Motor-Preserving Analgesic Strategies After Total Knee Arthroplasty: Evolving Roles of Genicular Nerve and Adductor Canal Blocks

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Abstract

Background: Total knee arthroplasty (TKA) is one of the most commonly performed orthopedic procedures for management of advanced knee osteoarthritis, providing substantial pain relief and functional improvement. Despite its clinical success, postoperative pain following TKA remains a major challenge that may negatively influence early mobilization, rehabilitation participation, patient satisfaction, hospital stay, and long-term recovery outcomes. Effective postoperative analgesia has therefore become a cornerstone of enhanced recovery after surgery (ERAS) pathways, with increasing emphasis on opioid-sparing and motor-preserving regional anesthesia techniques. Traditional analgesic modalities such as femoral nerve block, epidural analgesia, and systemic opioids provide satisfactory pain control but are frequently associated with quadriceps weakness, delayed ambulation, opioid-related adverse effects, and prolonged rehabilitation.

In recent years, motor-sparing peripheral nerve blocks have gained considerable attention as safer and functionally superior alternatives for postoperative pain management after TKA. Among these techniques, adductor canal block (ACB) and genicular nerve block (GNB) have emerged as promising strategies capable of providing effective analgesia while preserving quadriceps muscle strength and facilitating early ambulation. ACB primarily targets the sensory innervation of the anteromedial knee through blockade of the saphenous nerve and related branches within the adductor canal, whereas GNB focuses on selective blockade of articular sensory branches supplying the knee joint, including the superomedial, superolateral, inferomedial, and inferolateral genicular nerves. Both techniques are commonly performed under ultrasound guidance and have become increasingly integrated into multimodal analgesic protocols.

This review discusses the anatomical basis, technical considerations, mechanisms of analgesia, clinical applications, advantages, limitations, and safety profiles of both ACB and GNB in patients undergoing TKA. Furthermore, the review highlights their roles in postoperative functional recovery, opioid reduction, preservation of motor function, and optimization of rehabilitation outcomes. Current evidence supporting each technique and emerging concepts in motor-preserving analgesia are also explored to provide a contemporary perspective on postoperative pain management following total knee arthroplasty.

Keywords: Motor-Preserving, Analgesic Strategies,Total Knee Arthroplasty: Genicular Nerve ,Adductor Canal Blocks

Introduction

Total knee arthroplasty (TKA) is considered one of the most successful orthopedic procedures for management of advanced knee osteoarthritis and other debilitating degenerative joint disorders. The procedure provides substantial improvement in pain, functional mobility, joint stability, and quality of life. With the increasing prevalence of obesity, aging populations, and degenerative musculoskeletal diseases, the global demand for TKA has progressively increased over recent decades. Despite continuous improvements in surgical techniques, implant design, and perioperative care, postoperative pain after TKA remains a major clinical challenge that significantly affects postoperative recovery and rehabilitation outcomes. [1]

Postoperative pain following TKA is frequently severe during the early postoperative period and may negatively influence patient mobilization, physiotherapy participation, hospital length of stay, and overall patient satisfaction. Inadequate pain control may additionally increase perioperative stress responses and contribute to delayed functional recovery. Furthermore, severe acute postoperative pain has been identified as an important risk factor for development of persistent postoperative pain syndromes and chronic functional impairment after knee arthroplasty. Consequently, optimization of postoperative analgesia has become a fundamental component of enhanced recovery after surgery (ERAS) protocols designed to accelerate rehabilitation and improve perioperative outcomes. [2-4]

The pathophysiology of pain after TKA is multifactorial and involves extensive tissue trauma, inflammatory mediator release, peripheral nociceptor activation, and central sensitization. The complex sensory innervation of the knee joint further contributes to variability in postoperative pain patterns and analgesic requirements. Anatomical studies have demonstrated that the anterior aspect of the knee receives sensory innervation from branches of the femoral, saphenous, common peroneal, and obturator nerves, whereas the posterior capsule is mainly innervated by branches of the tibial and obturator nerves. Therefore, successful postoperative analgesia requires adequate coverage of multiple sensory pathways while minimizing motor blockade that may impair early ambulation. [5,6]

Traditionally, several analgesic modalities have been used following TKA, including systemic opioids, epidural analgesia, periarticular infiltration, and peripheral nerve blocks. Although opioid-based analgesia provides effective pain relief, its use is commonly associated with nausea, vomiting, constipation, urinary retention, respiratory depression, and delayed recovery. Epidural analgesia can achieve excellent analgesic efficacy but may result in hypotension, bilateral motor weakness, and delayed mobilization. Femoral nerve block (FNB), which has long been considered a standard regional analgesic technique for TKA, provides effective postoperative pain control but is frequently associated with quadriceps muscle weakness and increased risk of postoperative falls. [7-9]

Increasing emphasis on early mobilization and functional recovery has led to growing interest in motor-sparing regional anesthesia techniques capable of providing effective analgesia while preserving quadriceps strength. Adductor canal block (ACB) has therefore emerged as an important alternative to femoral nerve block in contemporary TKA analgesia protocols. By primarily targeting sensory branches within the adductor canal, particularly the saphenous nerve, ACB can provide satisfactory analgesia over the anteromedial aspect of the knee while preserving most motor fibers supplying the quadriceps muscle. Preservation of motor function with ACB has been associated with earlier ambulation, improved rehabilitation participation, and reduced incidence of knee buckling compared with femoral nerve block. [10-12]

However, isolated adductor canal block may provide insufficient analgesia for posterior knee pain, which represents an important source of postoperative discomfort after TKA. This limitation has stimulated increasing interest in additional sensory blockade techniques targeting the articular innervation of the knee joint. Genicular nerve block (GNB), initially introduced for management of chronic osteoarthritic knee pain, has recently gained increasing attention in perioperative pain medicine because of its selective blockade of sensory articular branches supplying the knee capsule. The technique targets the superomedial, superolateral, inferomedial, and inferolateral genicular nerves accompanying the corresponding genicular vessels around the femoral and tibial condyles. Since these branches are predominantly sensory, GNB offers the theoretical advantage of effective postoperative analgesia with minimal motor impairment. [13-15]

