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Optimization of regional anesthesia in orthopedic surgery: Benefits in postoperative pain management

Optimización de la anestesia regional en cirugía ortopédica: beneficios en el tratamiento del dolor postoperatorio

Otimização da anestesia regional em cirurgia ortopédica: benefícios no tratamento da dor pós-operatória

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ABSTRACT

One of the most noble medical procedures from a humanitarian standpoint is anesthesia. It offers the advantage of temporarily blocking the brain's response to painful stimuli. This action allows the surgeon to carry out their work smoothly and the patient to feel no pain, benefiting both parties. To explore the optimization of regional anesthesia in orthopedic surgery and its benefits in postoperative pain management, a comprehensive literature review was conducted. This review encompassed original articles, reviews, and meta-analyses published primarily in English and Spanish from. Relevant studies were identified through systematic searches in the Cochrane Library, EMBASE, and LILACS databases, employing a combination of controlled descriptors and free-text terms. Modern regional anesthesia (RA) techniques, such as ultrasound-guided blocks and continuous catheters, significantly improve postoperative pain management in orthopedic surgery compared to general anesthesia and traditional systemic analgesia. Ultrasound guidance enhances precision and safety, leading to effective, localized pain control, reduced opioid use and side effects, faster recovery, and increased patient satisfaction. Continuous catheters prolong these benefits, offering sustained and adjustable pain relief, facilitating rehabilitation, potentially decreasing chronic pain and shortening hospital stays. Although requiring specialized training and protocols, the strong evidence supports the value of these RA techniques in optimizing postoperative pain management and potentially improving healthcare costs and long-term outcomes, making their integration a priority in contemporary orthopedic practice.

Keywords: Anesthesia, Orthopedic, Pain, Postoperative.

RESUMEN

Uno de los procedimientos médicos más nobles desde el punto de vista humanitario es la anestesia. Ofrece la ventaja de bloquear temporalmente la respuesta del cerebro a los estímulos dolorosos. Esta acción permite al cirujano realizar su trabajo con fluidez y al paciente no sentir dolor, lo que beneficia a ambas partes. Para explorar la optimización de la anestesia regional en la cirugía ortopédica y sus beneficios en el manejo del dolor postoperatorio, se llevó a cabo una revisión bibliográfica exhaustiva. Esta revisión abarcó artículos originales, revisiones y metaanálisis publicados principalmente en inglés y español. Los estudios relevantes se identificaron mediante búsquedas sistemáticas en las bases de datos Cochrane Library, EMBASE y LILACS, empleando una combinación de descriptores controlados y términos de texto libre. Las técnicas modernas de anestesia regional (AR), como los bloqueos guiados por ecografía y los catéteres continuos, mejoran significativamente el tratamiento del dolor postoperatorio en la cirugía ortopédica en comparación con la anestesia general y la analgesia sistémica tradicional. La guía ecográfica mejora la precisión y la seguridad, lo que conduce a un control eficaz y localizado del dolor, una reducción del uso de opioides y de los efectos secundarios, una recuperación más rápida y una mayor satisfacción del paciente. Los catéteres continuos prolongan estos beneficios, ya que ofrecen un alivio del dolor sostenido y ajustable, facilitan la rehabilitación, pueden reducir el dolor crónico y acortar la estancia hospitalaria. Aunque requieren formación y protocolos especializados, las sólidas pruebas respaldan el valor de estas técnicas de AR para optimizar el tratamiento del dolor postoperatorio y mejorar potencialmente los costes sanitarios y los resultados a largo plazo, lo que hace que su integración sea una prioridad en la práctica ortopédica contemporánea.

Palabras clave: Anestesia, Ortopedia, Dolor, Postoperatorio.

