Pegem Journal of Education and Instruction, Vol. 14, No. 3, 2024 (pp. 1101-1100)

RESEARCH ARTICLE WWW.PEGEGOG.NET

Contemporary Regional Analgesic Techniques for Total Knee Arthroplasty: Integrating Adductor Canal and Genicular Nerve Blocks Into Multimodal Pain Pathways

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ABSTRACT

***Background*:** Total knee arthroplasty (TKA) is one of the most commonly performed orthopedic procedures worldwide for management of advanced knee osteoarthritis and other disabling degenerative joint diseases. Despite the significant functional improvement achieved after surgery, postoperative pain following TKA remains a major challenge that may adversely affect early ambulation, rehabilitation, hospital stay, patient satisfaction, and overall recovery outcomes. Contemporary perioperative care increasingly emphasizes enhanced recovery after surgery (ERAS) pathways that focus on early mobilization, opioid minimization, and preservation of motor function. Consequently, regional anesthesia techniques have evolved considerably from traditional motor-impairing approaches toward more selective sensory analgesic strategies.

Among modern peripheral nerve blocks, adductor canal block (ACB) and genicular nerve block (GNB) have emerged as important components of multimodal postoperative analgesia after TKA. Adductor canal block provides effective analgesia to the anteromedial aspect of the knee through blockade of the saphenous nerve and sensory branches within the adductor canal while relatively preserving quadriceps muscle strength. Genicular nerve block, originally introduced for management of chronic osteoarthritic knee pain, selectively targets periarticular sensory branches supplying the knee capsule and has recently gained increasing attention as a motor-preserving perioperative analgesic technique. Both approaches are commonly performed under ultrasound guidance and may reduce postoperative opioid requirements while facilitating early rehabilitation and functional recovery.

This review discusses the current concepts of multimodal regional analgesia after total knee arthroplasty with particular emphasis on integration of adductor canal block and genicular nerve block within contemporary pain management pathways. The anatomical basis, ultrasound-guided techniques, analgesic mechanisms, opioid-sparing effects, rehabilitation benefits, safety considerations, and current clinical evidence regarding these techniques are reviewed. In addition, the evolving role of combined regional analgesic strategies and their contribution to optimized postoperative recovery after total knee arthroplasty are explored.

Keywords: Regional Analgesic Techniques, Total Knee Arthroplasty, Adductor Canal, Genicular Nerve Blocks, Multimodal Pain Pathways

INTRODUCTION

Total knee arthroplasty (TKA) is widely considered one of the most successful orthopedic procedures for management of advanced degenerative knee disorders, particularly end-stage osteoarthritis. The procedure significantly improves pain, joint stability, mobility, and overall quality of life. Increasing life expectancy together with rising prevalence of obesity and degenerative joint diseases has resulted in a substantial global increase in the number of TKA procedures performed annually. Despite continuous advances in surgical techniques, prosthetic design, and perioperative care, postoperative pain following TKA remains a major clinical challenge that may adversely influence rehabilitation outcomes and postoperative recovery. [1]

Postoperative pain after TKA is often severe during the early postoperative period because the procedure involves extensive osseous resection, periosteal trauma, soft tissue dissection, and synovial manipulation. Inadequately controlled postoperative pain may impair early mobilization, reduce patient participation in physiotherapy, prolong hospital stay, and negatively affect patient satisfaction. Furthermore, severe acute postoperative pain has been identified as an important risk factor for development of persistent postoperative pain and chronic functional limitation after knee arthroplasty. Consequently, optimization of perioperative analgesia has become a fundamental component of enhanced recovery after surgery (ERAS) pathways aiming to accelerate rehabilitation and improve functional outcomes. [2]

Traditional postoperative analgesic modalities after TKA historically relied on systemic opioids, epidural analgesia, and femoral nerve block. Although these techniques provide satisfactory analgesic efficacy, they are frequently associated with significant adverse effects. Opioid-based regimens may result in nausea, vomiting, sedation, constipation, urinary retention, respiratory depression, and delayed recovery. Epidural analgesia can additionally produce hypotension, bilateral motor weakness, and delayed ambulation. Similarly, femoral nerve block, despite providing excellent anterior knee analgesia, is associated with quadriceps muscle weakness and increased risk of postoperative falls, which may interfere with early rehabilitation and mobilization goals. [3]

The increasing emphasis on rapid recovery and early ambulation has stimulated major advances in regional anesthesia strategies for TKA. Contemporary perioperative pain management now focuses on multimodal and motor-preserving analgesic techniques capable of providing effective pain control while minimizing opioid exposure and preserving lower limb motor function. Peripheral nerve blocks have therefore become central components of modern TKA analgesic pathways because they provide site-specific analgesia with fewer systemic adverse effects compared with traditional opioid-based regimens. [4]

Among contemporary regional anesthesia techniques, adductor canal block (ACB) has emerged as one of the most commonly utilized motor-sparing approaches following TKA. By targeting the saphenous nerve and sensory branches within the adductor canal, ACB provides effective analgesia to the anteromedial aspect of the knee while largely preserving quadriceps muscle strength. Preservation of motor function with ACB has been associated with improved ambulation, enhanced physiotherapy participation, and accelerated postoperative rehabilitation compared with femoral nerve block. Nevertheless, isolated ACB may provide inadequate analgesia of the posterior knee compartment, which frequently contributes to postoperative discomfort after arthroplasty procedures. [5]