The widespread use of ultrasound-guided regional anesthesia has further improved the precision, safety, and clinical applicability of both adductor canal block and genicular nerve block. Ultrasound guidance facilitates accurate identification of anatomical landmarks, vascular structures, and neural targets, allowing more precise local anesthetic deposition while reducing the risk of vascular puncture and nerve injury. Consequently, both techniques are increasingly incorporated into multimodal and opioid-sparing analgesic pathways aiming to optimize postoperative pain control, preserve motor function, facilitate early ambulation, and improve functional recovery after total knee arthroplasty. [12-15]

This review aims to discuss the evolving role of motor-preserving regional analgesic techniques after total knee arthroplasty, with particular focus on adductor canal block and genicular nerve block. The review highlights the anatomical basis, mechanisms of action, ultrasound-guided techniques, analgesic efficacy, influence on postoperative functional recovery, opioid-sparing potential, and safety profiles of both blocks. In addition, current evidence regarding their clinical applications and contribution to enhanced recovery after surgery pathways following total knee arthroplasty is explored.

Anatomy and Sensory Innervation of the Knee Joint

A comprehensive understanding of knee joint anatomy and sensory innervation is essential for successful application of regional analgesic techniques after total knee arthroplasty. The complexity of knee innervation represents one of the major challenges in achieving adequate postoperative analgesia while simultaneously preserving motor function. The knee joint is considered a modified hinge synovial joint composed of articulations between the femur, tibia, and patella. Stability and mobility of the joint depend on coordinated interactions between osseous structures, ligaments, menisci, joint capsule, and surrounding musculature. [16-18]

The knee capsule and periarticular tissues receive a rich sensory innervation originating primarily from branches of the femoral, obturator, sciatic, tibial, and common peroneal nerves. Anatomical studies have demonstrated considerable overlap and variability in the distribution of these articular branches, which partly explains the variability in postoperative pain patterns observed after TKA. The anterior aspect of the knee joint is predominantly supplied by branches derived from the femoral nerve, including the nerve to vastus medialis, nerve to vastus lateralis, nerve to vastus intermedius, and the infrapatellar branch of the saphenous nerve. Contributions from branches of the common peroneal nerve may also participate in anterolateral innervation. [19-21]

The posterior aspect of the knee capsule is mainly innervated by articular branches arising from the tibial nerve, posterior branch of the obturator nerve, and portions of the sciatic nerve. These posterior sensory pathways are clinically important because posterior knee pain frequently persists despite isolated anterior compartment blockade techniques such as adductor canal block. Consequently, incomplete posterior analgesia may negatively affect patient comfort and postoperative rehabilitation. [21,22]

To facilitate understanding of sensory distribution around the knee, several anatomical studies have subdivided the anterior capsule into four quadrants: superomedial, inferomedial, superolateral, and inferolateral regions. Each quadrant receives contributions from specific genicular branches accompanying the corresponding genicular vessels. The superomedial genicular nerve courses adjacent to the superior medial genicular artery near the medial femoral condyle, whereas the superolateral genicular nerve accompanies the superior lateral genicular artery around the lateral femoral condyle. Inferomedial and inferolateral genicular nerves similarly accompany their respective inferior genicular arteries along the proximal tibia. These sensory branches constitute the principal anatomical targets of genicular nerve block techniques. [6,13]

The adductor canal also represents an important anatomical region in contemporary regional anesthesia for TKA. The canal is located in the middle third of the thigh and extends from the apex of the femoral triangle to the adductor hiatus. It contains the femoral artery, femoral vein, saphenous nerve, and nerve to vastus medialis. Since the saphenous nerve is primarily sensory, blockade at this level provides analgesia to the medial and anteromedial aspects of the knee while largely preserving quadriceps motor function. However, spread of local anesthetic beyond the adductor canal toward the femoral triangle may inadvertently involve motor branches of the femoral nerve and reduce quadriceps strength. [10,11,23]

Recent cadaveric and ultrasonographic studies have significantly improved understanding of periarticular sensory anatomy and contributed to refinement of motor-sparing analgesic techniques. Advances in ultrasound-guided regional anesthesia now permit more accurate identification of vascular landmarks, fascial planes, and periosteal targets surrounding the knee joint. Such anatomical precision has facilitated the increasing use of selective sensory blockade approaches including adductor canal block and genicular nerve block within multimodal analgesic protocols after total knee arthroplasty. [5,12,14]

Postoperative Pain Following Total Knee Arthroplasty

Postoperative pain after total knee arthroplasty is considered one of the most severe forms of acute postoperative orthopedic pain. The procedure involves extensive surgical dissection of bone, periosteum, synovium, ligaments, joint capsule, and surrounding soft tissues, resulting in substantial activation of peripheral nociceptors and inflammatory cascades. Tissue injury during TKA induces local release of inflammatory mediators including prostaglandins, bradykinin, cytokines, and substance P, which subsequently sensitize peripheral nerve endings and amplify nociceptive transmission to the central nervous system. In addition to peripheral sensitization, sustained nociceptive input may promote central sensitization within the spinal cord and supraspinal pathways, contributing to hyperalgesia, allodynia, and prolonged postoperative pain states. Consequently, inadequate early postoperative analgesia may predispose patients to persistent postoperative pain and delayed functional recovery. [24]

The clinical presentation of pain after TKA is highly variable and may include nociceptive, inflammatory, neuropathic, and mechanical components. Nociceptive pain is typically described as aching, throbbing, or deep joint discomfort resulting from surgical trauma and periarticular inflammation. Neuropathic pain may develop secondary to irritation or injury of periarticular sensory nerves, particularly the infrapatellar branch of the saphenous nerve, and is commonly characterized by burning sensations, tingling, electric shock-like pain, or hypersensitivity around the incision site. Mechanical pain may additionally arise from soft tissue tension, prosthetic malalignment, instability, or impaired patellofemoral biomechanics. Such heterogeneity in pain mechanisms explains the difficulty of achieving adequate analgesia using a single analgesic modality and highlights the importance of multimodal pain management strategies. [25]