RESUMO

Um dos procedimentos médicos mais nobres do ponto de vista humanitário é a anestesia. Ela oferece a vantagem de bloquear temporariamente a resposta do cérebro aos estímulos dolorosos. Esta ação permite que o cirurgião realize o seu trabalho sem problemas e que o paciente não sinta dor, beneficiando ambas as partes. Para explorar a otimização da anestesia regional em cirurgia ortopédica e os seus benefícios no controlo da dor pós-operatória, foi realizada uma revisão exaustiva da literatura. Esta revisão englobou artigos originais, revisões e meta-análises publicados principalmente em inglês e espanhol. Os estudos relevantes foram identificados através de pesquisas sistemáticas nas bases de dados Cochrane Library, EMBASE e LILACS, empregando uma combinação de descritores controlados e termos de texto livre. Técnicas modernas de anestesia regional (AR), como bloqueios guiados por ultrassom e cateteres contínuos, melhoram significativamente o controle da dor pós-operatória em cirurgia ortopédica em comparação com a anestesia geral e a analgesia sistêmica tradicional. A orientação por ultrassom aumenta a precisão e a segurança, levando a um controle eficaz e localizado da dor, redução do uso de opióides e dos efeitos colaterais, recuperação mais rápida e maior satisfação do paciente. Os cateteres contínuos prolongam estes benefícios, oferecendo um alívio sustentado e ajustável da dor, facilitando a reabilitação, diminuindo potencialmente a dor crónica e encurtando os períodos de internamento hospitalar. Embora exija treino e protocolos especializados, a forte evidência apoia o valor destas técnicas de AR na otimização da gestão da dor pós-operatória e na potencial melhoria dos custos dos cuidados de saúde e dos resultados a longo prazo, tornando a sua integração uma prioridade na prática ortopédica contemporânea.

Palavras-chave: Anestesia Ortopédica, Dor Pós-Operatória.

Introduction

One of the most noble medical procedures from a humanitarian standpoint is anesthesia. It offers the advantage of temporarily blocking the brain's response to painful stimuli. This action allows the surgeon to carry out their work smoothly and the patient to feel no pain, benefiting both parties. When discussing anesthesia, it is convenient to consider an anatomical structure of vital interest: the vertebral column. Its importance lies in the protection it offers to the spinal cord and the nerve roots that originate from it. These structures are the target of the techniques used to administer anesthetic drugs. Among the types of anesthesia most used in practice are general anesthesia, epidural anesthesia, spinal anesthesia, and local anesthesia (1).

Pain is part of the human body as a warning to protect it, thereby triggering a series of reactions to limit damage. The International Association for the Study of Pain (IASP) has defined pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” (2).

The use of Regional Anesthesia is increasingly involved in the anesthetic and especially analgesic management of various orthopedic procedures. During the surgical procedure, very intense pain occurs in response to direct or indirect aggression caused by the surgical act, including the surgical technique, as well as the anesthetic technique, inadequate postures, muscle contractures, and influences important negative repercussions such as physical condition, causing generalized hemodynamic and neuroendocrine responses, in addition to affecting the emotional and economic state of the patient and medical institutions (3).

One of the most effective techniques for controlling postoperative pain is the use of analgesics via spinal administration, especially when chronic pain occurs in the first hours. It is mainly indicated in major surgery of the thorax, upper abdomen, and major orthopedic surgery. For these, a variety of techniques are used to manage severe postoperative pain, which include the use of the neuroaxial approach, especially epidural (4).

Currently, different drugs are available that not only provide an analgesic effect but also help prevent postoperative complications and consequently lead to an increase in perioperative morbidities. Among the best-known drugs are non-steroidal anti-inflammatory drugs (NSAIDs), opioids, recently alpha-2 agonists such as dexmedetomidine, ketamine, pregabalin, as well as analgesic techniques such as regional analgesia and patient-controlled analgesia (PCA) (5).

Methods

To explore the optimization of regional anesthesia in orthopedic surgery and its benefits in postoperative pain management, a comprehensive literature review was conducted. This review encompassed original articles, reviews, and meta-analyses published primarily in English and Spanish from. Relevant studies were identified through systematic searches in the Cochrane Library, EMBASE, and LILACS databases, employing a combination of controlled descriptors and free-text terms. The selection of studies was based on predefined criteria related to the administration of regional anesthesia techniques in orthopedic procedures and the evaluation of postoperative pain as a primary or secondary outcome.

Results

1. Fundamentals of Regional Anesthesia in Orthopedics

1.1. History and Evolution of Regional Techniques

It was approximately 100 years ago when the first peripheral nerve block was performed, a procedure carried out by Hirschel, and in recent years, its use has greatly increased due to ultrasound devices. The earliest evidence of ultrasound-guided blocks dates back about 20 years, but due to the improvement of these systems and the development of portable ultrasound machines, the use of regional blocks has surged. Employing ultrasound systems allows for the visualization of different structures in real-time, as well as observing the diffusion of the local anesthetic around the anesthetized nerve, thereby limiting over-dosage and potential systemic toxicity. Within regional anesthesia, we can discuss Peripheral Nerve Blocks, epidural and spinal anesthesia, and regional intravenous anesthesia (6).

