and delay mobilization. In contrast, the adductor canal block has been reported to offer comparable pain control while minimizing this drawback, thereby providing the advantage of motor sparing (47). Furthermore, although the adductor canal block alone provides relatively effective control of anterior knee pain, the addition of an IPACK block has been shown to significantly enhance posterior knee analgesia and facilitate functional mobilization (48).

This narrative review has several inherent limitations. First, although studies from specific databases within a defined time frame were screened, explicit inclusion and exclusion criteria were not applied. Second, unlike systematic reviews with meta-analysis, this review does not provide a quantitative analysis that highlights pooled, calculable outcomes across studies. Finally, the lack of a systematic approach may have led to the exclusion of relevant studies or to disproportionate emphasis on specific findings.

Table 1. Ultrasonography-guided peripheral nerve blocks performed in lower extremity orthopedic surgeries

Block	Clinical application	Target nerves/ structures	Advantages	Disadvantages	Complication
Femoral nerve block	Hip and femur surgery, anterior knee surgery	Femoral nerve in the inguinal region	Reliable analgesia; easy to perform	Quadriceps weakness, delayed mobilization; fall risk; limited coverage of posterior capsule	LAST, hematoma, infection, neuropathy
Fascia iliaca compartment block	Hip fractures, THA, femur surgery	Femoral, lateral femoral cutaneous, obturator nerves	Broad coverage; low motor block; suitable for elderly patients	Large volume required; variable obturator blockade	LAST, hematoma, local infection
PENG block	Hip fractures, THA	Femoral, obturator, accessory obturator articular branches	Motor-sparing; effective for anterior capsule pain; suitable in elderly and high fall-risk patients	Newer technique; variable learning curve; limited posterior coverage	LAST, infection
Psoas compartment block (lumbar plexus block)	Hip/femur surgery	Lumbar plexus (femoral, obturator, lateral femoral cutaneous)	Wide coverage with single injection	Technically difficult; higher risk of complications; not first-line in elderly	Bleeding and retroperitoneal hematoma, infection epidural spread, LAST, nerve damage
Sciatic nerve block	Hip, femur, knee (posterior), foot/ ankle surgery	Sciatic nerve	Strong analgesia, multiple approaches (subgluteal, popliteal)	Motor blockade	Hematoma, infection, ischemic neuropathy
Erector spinae plane block	Hip and pelvic surgery	Dorsal and ventral rami, lumbar plexus spread	Wide analgesic coverage, relatively safe	Variable spread	Hematoma, local infection pneumothorax (rare)
Quadratus lumborum block	Hip replacement, pelvic osteotomy	Thoracolumbar fascia, lumbar plexus	Provides visceral and somatic analgesia, prolonged effect	Technical variability, limited high-quality evidence	Retroperitoneal hematoma, LAST
Saphenous nerve block	ACL repair, meniscus surgery, TKA	Saphenous nerve	Purely sensory, motor-sparing block	Insufficient for posterior capsule pain	Hematoma, infection and nerve damage
Popliteal sciatic nerve block	Knee (posterior), ankle, foot surgery	Tibial and common peroneal nerves before bifurcation	Reliable coverage of posterior knee and below-knee procedures	Motor block	Hematoma, infection nerve damage, LAST
IPACK block	TKA (posterior capsule pain)	Genicular branches of tibial and obturator nerves	Motor-sparing; selective posterior capsule analgesia	Shorter duration than sciatic block, technical learning required	LAST, vascular puncture (rare)
Ankle block techniques	Foot surgery, toe amputations, hallux valgus	Tibial, deep peroneal, superficial peroneal, sural, saphenous nerves	Covers 5 nerves, motor-sparing; simple technique	Multiple injections required, time-consuming	LAST, vascular puncture, infection

LAST: Local anesthetic systemic toxicity, THA: Total hip arthroplasty, PENG: Pericapsular nerve group, ACL: Anterior cruciate ligament, TKA: Total knee arthroplasty, IPACK: Infiltration of local anesthetic between the popliteal artery and capsule of the knee

Conclusion

USG-guided PNBs are beneficial in reducing systemic side effects associated with general anesthesia and opioid use, while providing adequate analgesia. In orthopedic surgical practice, the choice of the appropriate block for lower extremity procedures should be guided by the specific surgical site, patient anatomy, and clinical considerations. Mastery of PNBs requires a thorough understanding of anatomy, associated risks, and potential complications to ensure both safety and efficacy. Advances in ultrasound guidance have enhanced the precision and safety of these interventions, making them indispensable in modern anesthetic practice. By adopting these techniques, anesthesiologists can improve perioperative pain management, shorten recovery times, and contribute to the overall quality of patient care in orthopedic surgery.