Genicular nerve block (GNB) has recently gained increasing interest as an additional motor-preserving regional analgesic technique in perioperative pain medicine. Initially developed for management of chronic osteoarthritic knee pain and radiofrequency ablation procedures, GNB selectively targets sensory articular branches surrounding the knee joint, including the superomedial, superolateral, inferomedial, and inferolateral genicular nerves. Because these branches are predominantly sensory, genicular nerve blockade theoretically allows effective periarticular analgesia without significant impairment of quadriceps motor function. Early clinical experiences suggest that GNB may improve postoperative pain control and facilitate early ambulation when integrated into multimodal analgesic pathways after TKA. [6]

Recent advances in ultrasound-guided regional anesthesia have substantially improved the precision, safety, and clinical applicability of peripheral nerve blocks around the knee joint. Ultrasound imaging permits direct visualization of fascial planes, vascular structures, periosteal landmarks, and neural targets, thereby improving block accuracy and reducing procedural complications. Consequently, combined regional analgesic strategies integrating adductor canal block, genicular nerve block,

periarticular infiltration, and posterior knee analgesic techniques are increasingly utilized to achieve more comprehensive multimodal pain control following total knee arthroplasty. [7]

This review discusses the contemporary concepts of regional analgesia after total knee arthroplasty with particular focus on integration of adductor canal block and genicular nerve block within multimodal perioperative pain pathways. The review highlights the anatomical basis, analgesic mechanisms, ultrasound-guided techniques, functional implications, opioid-sparing effects, safety considerations, and current clinical evidence supporting these evolving regional anesthesia strategies after TKA.

Contemporary Concepts of Multimodal Analgesia After Total Knee Arthroplasty

Multimodal analgesia has become the cornerstone of modern perioperative pain management after total knee arthroplasty. The concept is based on simultaneous targeting of multiple nociceptive pathways using different analgesic modalities in order to achieve superior pain control while minimizing opioid consumption and treatment-related adverse effects. Because postoperative pain after TKA is multifactorial and involves extensive inflammatory, nociceptive, and neuropathic mechanisms, reliance on a single analgesic technique is often insufficient. Consequently, contemporary perioperative protocols increasingly integrate systemic medications, periarticular infiltration, and regional anesthesia techniques within enhanced recovery pathways designed to optimize postoperative rehabilitation and functional recovery. [8]

The major objectives of multimodal analgesia after TKA include reduction of postoperative pain intensity, preservation of motor function, facilitation of early ambulation, acceleration of physiotherapy participation, minimization of opioid-related complications, and improvement of overall patient satisfaction. Effective multimodal analgesia additionally contributes to reduction in hospital length of stay, decreased healthcare costs, and lower incidence of postoperative complications associated with prolonged immobilization. Therefore, individualized multimodal pain pathways are now considered essential components of contemporary TKA perioperative management. [9]

Systemic non-opioid analgesics constitute an important foundation of multimodal pain management protocols. Acetaminophen is commonly utilized because of its favorable safety profile and opioid-sparing properties. Nonsteroidal anti-inflammatory drugs (NSAIDs) and selective cyclooxygenase-2 inhibitors reduce prostaglandin-mediated inflammatory responses and provide significant analgesic benefit after TKA. Gabapentinoids may additionally reduce central sensitization and postoperative neuropathic pain components, although concerns remain regarding sedation and dizziness in elderly patients. Such systemic agents are frequently administered preoperatively and continued during the postoperative period as part of standardized multimodal regimens. [10]

Regional anesthesia techniques represent one of the most important advances in multimodal TKA analgesia. Peripheral nerve blocks provide site-specific sensory blockade that substantially reduces postoperative opioid requirements and improves dynamic pain control during rehabilitation. Historically, femoral nerve block was widely utilized because of its excellent analgesic efficacy; however, concerns regarding quadriceps weakness and impaired mobilization have encouraged transition toward more selective motor-preserving approaches. This shift has contributed to growing adoption of adductor canal block and other selective sensory blockade techniques within contemporary perioperative pathways. [5]

Adductor canal block currently represents one of the most widely accepted motor-sparing regional analgesic techniques after TKA. By predominantly targeting the saphenous nerve and sensory branches within the adductor canal, ACB preserves most quadriceps motor function while providing effective analgesia to the anteromedial knee compartment. Preservation of lower limb strength facilitates earlier ambulation and active physiotherapy participation, both of which are essential elements of enhanced recovery protocols. Consequently, ACB has become increasingly incorporated into standardized fast-track arthroplasty programs. [11]

Despite its advantages, isolated adductor canal block may inadequately address posterior knee pain because posterior capsular innervation arises primarily from branches of the tibial and obturator nerves. Recognition of this limitation has stimulated increasing integration of supplementary posterior knee analgesic techniques within multimodal pathways. Among these approaches, infiltration between the popliteal artery and capsule of the knee (IPACK) block has gained significant attention because it provides posterior capsular sensory analgesia while preserving distal motor function. Combination of ACB with IPACK block has demonstrated improved postoperative pain control and functional recovery compared with isolated anterior compartment blockade alone. [12]