The advancement and improvement of regional anesthesia methods for various surgical procedures, particularly in obstetric, ophthalmic, and orthopedic surgeries, as well as the continuous enhancement of continuous regional analgesia, persist. In regional anesthesia training within the fields of anesthesiology and intensive care medicine, the emphasis on mastering essential techniques such as spinal block, epidural block, axillary brachial plexus block, femoral nerve block, and intravenous regional anesthesia is typically considered comprehensive. Generally, performing more peripheral blocks tends to reduce the occurrence of complications and adverse effects. Peripheral regional anesthesia is a crucial aspect of contemporary perioperative care. Peripheral regional anesthesia can be performed effectively with simple techniques, such as fascia iliaca compartment blocks, which require minimal technological resources. Among other methods, ultrasound has gained widespread clinical acceptance in this field to guide needle movement towards nerves, minimizing the risk of needle contact with critical structures and reducing potential complications (7).

Various types of blocks exist, each applied to a specific area of the body. Some of the most common include:

- **Brachial plexus block:** Performed on a group of nerves that control muscles and sensations in the arm and hand (8).
- **Cervical plexus block:** Performed on a group of nerves that control muscles and sensations in the neck and upper extremities (8).
- **Lumbar plexus block:** Originates numerous branches that innervate various muscles and regions of the posterior abdominal wall and the lower extremity. Together with the sacral plexus, they form a union known as the lumbosacral plexus, which gives rise to all the motor and sensory nerves of the lower extremity (8).
- **Sacral plexus block:** This plexus emits several branches including anterior, posterior, and one terminal branch; these provide motor and sensory innervation to the posterior portion of the thigh, the lower portion of the leg, the entire foot, and a part of the pelvis (8).

1.2. Mechanism of Action

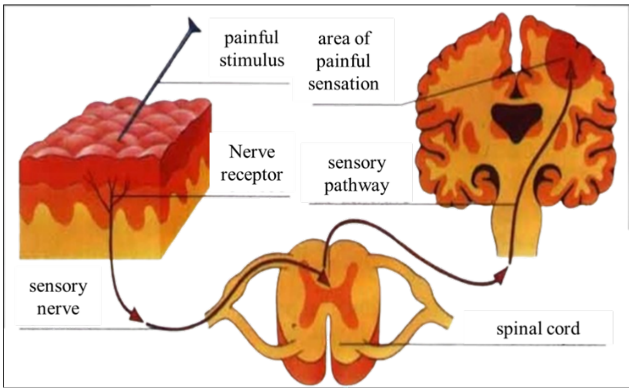

Figure 1. How is regional block achieved?

Source: Tamayo Gómez (9).

Regional anesthesia blocks the perception of pain by interrupting the transmission of nerve impulses from the area of the body where the surgery will be performed to the central nervous system. When a painful stimulus occurs in the periphery, nerve receptors detect it and generate an electrical signal that travels through sensory nerves towards the spinal cord and, subsequently, to the brain, where it is interpreted as pain. Regional anesthesia, by injecting a local anesthetic near the peripheral nerves, prevents the propagation of this nerve signal. By blocking the conduction along these nerves, pain information cannot reach the spinal cord or ascend to the brain, resulting in the absence of painful sensation in the anesthetized region. In essence, regional anesthesia acts as a barrier that silences the nervous communication between the surgical site and the pain processing centers in the central nervous system (9).

1.3. Comparison with General Anesthesia

This differs from general anesthesia in that it does not affect the patient's level of consciousness to relieve pain. There are several advantages over general anesthesia, such as avoiding airway manipulation, reduced doses of systemic drugs, fewer side effects from systemic drugs, faster recovery time, and significantly lower pain levels after surgery (10).