Ethics

Footnotes

Authorship Contributions

Surgical and Medical Practices: K.A., Concept: K.A., A.S.Ş., Design: K.A., A.S.Ş., Data Collection or Processing: K.A., Analysis or Interpretation: K.A., Literature Search: K.A., Writing: K.A., A.S.Ş.

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References

1. Genç A. Lower extremity peripheral nerve blocks. Gaziosmanpaşa Üniversitesi Tıp Fakültesi Dergisi. 2021;13(4):201-215.
2. Arslan K, Sahin AS. Should the paramedian approach be the first choice in spinal anesthesia of geriatric patients? Prospective randomized clinical trial. Bagcilar Med Bull. 2022;7(3):240-246.
3. Kücüksarac G, Arslan K, Sahin AS. Effect of dexamethasone on postoperative analgesia following the transversus abdominis plane block in gynecological laparotomies. Cureus. 2024;16(11):e73814.
4. Arslan K, Sahin AS. Effects of ultrasonography-guided transversus abdominis plane block on postoperative analgesia, gastrointestinal motility, and mobilization in patients delivering cesarean delivery under spinal anesthesia: a retrospective study. Duzce Med J. 2023;25(2):167-172.
5. Kang C, Hwang DS, Song JH, Lee GS, Lee JK, Hwang SJ, et al. Clinical analyses of ultrasound-guided nerve block in lower-extremity surgery: a retrospective study. J Orthop Surg (Hong Kong). 2021;29(1):2309499021989102.
6. Frawley G, Marchesini V, Loh B, Koziol J. Pediatric lower limb peripheral nerve blocks: indications, effectiveness, and the incidence of adverse events. Paediatr Anaesth. 2022;32(8):946-953.
7. Fillingham YA, Hannon CP, Kopp SL, Austin MS, Sershon RA, Stronach BM, et al. The efficacy and safety of regional nerve blocks in total knee arthroplasty: systematic review and direct meta-analysis. J Arthroplasty. 2022;37(10):1906-1921.e2.
8. Baethge C, Goldbeck-Wood S, Mertens S. SANRA-a scale for the quality assessment of narrative review articles. Res Integr Peer Rev. 2019;4:5.
9. Laumonerie P, Dalmas Y, Tibbo ME, Robert S, Durant T, Caste T, et al. Sensory innervation of the hip joint and referred pain: a systematic review of the literature. Pain Med. 2021;22(5):1149-1157.
10. Nagpal AS, Brennick C, Occhialini AP, Leet JG, Clark TS, Rahimi OB, et al. Innervation of the posterior hip capsule: a cadaveric study. Pain Med. 2021;22(5):1072-1079.
11. Gonabal V, Aggarwal S, Rani D, Panwar M. Comparison of ultrasound-guided suprainguinal fascia iliaca compartment block and pericapsular nerve group block for postoperative analgesia and associated cognitive dysfunction following hip and proximal femur surgery. J Anaesthesiol Clin Pharmacol. 2024;40(3):432-438.
12. Sertçakacılar G, Pektai Y, Çetingök H, Sabaz MS, Bostancı İ, Çukurova Z, et al. Retrospective investigation of the efficacy of blocks for analgesia in lower extremity surgery. Bakırköy Tıp Dergisi. 2019;15(4):376-382.
13. Lin DY, Morrison C, Brown B, Saies AA, Pawar R, Vermeulen M, et al. Pericapsular nerve group (PENG) block provides improved short-term analgesia compared with the femoral nerve block in hip fracture surgery: a single-center double-blinded randomized comparative trial. Reg Anesth Pain Med. 2021;46(5):398-403.
14. Migliorini F, Pappalardo G, Bardazzi T, Maffulli N, Bertini FA, Simeone F, et al. Continuous femoral nerve block as pain management following total knee arthroplasty: a systematic review. Arch Orthop Trauma Surg. 2025;145(1):238.
15. Casati A, Vinciguerra F, Santorsola R, Aldegheri G, Putzu M, Fanelli G. Sciatic nerve block with 0.5% levobupivacaine, 0.75% levobupivacaine or 0.75% ropivacaine: a double-blind, randomized comparison. Eur J Anaesthesiol. 2005;22(6):452-456.
16. Eshag MME, Hasan LOM, Elshenawy S, Ahmed MS, Emad Mostafa AE, Abdelghafar YA, et al. Fascia iliaca compartment block for postoperative pain after total hip arthroplasty: a systematic review and meta-analysis of randomized controlled trials. BMC Anesthesiol. 2024;24(1):95.
17. Yang Z, Xu W, Xu S. Comparison of the efficacy and safety of different puncture routes for ultrasound-guided fascia iliaca compartment block for early analgesia after hip arthroplasty: a meta-analysis. Medicine (Baltimore). 2024;103(35):e39313.
18. Girón-Arango L, Peng PWH, Chin KJ, Brull R, Perlas A. Pericapsular nerve group (PENG) block for hip fracture. Reg Anesth Pain Med. 2018;43(8):859-863.
19. Luo W, Liang J, Wu J, Luo Q, Wu H, Ou Y, et al. Effects of pericapsular nerve group (PENG) block on postoperative recovery in elderly patients with hip fracture: study protocol for a randomised, parallel controlled, double-blind trial. BMJ Open. 2022;12(3):e051321.
20. Quan J, Yang S, Chen Y, Chen K, Yu S. Ultrasound-guided comparison of psoas compartment block and supra-inguinal fascia iliaca compartment block for pain management in pediatric developmental dysplasia of hip surgeries. Front Pediatr. 2022;9:801409.
21. Aytolign HA, Mersha AT, Ferede YA. Analgesic efficacy of posterior and anterior psoas compartment block: lumbar plexus versus three -in-one nerve block after lower limb orthopedic surgery under spinal anesthesia: a prospective cohort study. Ann Med Surg (Lond). 2021;73:103160.
22. Sato M, Sasakawa T, Izumi Y, Onodera Y, Kunisawa T. Ultrasound-guided lumbar plexus block using three different techniques: a comparison of ultrasound image quality. J Anesth. 2018;32(5):694-701.
23. Shevlin S, Johnston D, Turbitt L. The sciatic nerve block. BJA Educ. 2020;20(9):312-320.
24. Forero M, Adhikary SD, Lopez H, Tsui C, Chin KJ. The erector spinae plane block: a novel analgesic technique in thoracic neuropathic pain. Reg Anesth Pain Med. 2016;41(5):621-627.