Genicular nerve block has additionally emerged as a promising component of multimodal analgesic protocols after TKA. By selectively targeting periarticular sensory branches surrounding the femoral and tibial condyles, GNB may provide effective analgesia without significant motor impairment. Early clinical studies suggest that incorporation of genicular nerve block within multimodal pain pathways may improve postoperative comfort, reduce opioid requirements, and facilitate rehabilitation after knee arthroplasty. Furthermore, the selective sensory nature of GNB makes it particularly attractive within modern recovery protocols emphasizing preservation of motor performance and accelerated ambulation. [13]

Recent advances in ultrasound-guided regional anesthesia have substantially enhanced the precision and safety of multimodal analgesic strategies. Ultrasound visualization permits accurate identification of vascular landmarks, fascial compartments, and periosteal targets, thereby improving block reliability and reducing procedural complications. Increasing anatomical understanding of periarticular sensory innervation has further contributed to refinement of selective sensory blockade techniques around the knee joint. Consequently, contemporary multimodal analgesia after TKA increasingly relies on individualized combinations of regional anesthesia techniques tailored according to patient characteristics, surgical factors, and rehabilitation goals. [14]

Adductor Canal Block Within Contemporary Multimodal Pain Pathways

Adductor canal block has become one of the central regional anesthesia techniques within modern multimodal analgesic protocols after total knee arthroplasty. The technique was primarily developed to overcome the major limitations associated with femoral nerve block, particularly postoperative quadriceps weakness and delayed mobilization. Because contemporary enhanced recovery pathways strongly prioritize early ambulation and preservation of functional capacity, adductor canal block has gained widespread acceptance as a motor-sparing alternative capable of providing effective analgesia while minimizing impairment of lower limb motor function. [15]

The adductor canal, also known as Hunter's canal, is an intermuscular tunnel located in the middle third of the thigh extending from the apex of the femoral triangle to the adductor hiatus. Anatomically, the canal is bordered medially by the sartorius muscle, laterally by the vastus medialis muscle, and posteriorly by the adductor longus and adductor magnus muscles. Important neurovascular structures contained within the canal include the femoral artery, femoral vein, saphenous nerve, and nerve to vastus medialis. Because the saphenous nerve is primarily sensory, blockade at this level provides analgesia to the medial and anteromedial aspects of the knee while preserving most quadriceps motor fibers. [16]

The analgesic mechanism of adductor canal block involves interruption of nociceptive transmission through blockade of the saphenous nerve together with sensory articular branches arising from the nerve to vastus medialis. Such selective sensory blockade provides effective postoperative analgesia during both rest and movement while preserving active knee extension strength more effectively than femoral nerve block. This preservation of quadriceps function represents one of the most clinically important advantages of ACB because it directly supports early physiotherapy participation and safe postoperative ambulation. [17]

Ultrasound guidance has significantly enhanced the precision and safety of adductor canal block. The procedure is commonly performed using a high-frequency linear ultrasound transducer placed over the anteromedial aspect of the mid-thigh to identify the sartorius muscle and femoral artery within the canal. The saphenous nerve is usually visualized adjacent to the femoral artery beneath the sartorius fascia. Following needle advancement using an in-plane approach, local anesthetic is injected around the neurovascular structures within the canal. Ultrasound guidance permits accurate needle placement, improved spread of local anesthetic, and reduction in complications such as vascular puncture or unintended nerve injury. [18]

Several clinical studies have demonstrated favorable postoperative outcomes with adductor canal block following TKA. Compared with femoral nerve block, ACB has been associated with superior preservation of quadriceps strength, earlier ambulation, improved participation in rehabilitation exercises, and lower incidence of postoperative knee buckling. In addition, reduction in opioid consumption and opioid-related adverse effects has been consistently reported with incorporation of ACB into multimodal analgesic pathways. Such findings have contributed to increasing integration of ACB within fast-track arthroplasty and ERAS protocols. [11]

Despite its advantages, adductor canal block is not without limitations. The sensory coverage provided by ACB predominantly involves the anterior and medial compartments of the knee joint, whereas posterior capsular innervation remains relatively unaffected. Consequently, some patients continue to experience clinically significant posterior knee pain despite adequate

anterior analgesia. Recognition of this limitation has encouraged increasing use of combined regional analgesic strategies integrating adductor canal block with IPACK block, periarticular infiltration, or genicular nerve block to improve circumferential knee analgesia. [12]

Another important consideration involves the spread of local anesthetic beyond the adductor canal. Excessive injectate volume or proximal diffusion toward the femoral triangle may inadvertently involve motor branches of the femoral nerve and reduce quadriceps strength, thereby diminishing the motor-sparing advantage of the technique. Anatomical variability within the canal may additionally influence block distribution and analgesic efficacy. Careful ultrasound-guided injection and optimization of local anesthetic volume are therefore essential to maximize analgesic benefit while preserving motor performance. [19]