2. Current Regional Anesthesia Techniques Used

2.1. Peripheral Nerve Blocks (e.g., Femoral, Sciatic, Brachial Plexus)

The brachial plexus, a crucial nerve network for the innervation of the upper limb, originates from the C5-T1 nerve roots, which are organized into trunks (superior, middle, and inferior). These trunks further divide into anterior and posterior divisions, which then regroup to form three fascicles: lateral, posterior, and medial. From these fascicles emerge the five main terminal branches that innervate the arm, forearm, and hand: musculocutaneous, axillary, radial, median, and ulnar. Brachial plexus block is a widely used regional anesthesia technique that can be performed via supraclavicular, infraclavicular, and axillary approaches. The supraclavicular block, in particular, provides complete and rapid anesthesia of the entire upper limb with a single injection, being especially useful for surgeries of the arm, forearm, and hand. The choice of local anesthetic and its concentration (lidocaine for short procedures, bupivacaine or ropivacaine for more extensive surgeries) is adapted to the estimated duration of the procedure and postoperative needs (6).

The femoral nerve block, also known as the crural nerve block, is an anesthetic technique used primarily for surgeries on the anterior aspect of the thigh and for postoperative pain control in this region. It is often combined with other blocks, such as the sciatic nerve block, to achieve complete analgesia of the knee. The femoral nerve, the largest of the lumbar plexus (L2-L4), innervates muscles such as the iliacus and pectineus, as well as the anterior muscles of the thigh (except the fascia lata), and provides sensation to the lateral and frontal aspects of the middle thigh, the medial part of the leg and foot, and the knee and hip joints. The block is performed at the level of the groin, frequently using ultrasound to guide the needle towards the nerve, which is generally located lateral to the femoral artery. Approximately 20 ml of local anesthetic is usually injected, sometimes with epinephrine to prevent vascular puncture. Complications are rare but may include hematoma, nerve injury, and catheter infection if left in place for continuous analgesia (6).

The sciatic nerve, the largest peripheral nerve in the body, originates in the pelvis (sacral plexus), exits through the greater sciatic notch, and descends along the posterior aspect of the thigh. In the lower third of the femur, it divides into the tibial nerve (internal popliteal sciatic) and the common peroneal nerve (external popliteal sciatic). The tibial nerve branches into the medial and lateral plantar nerves, while the peroneal nerve gives rise to branches around the knee and to the sural, superficial peroneal, and deep peroneal nerves. Occasionally, this division occurs at the origin of the sciatic nerve. To block this nerve, approximately 20 ml of local anesthetic is generally sufficient, considering whether the goal is surgical or analgesic. The block can be performed via a posterior approach (classic or parasacral in the gluteal region) or posterior in the popliteal fossa. It is a common technique for surgeries of the knee, calf, and for the symptomatic treatment of the Achilles tendon, ankle, and foot. Complications are rare and include local muscle spasms in the thigh, vascular puncture, and muscle spasms in the foot or toes (6).

The innervation of the foot comes from five main nerves: the internal saphenous (medial aspect), the sural or external saphenous (lateral aspect), the posterior tibial (deep plantar structures and sole), the superficial peroneal or musculocutaneous of the leg (dorsum), and the deep peroneal or anterior tibial (deep dorsal structures and the interdigital space between the first and second toes). The block of these nerves is performed at different points depending on the area to be intervened, and all five can even be blocked simultaneously. Although some nerves innervate deep structures and a complete block is not always required, studies suggest that total foot block for forefoot surgeries offers better postoperative pain control than selective block. The choice of local anesthetic (lidocaine, mepivacaine, bupivacaine, or ropivacaine, or combinations) depends on the estimated duration of the surgery, with lidocaine for short procedures and bupivacaine or ropivacaine for prolonged analgesia. Other types of regional blocks, such as spinal and epidural anesthesia, will be discussed below (6).

The fascia iliaca block is an alternative to the femoral or lumbar plexus block, based on the location of the femoral and lateral femoral cutaneous nerves below this fascia. By depositing a sufficient amount of local anesthetic under the fascia iliaca, the aim is to anesthetize both nerves simultaneously. The technique is usually guided by ultrasound, using a linear transducer to visualize the fascia iliaca, which is located above the nerves and the iliopsoas muscle. After anesthetizing the skin, a needle (22 gauge) is inserted until it pierces the fascia, which is confirmed visually with the ultrasound and by the tactile sensation. Between 30-40 ml of local anesthetic is injected to ensure successful blockade of the femoral and lateral femoral cutaneous nerves, although obturator nerve block with this technique is variable. Complications are rare, including block failure, local hematomas, neuropraxia, systemic toxicity from the anesthetic, quadriceps weakness, peritoneal perforation, and bladder puncture. Vascular or nerve puncture is very infrequent due to the distance of the block site from the neurovascular bundle (6).