25. Kendall MC, Alves L, Traill LL, De Oliveira GS. The effect of ultrasound-guided erector spinae plane block on postsurgical pain: a meta-analysis of randomized controlled trials. BMC Anesthesiol. 2020;20(1):99.

26. Koo CH, Ahn S, Na HS, Ryu JH, Shin HJ. Efficacy of quadratus lumborum block for analgesia in adult participants undergoing hip surgery: a meta-analysis of randomized controlled trials. J Clin Anesth. 2021;75:110560.

27. Tran J, Peng PWH, Gofeld M, Chan V, Agur AMR. Anatomical study of the innervation of posterior knee joint capsule: implication for image-guided intervention. Reg Anesth Pain Med. 2019;44(2):234-238.

28. Wang JH, Ma HH, Chou TA, Tsai SW, Chen CF, Wu PK, et al. Does the addition of iPACK block to adductor canal block provide improved analgesic effect in total knee arthroplasty? A systematic review and meta-analysis. J Knee Surg. 2023;36(4):345-353.

29. Guo J, Hou M, Shi G, Bai N, Huo M. iPACK block (local anesthetic infiltration of the interspace between the popliteal artery and the posterior knee capsule) added to the adductor canal blocks versus the adductor canal blocks in the pain management after total knee arthroplasty: a systematic review and meta-analysis. J Orthop Surg Res. 2022;17(1):387.

30. Tang X, Lai Y, Du S, Ning N. Analgesic efficacy of adding the IPACK block to multimodal analgesia protocol for primary total knee arthroplasty: a meta-analysis of randomized controlled trials. J Orthop Surg Res. 2022;17(1):565.

31. Silverman ER, Vydyanathan A, Gritsenko K, Shaparin N, Singh N, Downie SA, et al. The anatomic relationship of the tibial nerve to the common peroneal nerve in the popliteal fossa: implications for selective tibial nerve block in total knee arthroplasty. Pain Res Manag. 2017;2017:7250181.