Adductor canal block currently represents one of the most valuable motor-preserving regional anesthesia techniques within contemporary multimodal pain management pathways after total knee arthroplasty. Its favorable balance between analgesic efficacy and preservation of quadriceps function has established ACB as a key component of modern perioperative recovery protocols emphasizing early ambulation, opioid minimization, and accelerated functional rehabilitation. [20]

Genicular Nerve Block as an Emerging Component of Multimodal Analgesia

Genicular nerve block has recently attracted considerable attention as an emerging motor-preserving regional analgesic technique within multimodal perioperative pain pathways after total knee arthroplasty. Although originally introduced as an interventional pain management procedure for chronic osteoarthritic knee pain, the technique has progressively expanded into perioperative anesthesia practice because of its selective sensory blockade characteristics and potential role in facilitating early postoperative rehabilitation. Unlike traditional peripheral nerve blocks targeting larger mixed motor-sensory nerves, genicular nerve block focuses specifically on periarticular sensory articular branches supplying the knee capsule, thereby theoretically minimizing motor impairment while maintaining effective analgesia. [21]

The anatomical basis of genicular nerve block depends on selective blockade of the superomedial, superolateral, inferomedial, and inferolateral genicular nerves. These articular sensory branches accompany their corresponding genicular arteries around the femoral condyles and proximal tibia, supplying nociceptive innervation to periosteal, synovial, and capsular structures of the knee joint. Because postoperative pain following TKA arises substantially from periarticular tissue trauma and inflammatory activation, interruption of sensory transmission through these genicular branches may significantly reduce postoperative pain intensity and improve patient comfort during rehabilitation. [22]

Ultrasound guidance has become an essential component for accurate and safe performance of genicular nerve block. The procedure is commonly performed with the patient in the supine position and the knee slightly flexed to facilitate visualization of periarticular structures. A high-frequency linear transducer is sequentially positioned over the medial and lateral femoral condyles and proximal tibial region to identify the corresponding genicular arteries using color Doppler imaging. The targeted sensory nerves are located adjacent to these vascular landmarks near the periosteal surface. Following ultrasound-guided needle advancement, local anesthetic is deposited around the periosteal region near each genicular artery to achieve selective sensory blockade. Ultrasound guidance significantly improves procedural precision while reducing risk of vascular injury or inaccurate injectate placement. [7]

One of the principal advantages of genicular nerve block is preservation of quadriceps motor strength. Since the targeted nerves are predominantly sensory articular branches with minimal motor contribution, GNB generally avoids the clinically significant quadriceps weakness frequently observed with femoral nerve block. Preservation of lower limb motor performance is particularly important during the immediate postoperative period after TKA because early mobilization and physiotherapy are essential for prevention of complications such as venous thromboembolism, joint stiffness, and muscle wasting. Consequently, genicular nerve block may support accelerated rehabilitation pathways and improve postoperative functional recovery. [23]

Several preliminary studies have demonstrated promising analgesic outcomes with genicular nerve block following total knee arthroplasty. Reported benefits include reduced postoperative pain scores, decreased opioid consumption, improved ambulation ability, and enhanced patient satisfaction. In addition, some investigators have suggested that incorporation of GNB into multimodal analgesic pathways may improve dynamic pain control during physiotherapy sessions while maintaining adequate motor function. Such characteristics have contributed to increasing interest in combining genicular nerve block with adductor canal block or other selective sensory techniques in order to achieve more comprehensive perioperative analgesia. [24]

Despite these favorable findings, important limitations regarding genicular nerve block remain under investigation. The sensory innervation of the knee joint demonstrates considerable anatomical variability, and no universal consensus currently exists regarding the optimal number of targeted genicular branches, local anesthetic volume, or precise injection sites. Furthermore, isolated genicular nerve block may not consistently provide complete posterior capsular analgesia or deep intra-articular pain relief following extensive surgical procedures such as TKA. Consequently, GNB is frequently utilized as part of a broader multimodal analgesic strategy rather than a standalone regional technique. [25]

Another important consideration relates to the current evidence base supporting perioperative use of genicular nerve block. Although early clinical experiences and retrospective studies have reported encouraging results, available literature remains relatively limited compared with the substantial evidence supporting adductor canal block. Variability in study design, block technique, rehabilitation protocols, and postoperative outcome measures further complicates interpretation of existing data. Therefore, additional large-scale randomized controlled trials remain necessary to establish the precise role of GNB within contemporary multimodal pain pathways after total knee arthroplasty. [15]

The growing interest in selective sensory regional anesthesia reflects the broader transition in perioperative medicine toward individualized, rehabilitation-oriented, and opioid-sparing analgesic strategies. Within this evolving paradigm, genicular nerve block appears to represent a promising complementary technique capable of enhancing postoperative pain management while preserving motor function and supporting rapid recovery after total knee arthroplasty. [26]

Integration of Combined Regional Analgesic Techniques After Total Knee Arthroplasty