Several studies have demonstrated that poorly controlled postoperative pain after TKA significantly impairs early mobilization and rehabilitation outcomes. Pain during movement may limit active participation in physiotherapy sessions, reduce range of motion exercises, and delay weight-bearing activities. Early ambulation after TKA is critically important for prevention of postoperative complications including venous thromboembolism, pulmonary complications, joint stiffness, and muscle wasting. Furthermore, delayed mobilization is associated with prolonged hospitalization, increased healthcare costs, and reduced patient satisfaction. Therefore, effective postoperative analgesia should not only reduce resting pain scores but also facilitate dynamic pain control during movement and rehabilitation activities. [2]

Historically, systemic opioids represented the cornerstone of postoperative pain management following TKA. Although opioids provide effective analgesia, their widespread use is associated with multiple adverse effects including nausea, vomiting, sedation, constipation, urinary retention, respiratory depression, pruritus, and opioid-induced hyperalgesia. Moreover, excessive opioid consumption may impair early recovery pathways and prolong hospitalization. Growing concerns regarding opioid-related morbidity and dependence have therefore encouraged increasing reliance on multimodal and opioid-sparing analgesic protocols combining systemic medications with regional anesthesia techniques. [26]

Modern multimodal analgesia protocols after TKA typically combine acetaminophen, nonsteroidal anti-inflammatory drugs, gabapentinoids, periarticular infiltration, and peripheral nerve blocks in order to target different pain pathways simultaneously. Among these modalities, peripheral nerve blockade has become particularly important because of its ability to provide site-specific analgesia while minimizing systemic opioid exposure. However, the ideal regional analgesic technique should achieve a balance between adequate sensory blockade and preservation of motor function to optimize postoperative rehabilitation. This concept has driven the evolution from traditional femoral nerve block toward more selective motor-sparing techniques such as adductor canal block and genicular nerve block. [27]

The increasing emphasis on enhanced recovery after surgery protocols has further shifted perioperative priorities toward rapid functional recovery, earlier ambulation, reduced hospital stay, and improved patient-reported outcomes. Within this context, motor-preserving regional anesthesia techniques have gained substantial clinical importance because preservation of quadriceps strength is considered essential for safe ambulation and effective postoperative physiotherapy. Consequently, adductor canal block and genicular nerve block are increasingly incorporated into contemporary perioperative analgesic pathways for patients undergoing total knee arthroplasty. [15]

Evolution of Regional Analgesia Techniques in Total Knee Arthroplasty

Regional anesthesia techniques have undergone substantial evolution in the field of total knee arthroplasty over the past two decades. Earlier postoperative analgesic strategies relied predominantly on systemic opioids and epidural analgesia to control severe postoperative pain. Although these approaches provided effective analgesia, they were frequently associated with clinically significant adverse effects including sedation, respiratory depression, hypotension, urinary retention, delayed mobilization, and prolonged hospitalization. As perioperative care increasingly shifted toward enhanced recovery protocols and accelerated rehabilitation pathways, greater emphasis was placed on development of analgesic techniques capable of preserving motor function while maintaining adequate pain control. [7]

Femoral nerve block (FNB) subsequently emerged as one of the most widely utilized regional anesthesia techniques for TKA because of its excellent analgesic efficacy targeting the major sensory innervation of the anterior knee. Multiple studies demonstrated significant reductions in postoperative pain scores and opioid consumption with FNB compared with systemic analgesia alone. However, despite its analgesic effectiveness, femoral nerve block became increasingly associated with clinically important quadriceps weakness resulting from blockade of motor fibers supplying the quadriceps muscle. Such motor impairment negatively affected early ambulation, increased risk of knee buckling and falls, and potentially delayed postoperative rehabilitation. These limitations prompted growing interest in more selective sensory blockade approaches capable of minimizing motor dysfunction. [8]

The concept of motor-sparing analgesia subsequently led to increased utilization of adductor canal block as an alternative to femoral nerve block. Anatomically, the adductor canal primarily contains sensory neural structures including the saphenous nerve together with vascular structures and the nerve to vastus medialis. Since most quadriceps motor branches arise proximal to the adductor canal, local anesthetic administration within the canal can preserve quadriceps strength to a greater extent than femoral nerve block while still providing effective analgesia over the anteromedial aspect of the knee. Clinical studies have therefore demonstrated improved ambulation ability, earlier physiotherapy participation, and lower incidence of postoperative motor weakness with adductor canal block compared with femoral nerve block. [10]

Despite these advantages, isolated adductor canal block may not consistently provide adequate analgesia for the posterior compartment of the knee joint, which represents an important contributor to postoperative pain after TKA. This limitation encouraged further refinement of regional anesthesia strategies and stimulated increasing interest in supplementary posterior knee analgesic techniques including infiltration between the popliteal artery and capsule of the knee (IPACK) block, sciatic nerve block, and selective articular sensory nerve blockade. Such approaches aimed to optimize circumferential knee analgesia while preserving motor function and facilitating rapid postoperative recovery. [3]

Genicular nerve block has recently emerged as a promising sensory-selective regional analgesic technique in both chronic knee pain management and perioperative TKA analgesia. Unlike traditional nerve blocks targeting larger mixed motor-sensory nerves, GNB specifically targets articular sensory branches surrounding the femoral and tibial condyles. Because these genicular branches are predominantly sensory, the technique theoretically provides effective analgesia without substantial motor impairment. Early clinical studies demonstrated favorable postoperative pain relief, preservation of quadriceps strength, and facilitation of early ambulation following TKA using ultrasound-guided genicular nerve blockade. Consequently, GNB has attracted growing attention as a potential component of modern multimodal and opioid-sparing analgesic pathways. [13]

Recent advances in ultrasound-guided regional anesthesia have significantly accelerated the transition toward more precise and anatomically selective analgesic techniques. Ultrasound imaging enables direct visualization of fascial planes, vascular landmarks, periosteal targets, and neural structures, thereby improving block accuracy and safety while reducing risk of vascular puncture and local anesthetic misplacement. Such technological advances have facilitated broader implementation of both adductor canal block and genicular nerve block in contemporary perioperative pain management protocols after total knee arthroplasty. [12]