The obturator nerve, originating from the L2-L4 nerve roots, emerges from the psoas muscle and bifurcates into two terminal branches. The anterior branch innervates the obturator externus, adductor brevis and longus, pectineus muscles, as well as the medial aspect of the thigh cutaneously. The posterior branch innervates the obturator externus, adductor magnus, the hip joint, and the popliteal region cutaneously. For percutaneous block of the obturator nerve, although ultrasound guidance is preferred, non-ultrasound techniques such as Labat's (puncture lateral and caudal to the pubic spine) and the paravascular approach (puncture at the midpoint of the inguinal line between the femoral artery and the tendon of the adductor longus) exist. The three-in-one block, which aims to anesthetize the femoral, lateral femoral cutaneous, and obturator nerves with a single injection, is also mentioned (6).

The lateral femoral cutaneous nerve, composed of the L2-L4 nerve roots, is a purely sensory nerve that, after passing the inguinal region, divides into an anterior branch (sensation of the anterolateral thigh) and a posterior branch (lateral innervation of the thigh). Its block is used in superficial surgeries such as graft placement or interventions on the lateral aspect of the thigh, and also in the treatment of meralgia paresthetica. The technique is performed under ultrasound guidance, and the anesthetics of choice are usually mepivacaine or bupivacaine, sometimes combined with triamcinolone or methylprednisolone (6).

2.2. Epidural and Spinal Anesthesia: Indications and Differences

Epidural Anesthesia: Both the intradural (ID) and epidural (EPI) techniques share many methodological aspects, which is why they are analyzed together. In both cases, the local anesthetic (LA) is placed in contact with sensory, motor, and vegetative nerve roots, leading to a metameric sensory, motor, and autonomic blockade, although with differences (11).

Spinal Intradural Anesthesia (AI): This involves the direct injection of local anesthetic (LA) into the subarachnoid space after lumbar puncture, with an immediate effect that blocks sensation, motor function, and the autonomic system below the level of injection and some superior metameres. Hypotension is a complication dependent on the extent of the blockade. It is used for infraumbilical surgery with high-concentration, low-volume LA but is contraindicated in certain conditions such as shock or intracranial hypertension.

Spinal Epidural Anesthesia (AE): In contrast, this involves depositing the LA into the epidural space, allowing for a more selective and slower-onset but longer-duration blockade, with a lower risk of hypotension and the possibility of continuous analgesia via a catheter. Bupivacaine is a common drug used, with less cephalad migration and a lower risk of post-dural puncture headache compared to AI (11).

Table 1. Differences between Epidural and Spinal Anesthesia.

Characteristic	Spinal Anesthesia (Intradural)	Epidural Anesthesia
Site of Injection	Intradural (subarachnoid) space, where CSF is located	Epidural (virtual) space, between the dura mater and the ligamentum flavum
Contact with CSF	Yes, the anesthetic mixes with the CSF	No, the anesthetic is deposited outside the dura mater
Type of Needle	Fine needle, with a sharp tip	Thicker needle (e.g., Touhy), with a blunt tip
Loss of Resistance	Dura mater is pierced, with CSF outflow	Loss of resistance is noted upon entering the epidural space
Onset of Block	Very rapid (immediate)	Slower (10-20 minutes)
Duration of Block (Single Dose)	Generally shorter (1-2 hours)	Generally longer (depends on dose and drug)
Extent of Block	More predictable and dense for a given level	More variable and segmental, extent can be better controlled
Motor Block	Generally dense	Can be selective (sensory block with less motor block)
Autonomic Block (Hypotension)	More intense and rapid, higher risk of hypotension	Less intense and more gradual, lower risk of hypotension
Catheter for Repeated/Continuous Doses	Not usually used (risk of meningeal infection)	Commonly used to prolong analgesia or anesthesia

Volume of Local Anesthetic	Low (2-3 ml)	Higher (10-20 ml or more)
Concentration of Local Anesthetic	High	More variable, can be lower for analgesia
Post-Dural Puncture Headache	Higher risk (due to direct dural puncture)	Lower risk (unless accidental dural puncture)
Common Uses	Short to moderate duration infraumbilical surgery	Surgery of variable duration, labor analgesia, postoperative analgesia

Source: Hernánz de la Fuente & Rabanal Llevot (11).