The complex sensory innervation of the knee joint together with the multifactorial nature of postoperative pain after total knee arthroplasty has encouraged increasing integration of combined regional analgesic techniques within contemporary multimodal pain pathways. Although individual regional blocks such as adductor canal block or genicular nerve block may provide satisfactory analgesia to specific anatomical regions, isolated single-technique approaches often fail to achieve complete circumferential pain control. Consequently, modern perioperative analgesic strategies increasingly combine complementary sensory blockade techniques in order to optimize postoperative analgesia while preserving lower limb motor function. [27]

Adductor canal block alone primarily targets the anterior and medial sensory innervation of the knee through blockade of the saphenous nerve and related articular branches. However, posterior capsular pain remains an important source of postoperative discomfort following TKA because posterior innervation is predominantly derived from branches of the tibial and obturator nerves. Recognition of this limitation has contributed to the growing use of combined analgesic approaches incorporating posterior knee sensory blockade together with ACB to improve overall postoperative pain control. [28]

One of the most widely utilized complementary posterior knee techniques is infiltration between the popliteal artery and capsule of the knee (IPACK) block. The IPACK technique involves ultrasound-guided injection of local anesthetic into the interspace between the popliteal artery and posterior capsule, thereby targeting terminal sensory branches supplying the posterior knee compartment while preserving distal motor function of the tibial and common peroneal nerves. Combination of adductor canal block with IPACK block has demonstrated improved posterior knee analgesia, reduced opioid consumption, and enhanced early ambulation compared with isolated adductor canal blockade alone. [29]

Genicular nerve block has additionally emerged as a promising complementary technique within combined multimodal analgesic pathways. Because GNB selectively targets periarticular sensory branches surrounding the femoral and tibial condyles, integration of genicular nerve blockade with adductor canal block may provide broader periarticular analgesic coverage while maintaining preservation of quadriceps motor strength. Preliminary retrospective studies evaluating combined ACB and GNB approaches have reported favorable postoperative pain control and satisfactory rehabilitation outcomes after both primary and revision total knee arthroplasty. [24]

Periarticular local anesthetic infiltration also continues to play an important role within combined multimodal analgesic protocols after TKA. Periarticular infiltration involves direct intraoperative administration of local anesthetic mixtures into periosteal, capsular, ligamentous, and muscular tissues surrounding the knee joint. Such infiltration techniques may complement peripheral nerve blocks by targeting residual nociceptive pathways not adequately covered through isolated neural blockade alone. Combination of periarticular infiltration with motor-preserving regional anesthesia techniques may therefore provide synergistic analgesic benefit during the early postoperative period. [30]

The increasing integration of multiple regional analgesic modalities reflects the evolving philosophy of individualized perioperative pain management. Rather than relying on a single "ideal" nerve block, contemporary analgesic strategies increasingly emphasize balanced multimodal combinations tailored according to patient comorbidities, surgical complexity, rehabilitation priorities, and institutional expertise. Patients at high risk for opioid-related complications or delayed mobilization may particularly benefit from selective sensory blockade combinations capable of minimizing systemic opioid exposure while preserving functional recovery. [31]

Ultrasound guidance has substantially facilitated implementation of combined regional anesthesia techniques around the knee joint. Improved visualization of fascial planes, periosteal landmarks, vascular structures, and neural targets allows more precise execution of multiple complementary blocks during the same perioperative session. Advances in anatomical understanding of periarticular innervation have further contributed to refinement of selective sensory blockade strategies designed to maximize analgesic coverage while minimizing motor impairment. [14]

Despite encouraging clinical outcomes associated with combined regional analgesic pathways, important challenges remain regarding optimal block combinations, local anesthetic dosing, timing of administration, and long-term functional outcomes. Variability among published studies and lack of standardized multimodal protocols continue to limit definitive comparisons between analgesic strategies. Therefore, further prospective randomized investigations remain necessary to establish evidence-based recommendations regarding integration of adductor canal block, genicular nerve block, IPACK block, and periarticular infiltration within contemporary multimodal pain management after total knee arthroplasty. [15]

Functional Recovery, Opioid Reduction, and Enhanced Recovery After Surgery Pathways

Enhanced recovery after surgery (ERAS) protocols have substantially transformed perioperative management in total knee arthroplasty by emphasizing early mobilization, reduction of perioperative morbidity, shortened hospitalization, and accelerated functional recovery. Effective postoperative analgesia represents one of the central pillars of ERAS pathways because inadequate pain control directly impairs ambulation, physiotherapy participation, and rehabilitation outcomes. Consequently, contemporary perioperative analgesic strategies increasingly focus on motor-preserving regional anesthesia techniques capable of optimizing pain relief while maintaining lower limb functional performance. [32]

Early ambulation following TKA is critically important for prevention of postoperative complications including venous thromboembolism, pulmonary atelectasis, muscle wasting, joint stiffness, and delayed functional recovery. Preservation of quadriceps muscle strength is therefore considered a major determinant of successful postoperative rehabilitation. Traditional femoral nerve block, although highly effective for postoperative analgesia, frequently impairs quadriceps function because of blockade of motor fibers supplying the extensor mechanism of the knee. Recognition of these limitations significantly contributed to the growing transition toward selective sensory regional anesthesia techniques such as adductor canal block and genicular nerve block. [33]