Current trends in postoperative analgesia increasingly emphasize individualized multimodal strategies integrating peripheral nerve blocks, systemic non-opioid medications, periarticular infiltration techniques, and enhanced rehabilitation protocols. Within this evolving paradigm, motor-preserving regional anesthesia techniques are becoming central components of perioperative care because they directly support early mobilization, accelerated physiotherapy participation, reduction of opioid-related adverse effects, and optimization of functional recovery after TKA. [27]

Adductor Canal Block

Adductor canal block (ACB) has emerged as one of the most important motor-sparing regional analgesic techniques in contemporary total knee arthroplasty practice. The technique was developed to overcome the major limitations associated with femoral nerve block, particularly postoperative quadriceps weakness and delayed mobilization. By selectively targeting predominantly sensory neural structures within the adductor canal, ACB provides effective analgesia while preserving most quadriceps motor function, thereby supporting early ambulation and rehabilitation after TKA. Consequently, adductor canal block has become increasingly integrated into enhanced recovery after surgery protocols and multimodal analgesic pathways for knee arthroplasty patients. [28]

The adductor canal, also referred to as Hunter’s canal or the subsartorial canal, is an aponeurotic tunnel located in the middle third of the thigh extending from the apex of the femoral triangle to the adductor hiatus. The canal is bordered anteromedially by the sartorius muscle, laterally by the vastus medialis muscle, and posteriorly by the adductor longus and adductor magnus muscles. It contains several important neurovascular structures including the femoral artery, femoral vein, saphenous nerve, and nerve to vastus medialis. Since the saphenous nerve represents the major terminal sensory branch of the femoral nerve, blockade at this level predominantly affects sensory innervation of the medial and anteromedial aspects of the knee and leg while relatively sparing quadriceps motor fibers. [29]

The analgesic mechanism of ACB primarily depends on blockade of the saphenous nerve together with articular branches arising from the nerve to vastus medialis and occasionally branches of the obturator nerve. Through interruption of nociceptive transmission from the anterior and medial compartments of the knee joint, ACB can significantly reduce postoperative pain intensity and opioid requirements after TKA. Preservation of quadriceps motor function is considered the principal advantage of the technique compared with femoral nerve block, particularly during the early postoperative period when active physiotherapy and ambulation are essential for functional recovery. [30]

Ultrasound guidance has significantly improved the accuracy and safety of adductor canal block. The procedure is commonly performed with the patient in the supine position and the lower limb slightly externally rotated. A high-frequency linear ultrasound transducer is placed over the anteromedial aspect of the mid-thigh to identify the sartorius muscle overlying the femoral artery within the adductor canal. The saphenous nerve is usually visualized adjacent to the femoral artery beneath the sartorius muscle. Following aseptic preparation, the block needle is advanced using an in-plane technique until the tip is positioned adjacent to the artery beneath the sartorius fascia, after which local anesthetic is injected to surround the neural structures within the canal. Ultrasound guidance not only improves block success rates but also minimizes the risk of vascular puncture and local anesthetic misplacement. [31]

Several clinical studies have demonstrated favorable analgesic outcomes with adductor canal block following TKA. Compared with femoral nerve block, ACB has been associated with improved preservation of quadriceps strength, earlier ambulation, lower incidence of postoperative knee buckling, and enhanced participation in physiotherapy sessions. Furthermore, patients receiving ACB often demonstrate shorter hospital stay and faster achievement of rehabilitation milestones while maintaining satisfactory postoperative analgesia. Such findings have contributed to widespread adoption of the technique within modern fast-track arthroplasty programs. [32]

Despite its important advantages, adductor canal block has several limitations. The analgesic coverage provided by ACB is predominantly confined to the anterior and medial aspects of the knee joint, while posterior capsular pain may remain inadequately controlled. Since posterior knee innervation is mainly supplied by branches of the tibial and obturator nerves, isolated ACB may fail to provide complete circumferential analgesia after TKA. Consequently, supplementary posterior knee analgesic techniques such as IPACK block or periarticular infiltration are frequently combined with ACB to improve postoperative pain control. [33]

Another important consideration relates to the volume and spread of local anesthetic within the adductor canal. Excessive injectate volume or proximal spread toward the femoral triangle may inadvertently involve motor branches of the femoral nerve, potentially resulting in quadriceps weakness despite the intended motor-sparing nature of the block. Anatomical variability within the canal may additionally influence block distribution and analgesic efficacy. Therefore, careful ultrasound-guided needle placement and optimization of local anesthetic volume remain essential for maximizing analgesic benefit while minimizing motor impairment. [34]

Although adductor canal block is generally considered safe, potential complications may still occur. These include vascular puncture, hematoma formation, infection, local anesthetic systemic toxicity, nerve injury, and rare allergic reactions to local anesthetic agents. Proper ultrasound guidance, adherence to aseptic technique, incremental injection with repeated aspiration, and careful patient monitoring significantly reduce the incidence of such complications. Overall, ACB remains one of the most valuable motor-preserving regional anesthesia techniques currently available for postoperative analgesia after total knee arthroplasty. [35]