32. Teixeira F, Sousa CP, Martins Pereira AP, Gonçalves D, Sampaio JC, Sá M. Comparative efficacy of iPACK vs popliteal sciatic nerve block for pain management following total knee arthroplasty: a retrospective analysis. Cureus. 2024;16(1):e51557.

33. Kampitak W, Tanavalee A, Ngarmukos S, Tantavisut S. Motor-sparing effect of iPACK (interspace between the popliteal artery and capsule of the posterior knee) block versus tibial nerve block after total knee arthroplasty: a randomized controlled trial. Reg Anesth Pain Med. 2020;45(4):267-276.

34. Delbos A, Philippe M, Clément C, Olivier R, Coppens S. Ultrasound-guided ankle block. History revisited. Best Pract Res Clin Anaesthesiol. 2019;33(1):79-93.

35. Gianakos AL, Romanelli F, Rao N, Badri M, Lubberts B, Guss D, et al. combination lower extremity nerve blocks and their effect on postoperative pain and opioid consumption: a systematic review. J Foot Ankle Surg. 2021;60(1):121-131.

36. Vasques F, Behr AU, Weinberg G, Ori C, Di Gregorio G. A review of local anesthetic systemic toxicity cases since publication of the American Society of Regional Anesthesia recommendations: to whom it may concern. Reg Anesth Pain Med. 2015;40(6):698-705.

37. Gitman M, Fettiplace MR, Weinberg GL, Neal JM, Barrington MJ. Local anesthetic systemic toxicity: a narrative literature review and clinical update on prevention, diagnosis, and management. Plast Reconstr Surg. 2019;144(3):783-795.

38. Neal JM, Neal EJ, Weinberg GL. American Society of Regional Anesthesia and pain medicine local anesthetic systemic toxicity checklist: 2020 version. Reg Anesth Pain Med. 2021;46(1):81-82.

39. Malchow RJ, Gupta RK, Shi Y, Shotwell MS, Jaeger LM, Bowens C. Comprehensive analysis of 13,897 consecutive regional anesthetics at an ambulatory surgery center. Pain Med. 2018;19(2):368-384.

40. Kamel I, Ahmed MF, Sethi A. Regional anesthesia for orthopedic procedures: what orthopedic surgeons need to know. World J Orthop. 2022;13(1):11-35.

41. Verlinde M, Hollmann MW, Stevens MF, Hermanns H, Werdehausen R, Lirk P. Local anesthetic- induced neurotoxicity. Int J Mol Sci. 2016;17(3):339.

42. Yeniocak T, Canbolat N. Retrospective analysis of ultrasound-guided infraclavicular block: effect of experience of anesthesiologists on volume of local anesthetic administered. Pain Res Manag. 2019;2019:4846956.

43. She C, Liu H. The efficacy of pericapsular nerve group block for reducing pain and opioid consumption after total hip arthroplasty: a systematic review and meta-analysis. J Orthop Surg Res. 2024;19(1):229.

44. Duan L, Zhang L, Shi CG, Huang LG, Ao H, Wang ZP, et al. Comparison of continuous pericapsular nerve group (PENG) block versus continuous fascia iliaca compartment block on pain management and quadriceps muscle strength after total hip arthroplasty: a prospective, randomized controlled study. BMC Anesthesiol. 2023;23(1):233.

45. Li XD, Han C, Yu WL. Comparison of femoral nerve block and fascia iliaca block for proximal femoral fracture in the elderly patient: a meta-analysis. Geriatr Orthop Surg Rehabil. 2022;13:21514593221111647.

46. Wang F, Wu J, Wu Y, Han X, Dai H, Chen Q. Different peripheral nerve blocks for patients undergoing total knee arthroplasty: a network meta-analysis of randomized controlled trials. Arch Orthop Trauma Surg. 2024;144(9):4179-4206.

47. Gadsden JC, Sata S, Bullock WM, Kumar AH, Grant SA, Dooley JR. The relative analgesic value of a femoral nerve block versus adductor canal block following total knee arthroplasty: a randomized, controlled, double-blinded study. Korean J Anesthesiol. 2020;73(5):417-424.

48. Pryambodho P, Kwan L, Tantri AR, Lubis AMT. Comparison between combination of proximal adductor canal block and infiltration between popliteal artery and capsule of knee (iPACK) with large-volume distal adductor canal block in facilitating early mobilization after total knee replacement: a randomized, single-blind study. Bali Journal of Anesthesiology. 2024;8(3):p158-163.