Adductor canal block has demonstrated important functional advantages within ERAS pathways because it largely preserves active knee extension while providing satisfactory analgesia to the anterior and medial knee compartments. Several studies have reported earlier ambulation, improved participation in physiotherapy sessions, reduced incidence of knee buckling, and faster achievement of rehabilitation milestones with ACB compared with femoral nerve block. Such benefits may contribute to shorter hospital stay and improved patient satisfaction after TKA. [11]

Similarly, genicular nerve block has gained increasing interest because of its selective periarticular sensory blockade and minimal motor involvement. Preservation of quadriceps strength following GNB may facilitate early mobilization and improve patient confidence during ambulation in the immediate postoperative period. Preliminary reports additionally suggest that incorporation of genicular nerve block within multimodal analgesic protocols may improve dynamic pain control during rehabilitation exercises while reducing reliance on systemic opioid medications. [23]

Reduction of perioperative opioid exposure represents another major objective of contemporary ERAS protocols after TKA. Excessive opioid consumption is associated with nausea, vomiting, constipation, urinary retention, sedation, respiratory depression, delayed mobilization, and prolonged hospitalization. In addition, increasing concern regarding chronic opioid dependence has encouraged widespread adoption of opioid-sparing perioperative analgesic pathways. Peripheral nerve blocks therefore play an increasingly important role within multimodal analgesia because they reduce postoperative nociceptive transmission while minimizing systemic opioid requirements. [34]

Combination regional analgesic strategies integrating adductor canal block, genicular nerve block, IPACK block, and periarticular infiltration may further enhance postoperative functional recovery by providing more comprehensive circumferential analgesia. Improved pain control during movement may facilitate earlier initiation of physiotherapy and greater patient participation in rehabilitation exercises. Such multimodal regional pathways are particularly valuable in elderly patients and individuals with multiple medical comorbidities where minimization of opioid-related complications and preservation of mobility are especially important. [35]

Patient-centered perioperative care has become increasingly important within modern arthroplasty programs. In addition to objective clinical outcomes, contemporary ERAS pathways emphasize patient comfort, satisfaction, early return to independence, and overall quality of recovery. Effective motor-preserving analgesia contributes significantly to these goals by reducing postoperative discomfort while enabling functional mobility and active rehabilitation participation. Consequently, integration of selective sensory regional anesthesia techniques has become a defining feature of modern perioperative management after total knee arthroplasty. [36]

Despite significant advances in multimodal and motor-preserving analgesia, further research remains necessary to establish standardized evidence-based ERAS protocols integrating adductor canal block and genicular nerve block within contemporary arthroplasty practice. Future investigations should focus on long-term functional outcomes, optimal block combinations, patient selection criteria, opioid reduction strategies, and cost-effectiveness analyses in order to optimize perioperative recovery after total knee arthroplasty. [15]

Current Challenges and Future Perspectives in Regional Analgesia After Total Knee Arthroplasty

Despite the substantial progress achieved in regional anesthesia techniques for total knee arthroplasty, several important clinical challenges remain unresolved. One of the major difficulties involves the highly complex and variable sensory innervation of the knee joint. Considerable anatomical overlap exists between branches of the femoral, obturator, tibial, sciatic, and common peroneal nerves, resulting in variability in postoperative pain distribution and analgesic response among patients. Consequently, no single regional anesthesia technique consistently provides complete circumferential analgesia after TKA, which has encouraged continued development of combined and individualized multimodal analgesic strategies. [37]

Another important challenge relates to the absence of standardized protocols regarding optimal combinations of regional anesthesia techniques. Considerable heterogeneity currently exists among published studies concerning local anesthetic agents, injectate volume, ultrasound-guided approaches, targeted neural structures, timing of block administration, and perioperative rehabilitation protocols. Such variability complicates direct comparison between studies and limits the ability to establish universally accepted evidence-based recommendations regarding integration of adductor canal block, genicular nerve block, IPACK block, and periarticular infiltration within contemporary TKA analgesic pathways. [15]

Although adductor canal block is widely accepted as a motor-preserving alternative to femoral nerve block, several technical and anatomical concerns continue to be investigated. Spread of local anesthetic beyond the adductor canal may unintentionally involve proximal femoral motor branches and partially reduce quadriceps strength, thereby compromising early mobilization. Furthermore, isolated ACB may inadequately control posterior capsular pain, particularly in patients undergoing extensive surgical manipulation or revision arthroplasty. These limitations have stimulated ongoing efforts to refine selective sensory blockade techniques capable of improving analgesic coverage without impairing motor performance. [38]

Similarly, the precise role of genicular nerve block within perioperative TKA analgesia remains incompletely defined. Although preliminary clinical studies have demonstrated promising outcomes regarding pain reduction and preservation of motor function, the current evidence base remains relatively limited compared with established techniques such as adductor canal block. Questions additionally persist regarding the optimal number of targeted genicular branches, ideal injectate volume, long-term outcomes, and comparative efficacy when combined with other regional anesthesia modalities. Large prospective randomized trials remain necessary to validate the routine perioperative application of genicular nerve block after total knee arthroplasty. [24]