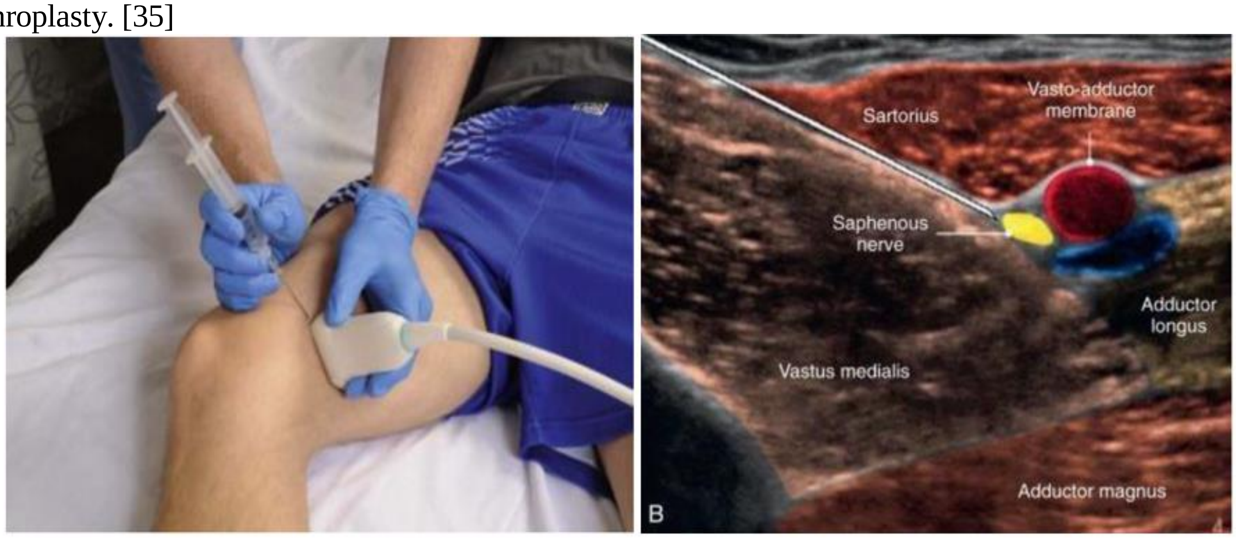

Figure 1: Technique and Ultrasound of adductor canal block [35]

Genicular Nerve Block

Genicular nerve block (GNB) has recently emerged as an innovative motor-preserving regional analgesic technique for management of postoperative pain after total knee arthroplasty. Initially introduced as an interventional pain procedure for chronic osteoarthritic knee pain and radiofrequency ablation therapy, the technique has progressively gained interest in perioperative anesthesia because of its ability to selectively target sensory articular branches innervating the knee joint while preserving motor function. In contrast to conventional peripheral nerve blocks directed toward mixed motor-sensory nerves, genicular nerve block focuses specifically on periarticular sensory innervation, thereby offering the potential advantage of effective analgesia without significant quadriceps weakness. [36]

The sensory innervation of the knee joint is highly complex and involves contributions from the femoral, obturator, sciatic, tibial, and common peroneal nerves. To simplify understanding of this intricate neural network, the knee has been anatomically divided into superomedial, superolateral, inferomedial, and inferolateral quadrants according to distribution of the genicular nerves. The superomedial genicular nerve accompanies the superior medial genicular artery near the medial femoral condyle, whereas the superolateral genicular nerve courses adjacent to the superior lateral genicular artery around the lateral femoral condyle. Similarly, the inferomedial and inferolateral genicular nerves travel near their corresponding inferior genicular arteries along the proximal tibial region. These periosteal sensory branches constitute the principal anatomical targets of ultrasound-guided genicular nerve blockade. [37]

The analgesic efficacy of genicular nerve block is primarily related to interruption of sensory nociceptive transmission arising from the anterior and periarticular components of the knee capsule. Because the targeted genicular branches are predominantly sensory, the block generally preserves quadriceps muscle strength and lower limb motor function. Such motor preservation is particularly advantageous in patients undergoing TKA because early ambulation and active physiotherapy represent essential components of postoperative rehabilitation and enhanced recovery protocols. Preservation of motor strength may additionally reduce risk of falls, facilitate earlier mobilization, and improve overall postoperative functional outcomes. [38]

Ultrasound guidance has become the preferred imaging modality for performing genicular nerve block because it enables direct visualization of periosteal landmarks, surrounding vascular structures, and needle trajectory. The procedure is commonly performed with the patient in the supine position and the knee slightly flexed. A high-frequency linear ultrasound transducer is sequentially positioned over the medial and lateral femoral condyles and the medial tibial condyle to identify the corresponding genicular arteries serving as anatomical landmarks for adjacent sensory nerves. After aseptic preparation and local skin infiltration, the block needle is advanced toward the periosteal surface near each targeted genicular artery, followed by careful injection of local anesthetic after negative aspiration. Accurate periosteal spread of injectate along the course of the sensory nerve is considered essential for successful blockade. [39]

Several early clinical studies and case series have demonstrated promising analgesic outcomes with genicular nerve block following total knee arthroplasty. Reported benefits include reduction in postoperative pain scores, decreased opioid consumption, preservation of quadriceps strength, improved ambulation, and enhanced participation in physiotherapy programs. In addition, the technique may provide an attractive alternative in situations where femoral nerve block or extensive motor blockade is undesirable. The motor-sparing nature of GNB has therefore contributed to growing interest in its incorporation within multimodal and opioid-sparing analgesic pathways after TKA. [40]

Despite these promising findings, several important limitations of genicular nerve block remain under investigation. The sensory innervation of the knee demonstrates considerable anatomical variability, and no universal consensus currently exists regarding the optimal number of targeted genicular branches, injectate volume, or exact anatomical injection sites. Furthermore, isolated GNB may not consistently provide complete analgesia of deeper intra-articular or posterior capsular structures, particularly in extensive surgical procedures such as TKA. Consequently, some clinicians advocate combining GNB with additional regional anesthesia techniques including adductor canal block or IPACK block to achieve more comprehensive perioperative analgesia. [41]

Complications associated with genicular nerve block are generally uncommon when performed under ultrasound guidance; however, potential adverse events may still occur. These include vascular puncture, hematoma formation, infection, local anesthetic systemic toxicity, transient sensory disturbances, and rare nerve injury. Because the targeted nerves course in close proximity to periarticular vessels, meticulous ultrasound-guided needle placement and repeated aspiration before injection are essential to minimize intravascular injection risk. Appropriate patient selection, strict aseptic precautions, and operator familiarity with periarticular anatomy further contribute to procedural safety. [42]

The growing interest in selective sensory blockade techniques reflects the broader transition in modern regional anesthesia toward individualized, motor-preserving, and function-oriented analgesic strategies. Within this evolving perioperative paradigm, genicular nerve block represents a promising addition to multimodal pain management pathways after total knee arthroplasty, particularly in patients where preservation of lower limb motor function and rapid rehabilitation are major clinical priorities. [15]