2.3. Use of Ultrasound in Regional Anesthesia

The ultrasound technique for central neuroaxial block involves the use of a low-frequency curvilinear probe in different planes. Five basic views of the vertebral column are performed to visualize the lumbar sonoanatomy, which is easier than in the thoracic region due to the more favorable anatomy. Ultrasound can be performed before the procedure or in real-time and has proven particularly useful in patients with specific physical characteristics or medical conditions. The real-time ultrasound-guided technique has shown positive results compared to pre-procedure ultrasound (12).

3. Optimization in the Postoperative Context

The use of opioids for postoperative pain management in orthopedic surgery, despite its tradition, entails significant short-term risks (adverse effects, longer hospital stays, dependence, death) and long-term risks (opioid epidemic, substance use disorder, mortality). The increasing prescription, especially in opioid-naïve patients, is associated with a higher risk of chronic use, even after minor surgeries such as total knee and hip arthroplasty. Furthermore, a considerable proportion of prescribed opioids are unused and not safely disposed of, contributing to their diversion. To mitigate dependence, it is crucial to implement multimodal pain management programs that integrate peripheral nerve blocks, local anesthetic infiltration, paracetamol, NSAIDs, gabapentinoids, cannabinoids, and non-pharmacological therapies, recognizing the challenges in older patients and those with chronic pain (13). Regional anesthesia (RA) in orthopedic procedures attenuates several complications linked to general anesthesia (GA), such as nausea, vomiting, airway trauma, hypoxia, respiratory depression, and the risk of pulmonary aspiration. The advantages of RA include superior postoperative pain control, reduced opioid consumption and its side effects, shorter hospital stays, early initiation of physical therapy, reduced readmission rates, greater patient satisfaction, faster recovery, fewer unplanned admissions for pain, better intraoperative muscle relaxation, less blood loss, and a reduction in urinary retention and ileus (14).

Contrary to the initial belief that continuous regional analgesia would increase costs, a 2009 study demonstrated that the implementation of multimodal anesthesia and analgesia based on regional techniques was not only not more expensive but decreased the total cost of the procedure by 15%, mainly due to the lower need for opioids, fewer related adverse effects and their treatment costs, shorter operating room time, and shorter hospital stays (15). The length of hospital stay (LHS) is considered an indirect indicator of efficiency, and enhanced recovery after surgery (ERAS) protocols aim to reduce it through a multidisciplinary approach, incorporating RA to decrease acute pain and postoperative nausea and vomiting, in addition to improving mobilization. Both RA alone and in combination with GA appear to reduce LHS in orthopedic surgery and other specialties, although the difference in the largest meta-analysis was measured in hours. In outpatient surgery, while unplanned admission rates are low, a higher risk has been demonstrated with GA compared to RA (16). A prospective observational study by Doo et al (17) found no significant differences in patient-centered quality of recovery between RA (brachial plexus block with dexmedetomidine) and GA (sevoflurane with remifentanil) in orthopedic forearm surgery, even though the RA group showed better outcomes in the PACU (less pain, opioid consumption, and nausea/vomiting), suggesting that patient expectations or previous anesthesia experiences might influence the perception of recovery.

4. Technological Innovations and Recent Advances

4.1. Image-Guided Techniques (Ultrasound vs. Neurostimulators)

Ultrasound enhances the success of nerve blocks by visualizing anatomical structures through sound waves reflected by tissues (18). Its ability to evaluate soft tissues in real-time is operator-dependent and requires a thorough understanding of anatomy (18). Precise nerve localization, crucial for avoiding complications of "blind" techniques, is optimized with ultrasound (5-10 MHz probes, even better with 12-15 MHz), overcoming the limitations of non-visual or costly methods like MRI and CT (18). The puncture technique, influenced by anatomy and the nerve's relationship with adjacent structures, varies depending on the block (interscalene proximal to the transducer, supraclavicular in-plane needle-transducer, axillary with the arm abducted and infiltration near the artery) (18).

Neurostimulators

Fifty years ago, Dr. Greenblat published the first report on the use of neurostimulators, demonstrating 100% specificity and 74% sensitivity, making it a less precise technique than ultrasound (19).