Future developments in perioperative regional anesthesia are likely to focus increasingly on individualized and precision-guided analgesic approaches. Advances in ultrasound imaging, anatomical mapping, and artificial intelligence-assisted imaging technologies may further improve procedural accuracy and facilitate more selective targeting of periarticular sensory pathways. Enhanced understanding of knee joint innervation may additionally contribute to development of novel sensory-selective

blockade techniques capable of optimizing analgesic efficacy while preserving motor function and accelerating rehabilitation. [14]

Long-acting local anesthetic formulations and extended-duration analgesic techniques also represent promising future directions in TKA pain management. Liposomal local anesthetics, continuous peripheral nerve catheter techniques, and novel drug delivery systems may prolong postoperative analgesia and further reduce opioid requirements while maintaining functional recovery. Such approaches may become increasingly valuable within outpatient and short-stay arthroplasty programs where prolonged postoperative pain control remains particularly important. [39]

The growing emphasis on value-based healthcare and patient-centered outcomes will likely continue to influence future analgesic pathway development after TKA. Beyond traditional pain scores, increasing attention is now directed toward functional recovery, quality of rehabilitation, patient satisfaction, opioid reduction, early discharge readiness, and long-term mobility outcomes. Consequently, future research should prioritize comprehensive outcome assessment integrating both analgesic efficacy and functional rehabilitation endpoints in order to optimize perioperative recovery strategies after total knee arthroplasty. [40]

Contemporary regional anesthesia for total knee arthroplasty continues to evolve toward increasingly selective, motor-preserving, and rehabilitation-oriented analgesic strategies. Integration of adductor canal block and genicular nerve block within multimodal perioperative pathways represents an important step toward achieving balanced analgesia that supports early ambulation, opioid minimization, and enhanced postoperative recovery. Continued anatomical research, technological innovation, and high-quality clinical trials will remain essential for refining these evolving regional analgesic approaches in future arthroplasty practice. [41]

Safety Considerations and Potential Complications of Contemporary Regional Analgesic Techniques

Although contemporary regional anesthesia techniques have significantly improved postoperative pain management after total knee arthroplasty, careful attention to safety considerations and potential complications remains essential for optimal perioperative outcomes. The increasing integration of adductor canal block, genicular nerve block, IPACK block, and combined multimodal analgesic approaches has enhanced postoperative analgesia while reducing opioid consumption and preserving motor function. Nevertheless, these techniques still carry procedural risks that require detailed anatomical knowledge, ultrasound proficiency, appropriate patient selection, and adherence to strict safety precautions. [42]

Adductor canal block is generally considered a safe and reliable motor-preserving regional anesthesia technique because the targeted structures are relatively superficial and easily visualized under ultrasound guidance. However, the close anatomical relationship between the saphenous nerve and femoral vessels within the adductor canal creates potential risk of vascular puncture, hematoma formation, and inadvertent intravascular injection. Local anesthetic systemic toxicity (LAST), although uncommon, remains a potentially serious complication particularly when high local anesthetic volumes are used or accidental intravascular administration occurs. Incremental injection with repeated aspiration and continuous ultrasound visualization significantly reduce these risks. [43]

Another important concern associated with adductor canal block involves unintended proximal spread of local anesthetic toward the femoral triangle. Such spread may partially involve motor branches of the femoral nerve and compromise quadriceps muscle strength, thereby reducing the motor-sparing advantage of the technique. Postoperative quadriceps weakness may impair ambulation and increase fall risk during the early rehabilitation period. Optimization of injectate volume, accurate fascial plane identification, and proper ultrasound-guided needle placement are therefore essential for preserving lower limb motor function after TKA. [44]

Neurological complications following adductor canal block are uncommon but may occur secondary to direct needle trauma, intraneural injection, compression hematoma, or local anesthetic neurotoxicity. Reported manifestations include transient paresthesia, numbness, dysesthesia, or sensory disturbances along the distribution of the saphenous nerve. Most neurological symptoms are temporary and resolve spontaneously; however, meticulous ultrasound-guided needle advancement and avoidance of high-pressure injection remain important preventive measures. [45]

Genicular nerve block similarly demonstrates a favorable safety profile because the targeted structures are small periarticular sensory branches rather than major mixed motor-sensory nerves. Nevertheless, the genicular nerves accompany periarticular vascular structures around the femoral condyles and proximal tibia, creating potential risk of vascular injury and hematoma

formation. Use of color Doppler ultrasound imaging facilitates identification of the genicular arteries and significantly improves procedural safety during needle advancement and injectate placement. [7]

Because genicular nerve block targets predominantly sensory periarticular branches, significant motor weakness is rarely encountered following the procedure. However, transient localized sensory changes, periosteal discomfort, numbness, or neuropathic symptoms may occasionally occur. Rare complications reported following periarticular interventional procedures involving the genicular nerves include prolonged sensory disturbance, local infection, and post-procedural pain flare. Strict aseptic precautions together with accurate anatomical targeting are therefore essential to minimize procedural morbidity. [46]