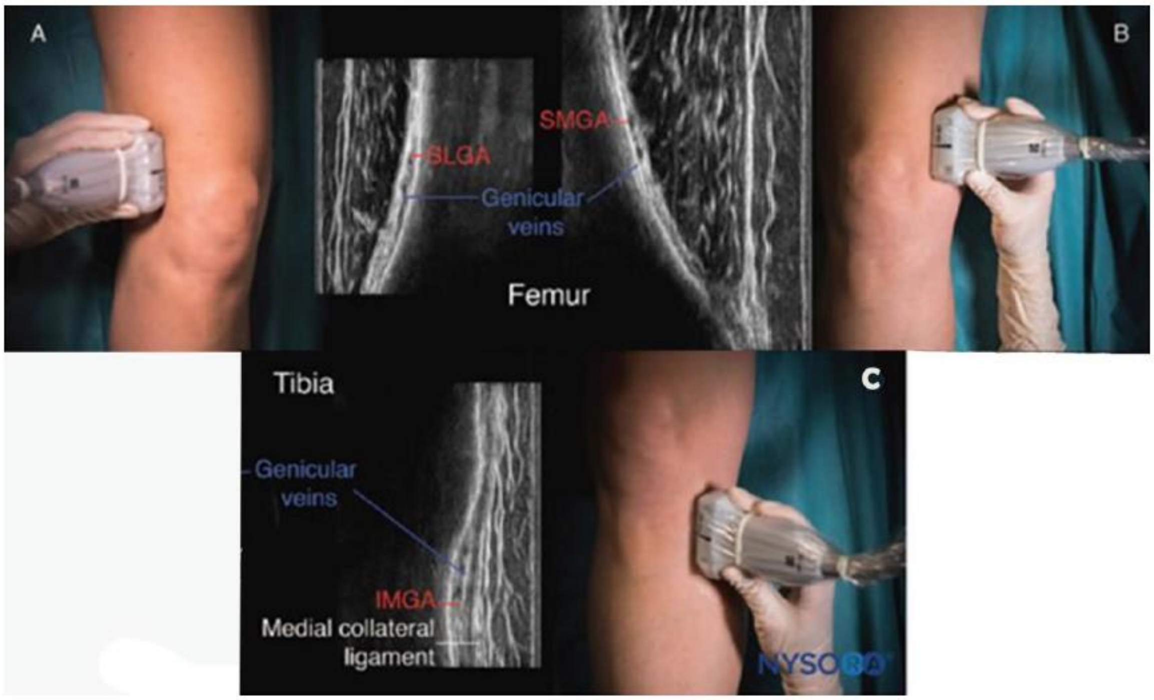

Figure 2: Sonoanatomy of the genicular nerves in a coronal plane. SLGA, SMGA, IMGA. (A) Transducer position and sonoanatomy of SLGN. (B) Transducer position and sonoanatomy of SMGN. (C) Transducer position and sonoanatomy of IMGN. [41]

Comparative Analgesic Efficacy of Adductor Canal Block and Genicular Nerve Block

The growing emphasis on enhanced recovery after surgery protocols has increased interest in identifying the optimal motor-preserving regional analgesic technique for patients undergoing total knee arthroplasty. Both adductor canal block and genicular nerve block have demonstrated favorable postoperative analgesic profiles while preserving lower limb motor function; however, important differences exist regarding anatomical targets, sensory coverage, functional outcomes, and overall analgesic efficacy. Comparative evaluation of these techniques remains essential for determining their respective roles within contemporary multimodal analgesic pathways after TKA. [43]

Adductor canal block primarily targets the saphenous nerve together with sensory articular branches within the adductor canal, thereby providing effective analgesia to the anteromedial aspect of the knee. Because the technique indirectly affects sensory pathways supplying the anterior capsule and periarticular tissues, ACB has consistently demonstrated significant reductions in postoperative pain scores and opioid consumption following TKA. Multiple studies have additionally shown improved quadriceps preservation and earlier ambulation compared with femoral nerve block. Nevertheless, isolated ACB may provide incomplete analgesia of the posterior knee compartment, which often contributes substantially to postoperative pain after arthroplasty procedures. [44]

In contrast, genicular nerve block directly targets the articular sensory branches innervating the periosteal and capsular structures surrounding the knee joint. By selectively blocking the superomedial, superolateral, inferomedial, and inferolateral genicular nerves, GNB theoretically offers broader periarticular sensory coverage without involvement of major motor fibers. The motor-sparing nature of the technique has generated increasing interest regarding its potential role in facilitating early rehabilitation and functional recovery after TKA. Early clinical experiences and preliminary studies have demonstrated favorable analgesic outcomes with preservation of quadriceps strength and reduced opioid requirements. [40]

Functional recovery represents one of the most important clinical endpoints when comparing contemporary regional anesthesia techniques after TKA. Preservation of quadriceps strength is particularly critical during the immediate postoperative period because early mobilization reduces risk of thromboembolic complications, enhances participation in physiotherapy, and accelerates hospital discharge. Although adductor canal block is generally considered a motor-sparing technique, proximal spread of local anesthetic toward the femoral triangle may occasionally produce partial quadriceps weakness. Genicular nerve block may theoretically provide superior motor preservation because the targeted branches are almost exclusively sensory. This characteristic has led some investigators to consider GNB as a potentially valuable adjunct or alternative within rapid recovery arthroplasty protocols. [45]

Another important consideration involves the pattern of postoperative pain after TKA. Pain following knee arthroplasty arises from multiple periarticular structures involving both anterior and posterior sensory pathways. ACB predominantly addresses anterior and medial pain components, whereas GNB targets periarticular articular branches distributed around the femoral and tibial condyles. However, neither technique alone consistently provides complete circumferential analgesia of the knee joint. Consequently, combined regional analgesic approaches integrating adductor canal block, genicular nerve block, periarticular infiltration, or IPACK block may provide superior analgesic outcomes compared with isolated single-technique strategies. [46]

Current evidence comparing adductor canal block and genicular nerve block remains relatively limited, and most available studies involve small sample sizes, retrospective analyses, or preliminary clinical observations. Variability in local anesthetic volume, injection technique, targeted anatomical sites, rehabilitation protocols, and outcome measures further complicates direct comparison between studies. Nevertheless, available data generally support the effectiveness of both techniques as components of multimodal and opioid-sparing postoperative analgesia after TKA. Future randomized controlled trials with standardized methodologies are still required to establish the optimal indications, comparative efficacy, and long-term functional outcomes associated with each technique. [41]

The choice between adductor canal block and genicular nerve block should therefore be individualized according to surgical factors, patient characteristics, rehabilitation goals, and institutional expertise. In many clinical settings, integration of multiple complementary motor-preserving regional anesthesia techniques may ultimately provide the most effective balance between analgesia, functional recovery, opioid reduction, and patient satisfaction following total knee arthroplasty. [15]

Functional Recovery and Early Ambulation After Total Knee Arthroplasty

Early functional recovery following total knee arthroplasty has become a principal objective of contemporary perioperative care pathways. Successful postoperative rehabilitation depends not only on adequate pain control but also on preservation of lower limb motor function, particularly quadriceps muscle strength. Early ambulation after TKA is strongly associated with reduced risk of venous thromboembolism, improved pulmonary function, decreased muscle wasting, shorter hospital stay, and higher patient satisfaction. Consequently, modern regional anesthesia strategies increasingly prioritize motor preservation together with effective analgesia in order to optimize postoperative functional outcomes. [47]

Quadriceps weakness represents one of the most clinically significant limitations of traditional femoral nerve block. Since the femoral nerve contains major motor fibers supplying the quadriceps muscle, blockade at this level may impair knee extension strength and increase the incidence of postoperative knee buckling and falls. Such motor impairment can substantially delay physiotherapy participation and negatively influence rehabilitation milestones during the immediate postoperative period. Recognition of these limitations contributed significantly to the transition toward motor-sparing analgesic techniques such as adductor canal block and genicular nerve block. [32]

Adductor canal block has demonstrated favorable effects on postoperative ambulation and rehabilitation because it largely preserves quadriceps motor function while providing satisfactory analgesia to the anterior and medial aspects of the knee. Several clinical studies have reported earlier walking ability, improved participation in physical therapy, and reduced incidence of motor weakness with ACB compared with femoral nerve block. Preservation of active knee extension allows patients to perform early mobilization exercises more effectively, thereby supporting accelerated recovery pathways after TKA. [48]

Nevertheless, functional recovery following adductor canal block may still be influenced by several technical and anatomical factors. Excessive local anesthetic volume or proximal spread toward the femoral triangle may inadvertently affect motor branches of the femoral nerve and partially reduce quadriceps strength. Furthermore, inadequate control of posterior knee pain may impair patient comfort during ambulation despite preservation of motor function. For this reason, additional analgesic techniques targeting posterior sensory innervation are frequently incorporated into multimodal recovery protocols alongside ACB. [45]

Genicular nerve block offers an alternative motor-preserving strategy because the targeted genicular branches are predominantly sensory articular nerves with minimal motor contribution. Theoretically, selective blockade of these periarticular sensory pathways permits maintenance of lower limb motor performance while reducing postoperative pain intensity. Preliminary clinical studies evaluating GNB after TKA have reported preservation of quadriceps strength, facilitation of early ambulation, and satisfactory participation in rehabilitation programs. Such findings suggest that genicular nerve block may represent a valuable adjunct within fast-track arthroplasty pathways emphasizing rapid mobilization and opioid minimization. [38]

The increasing integration of motor-preserving regional anesthesia techniques into enhanced recovery after surgery protocols reflects the evolving priorities of perioperative medicine. Contemporary TKA recovery programs aim to achieve earlier ambulation within hours after surgery, rapid initiation of physiotherapy, shorter hospitalization, and earlier return to functional independence. Effective regional analgesia that minimizes sedation and preserves motor performance plays a central role in achieving these objectives. Consequently, both adductor canal block and genicular nerve block are becoming increasingly important components of individualized rehabilitation-oriented analgesic strategies after total knee arthroplasty. [49]

Despite encouraging early evidence, additional high-quality prospective studies remain necessary to determine the precise functional advantages of different motor-preserving regional anesthesia techniques. Standardized assessment of ambulation ability, quadriceps strength, rehabilitation milestones, fall risk, and patient-reported functional outcomes will be essential for clarifying the optimal role of ACB and GNB within future perioperative recovery pathways after TKA. [15]

Opioid-Sparing Effects and Multimodal Analgesia

Reduction of perioperative opioid consumption has become a major objective in modern postoperative pain management following total knee arthroplasty. Although opioids remain effective analgesic agents for severe postoperative pain, their use is frequently associated with numerous adverse effects including nausea, vomiting, sedation, constipation, urinary retention, respiratory depression, delayed mobilization, and opioid-induced hyperalgesia. In addition, prolonged perioperative opioid exposure may increase the risk of chronic opioid use and negatively affect postoperative recovery and patient satisfaction. Consequently, contemporary enhanced recovery protocols strongly emphasize opioid-sparing multimodal analgesic strategies integrating regional anesthesia techniques with systemic non-opioid medications. [50]

Multimodal analgesia refers to the combined use of multiple analgesic modalities targeting different nociceptive pathways simultaneously in order to optimize pain control while minimizing opioid requirements. Such protocols commonly incorporate acetaminophen, nonsteroidal anti-inflammatory drugs, COX-2 inhibitors, gabapentinoids, periarticular infiltration, and peripheral nerve blocks. Among these modalities, regional anesthesia techniques have become particularly valuable because they provide site-specific analgesia with fewer systemic adverse effects compared with opioid-based regimens. Motor-preserving regional analgesia additionally supports early ambulation and rehabilitation, which are critical components of postoperative recovery after TKA. [27]

Adductor canal block has demonstrated important opioid-sparing effects in patients undergoing total knee arthroplasty. By reducing nociceptive transmission from the anterior and medial compartments of the knee joint, ACB can significantly decrease postoperative opioid consumption and improve dynamic pain control during rehabilitation activities. Several studies have shown that patients receiving ACB require lower cumulative opioid doses during the early postoperative period while maintaining satisfactory analgesic efficacy and functional recovery. Such reductions in opioid exposure may consequently decrease opioid-related adverse effects and facilitate faster postoperative recovery. [46]