Combined multimodal regional analgesic strategies may additionally increase cumulative local anesthetic exposure when multiple blocks are performed simultaneously. Integration of adductor canal block, genicular nerve block, IPACK block, and periarticular infiltration requires careful calculation of total local anesthetic dose in order to minimize risk of systemic toxicity. Elderly patients and individuals with hepatic dysfunction, cardiac disease, or reduced plasma protein binding capacity may be particularly susceptible to local anesthetic toxicity and therefore require cautious dose adjustment and careful perioperative monitoring. [47]

Ultrasound guidance has become one of the most important advancements contributing to improved safety of contemporary regional anesthesia techniques after TKA. Real-time visualization of fascial planes, vascular structures, periosteal landmarks, and needle trajectory substantially improves block accuracy while reducing risk of inadvertent vascular puncture or neural injury. Ongoing advances in ultrasound technology and regional anesthesia training are expected to further enhance procedural safety and expand clinical applications of selective sensory regional analgesic techniques in perioperative orthopedic practice. [48]

Contemporary perioperative pain management after total knee arthroplasty has progressively shifted toward multimodal and motor-preserving regional anesthesia strategies designed to optimize analgesia while facilitating early rehabilitation and functional recovery. Current evidence strongly supports the important role of peripheral nerve blocks within enhanced recovery after surgery pathways because these techniques significantly reduce postoperative opioid requirements and improve patient participation in physiotherapy. Among available regional analgesic modalities, adductor canal block has become one of the most widely accepted motor-sparing techniques owing to its favorable balance between analgesic efficacy and preservation of quadriceps muscle strength. [49]

Adductor canal block currently possesses the strongest clinical evidence among motor-preserving regional anesthesia techniques after TKA. Multiple clinical studies and comparative analyses have demonstrated that ACB provides effective analgesia with superior preservation of ambulation ability and lower incidence of postoperative knee buckling compared with femoral nerve block. Consequently, ACB is now incorporated into many contemporary fast-track arthroplasty and ERAS protocols. Nevertheless, isolated adductor canal block may inadequately address posterior capsular pain because of incomplete coverage of posterior sensory innervation pathways. [50]

Genicular nerve block represents an increasingly promising complementary sensory-selective technique within modern multimodal analgesic pathways. The principal advantage of GNB lies in its ability to target periarticular sensory branches while preserving lower limb motor function. Preliminary clinical experiences have demonstrated encouraging results regarding postoperative pain reduction, opioid sparing, and facilitation of rehabilitation after TKA. However, compared with adductor canal block, the current evidence supporting perioperative genicular nerve blockade remains relatively limited and largely based on retrospective studies, case series, and early clinical observations. Additional prospective randomized investigations remain necessary to establish standardized protocols and clarify its precise role within contemporary arthroplasty analgesia. [51]

Current evidence additionally suggests that combined regional analgesic approaches may provide superior postoperative pain control compared with isolated single-block techniques. Integration of adductor canal block with IPACK block, genicular nerve block, or periarticular infiltration may improve circumferential knee analgesia by simultaneously addressing anterior and posterior sensory pathways. Such combined strategies appear particularly beneficial in patients with severe postoperative pain, revision arthroplasty procedures, or individuals requiring accelerated rehabilitation and early discharge pathways. [52]

Selection of the optimal regional analgesic strategy should remain individualized according to patient characteristics, surgical complexity, rehabilitation priorities, institutional expertise, and available ultrasound-guided regional anesthesia resources. Elderly patients and individuals at high risk for opioid-related complications may derive particular benefit from motor-preserving multimodal approaches that minimize systemic opioid exposure while maintaining ambulation ability and functional

independence. Similarly, patients undergoing fast-track or outpatient arthroplasty programs may benefit substantially from selective sensory blockade strategies facilitating earlier discharge readiness and postoperative mobility. [53]

Conclusion

Contemporary regional analgesia after total knee arthroplasty has evolved toward increasingly selective, multimodal, and motor-preserving strategies aimed at optimizing postoperative pain control while facilitating early rehabilitation and functional recovery. Adductor canal block has become a well-established component of enhanced recovery pathways because of its favorable balance between analgesic efficacy and preservation of quadriceps strength, whereas genicular nerve block represents a promising emerging adjunct that may further enhance periarticular sensory analgesia with minimal motor impairment. Integration of these techniques within individualized multimodal pain pathways may reduce opioid consumption, improve ambulation, accelerate physiotherapy participation, and enhance overall postoperative recovery after total knee arthroplasty. Continued refinement of ultrasound-guided techniques and further high-quality clinical studies remain essential to optimize their future role in modern perioperative orthopedic anesthesia practice.

How to cite this article: Mona Abdelrazik Shahin, Shereen Elsayed Abd Ellatif, Soha Saad Eldin Mohamed (2024). Contemporary Regional Analgesic Techniques for Total Knee Arthroplasty: Integrating Adductor Canal and Genicular Nerve Blocks Into Multimodal Pain Pathways. Vol. 14, No. 3, 2024,1101--1113.

Source of support: None.

Conflict of interest: Nil.

Accepted: 26.03.2024 **Received** 03.03.2024

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