Similarly, genicular nerve block has shown promising potential as an opioid-sparing analgesic technique following TKA. Selective blockade of periarticular sensory branches may reduce postoperative nociceptive input without impairing motor performance, thereby improving patient comfort during early mobilization and physiotherapy. Preliminary studies evaluating GNB after knee arthroplasty have reported reductions in postoperative pain scores and opioid requirements together with preservation of quadriceps strength. Although current evidence remains relatively limited, the technique appears to represent a promising component of multimodal opioid-sparing perioperative analgesia. [38]

The combination of multiple regional anesthesia techniques has attracted increasing attention in an attempt to achieve more comprehensive analgesic coverage after TKA. Because postoperative pain originates from both anterior and posterior sensory pathways, isolated single-block strategies may provide incomplete analgesia. Consequently, combined approaches such as adductor canal block with IPACK block or genicular nerve block may improve posterior knee analgesia while maintaining motor preservation. Such multimodal regional strategies may further reduce opioid requirements and enhance functional recovery compared with isolated techniques alone. [51]

Optimization of opioid-sparing analgesia is particularly important in elderly patients and individuals with significant medical comorbidities undergoing TKA. Excessive opioid exposure in such populations may increase the incidence of postoperative delirium, respiratory complications, prolonged immobility, and delayed discharge. Motor-preserving regional anesthesia techniques therefore offer important advantages by reducing systemic opioid dependence while simultaneously supporting safer rehabilitation and earlier return to functional activity. [7]

Safety Profile and Potential Complications of Motor-Preserving Regional Analgesia

Although adductor canal block and genicular nerve block are generally considered safe regional anesthesia techniques, understanding their potential complications and safety considerations remains essential for optimal perioperative management. The increasing use of ultrasound-guided regional anesthesia has substantially improved procedural accuracy and reduced complication rates; however, no regional analgesic intervention is completely free of risk. Appropriate patient selection, detailed anatomical knowledge, meticulous aseptic precautions, and careful ultrasound-guided needle manipulation are therefore fundamental components for minimizing adverse events associated with these procedures. [52]

Adductor canal block is commonly regarded as a relatively safe procedure because the targeted anatomical structures are superficial and easily visualized under ultrasound guidance. Nevertheless, complications may still occur, particularly due to the close relationship between the saphenous nerve and femoral vessels within the adductor canal. Inadvertent vascular puncture may result in hematoma formation, intravascular local anesthetic injection, or vascular injury. Although rare, local anesthetic systemic toxicity remains a potentially serious complication, especially when large volumes of local anesthetic are administered or accidental intravascular injection occurs. Ultrasound guidance together with incremental aspiration during injection significantly decreases these risks. [53]

Another important concern with adductor canal block involves unintended proximal spread of local anesthetic toward the femoral triangle. Excessive proximal diffusion may partially involve motor branches of the femoral nerve and reduce quadriceps strength, thereby compromising the intended motor-sparing advantage of the technique. Such motor weakness may impair ambulation and increase fall risk during the immediate postoperative period. Consequently, optimization of local anesthetic volume, accurate needle placement, and understanding of fascial anatomy are important factors for preserving functional recovery after TKA. [54]

Neurological complications after adductor canal block are uncommon but remain possible. Direct needle trauma, intraneural injection, or compressive hematoma formation may produce transient paresthesia, sensory disturbances, or rarely prolonged nerve injury. Most reported neurological symptoms are temporary and resolve spontaneously; however, adherence to careful ultrasound-guided visualization and avoidance of high injection pressures are essential preventive measures. Infection at the injection site is also rare but may occur in cases of inadequate aseptic technique. [55]

Genicular nerve block similarly demonstrates a favorable safety profile because the targeted nerves are superficial periarticular sensory branches located adjacent to identifiable osseous and vascular landmarks. Ultrasound guidance permits accurate localization of the corresponding genicular arteries, thereby facilitating safe periosteal deposition of local anesthetic. Nevertheless, because the genicular nerves course in close proximity to periarticular vessels, vascular puncture and hematoma formation remain potential complications. Careful Doppler ultrasound assessment and repeated aspiration before injection are therefore recommended during the procedure. [39]

Neurological injury associated with genicular nerve block is considered uncommon because the targeted branches are small sensory articular nerves rather than major mixed peripheral nerves. However, transient numbness, dysesthesia, localized neuropathic symptoms, or periosteal irritation may occasionally occur. Rare cases of persistent sensory disturbances have been reported following periarticular interventional procedures involving genicular nerves, particularly during radiofrequency ablation techniques. Appropriate procedural technique and precise anatomical targeting remain essential to minimize these complications. [56]

Allergic reactions to local anesthetic agents represent another rare but important consideration in both adductor canal and genicular nerve blocks. Clinical manifestations may range from mild cutaneous reactions to severe anaphylaxis. Thorough preoperative assessment regarding prior anesthetic allergies and immediate availability of resuscitative equipment are therefore mandatory whenever regional anesthesia procedures are performed. In addition, careful dose calculation is essential to reduce the risk of systemic local anesthetic toxicity, particularly when multiple regional blocks are combined within multimodal analgesic protocols. [35]

The overall safety and success of motor-preserving regional analgesia techniques strongly depend on operator expertise, ultrasound proficiency, and detailed understanding of periarticular anatomy. Continuous advances in ultrasound technology, anatomical research, and regional anesthesia training are expected to further improve procedural safety and broaden the clinical applications of adductor canal block and genicular nerve block in perioperative pain management after total knee arthroplasty. [30]

Conclusion

Motor-preserving regional analgesia has become a fundamental component of contemporary perioperative management after total knee arthroplasty, with increasing emphasis on optimizing pain control while preserving functional recovery and early ambulation. Both adductor canal block and genicular nerve block represent effective opioid-sparing analgesic techniques that minimize quadriceps weakness compared with traditional femoral nerve blockade. Adductor canal block provides reliable analgesia for the anteromedial knee with favorable rehabilitation outcomes, whereas genicular nerve block offers selective periarticular sensory blockade with promising motor-preserving advantages. Integration of these techniques within multimodal enhanced recovery pathways may improve postoperative analgesia, reduce opioid-related adverse effects, facilitate early physiotherapy participation, and accelerate functional recovery after total knee arthroplasty. Further large-scale randomized studies remain necessary to establish the optimal indications, combinations, and long-term outcomes of these evolving regional anesthesia strategies.

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