Compared to the conventional nerve block method using anatomical localization and paresthesia, localization via neurostimulation is more precise, objective, and safer. However, neurostimulator guidance operates blindly, and there is a high failure rate in patients with anatomical variations. The use of neurostimulation increases the success rate of nerve blocks and reduces the blocking time compared to conventional paresthesia guidance. Sia et al. compared the difference between paresthesia guidance and neurostimulation guidance in brachial plexus block. The results showed that the neurostimulation group was superior to the paresthesia group in the success rate (91% versus 76%, respectively) and in the onset time of the block. Additionally, in a three-point axillary brachial plexus block, nerve block guided by neurostimulation can shorten the block onset time and the waiting time for surgeons, which is helpful for emergency surgery and patient satisfaction, as well as reducing the discomfort of a tourniquet. This is related to the high precision of localization and a more effective block of the musculocutaneous nerve (20).

Ultrasound vs. Neurostimulators

In current practice, ultrasound offers more intuitive and precise guidance, showing the relationship between nerves, vessels, and muscles in real-time, and allowing for the monitoring of local anesthetic spread. Although neurostimulation provides improvements over paresthesia, ultrasound is positioned as a superior technique due to its direct visualization capabilities and its potential to minimize complications and optimize the administration of regional anesthesia.

4.2. New Local Anesthetics and Adjuvants

- **Dexmedetomidine:** Dexmedetomidine, an α2 adrenergic agonist approved for intravenous sedation, is used off-label as an adjuvant in peripheral nerve blocks and neuroaxial anesthesia, showing efficacy and a relatively good safety profile in preclinical and clinical studies. Its combination with local anesthetics appears well-tolerated, with no evidence of neurotoxicity or axonal/myelin damage, and it may even attenuate the acute pro-inflammatory effects of these. A study with epidural ropivacaine (7.5 mg/ml) and dexmedetomidine (1 μg/kg) demonstrated a significant prolongation of the duration of sensory block (+160 min), motor block (+126 min), and postoperative analgesia (+184 min), with a tolerable side effect of more pronounced sedation. Another study found that epidural dexmedetomidine reduced the need for propofol for the induction of general anesthesia (21).

- **Lidocaine:** The first amide local anesthetic introduced into clinical practice, notable for its versatility and common use due to its potency, rapid onset of action, and moderate duration (prolongable with epinephrine), as well as its activity as a topical anesthetic. It is used in various concentrations for infiltration, peripheral nerve blocks, and epidural anesthesia, and in hypertonic solution for short-duration spinal anesthesia. It is also used topically in multiple formulations. Additionally, lidocaine is used as a class Ib antiarrhythmic, effective mainly in ventricular arrhythmias. Its primary metabolism is hepatic, producing monoethylglycinexylidide (an active antiarrhythmic with a prolonged half-life) and then xylidide (less active and eliminated by urine) (22).

- **Dexamethasone:** Dexamethasone, an α2 adrenergic agonist, is used as an adjuvant in regional anesthesia to prolong analgesia, although its exact perineural mechanism and the best route of administration (perineural vs. intravenous) are still under investigation. Studies suggest that both routes reduce postoperative pain and opioid consumption, with possible superiority of the perineural route in the duration of the block. However, safety, especially neurotoxicity associated with corticosteroid excipients, is a significant concern, and the optimal perineural dose is not yet clearly defined, with even a possible ceiling effect and the need for more high-quality research to confirm its long-term efficacy and safety (23).

- **Triamcinolone:** Perineural triamcinolone has been shown to reduce ectopic nerve discharges and prevent their development in newly resected nerves. Although its clinical evidence is less than that of dexamethasone, one study showed prolonged pain relief with few opioid requirements in interscalene blocks. However, the general neurotoxicity of glucocorticoids, associated with preservatives such as parabens and solvents such as benzyl alcohol and polyethylene glycol, warrants caution. Dilution with saline and local anesthetics may not reduce the particle size of some steroids, including triamcinolone. Microscopic studies have found large particles (>10,000 microns) in triamcinolone and methylprednisolone, unlike dexamethasone and betamethasone, which behave more like liquids. Another study observed smaller particles in both types of compounds. It is suggested that dexamethasone has significantly smaller particles with less tendency to aggregate, which could reduce the risk of embolic infarctions from accidental intra-arterial injection, something that has not been assured for triamcinolone (23).

- **Magnesium Sulfate:** Magnesium sulfate is not a direct analgesic but an adjuvant that enhances the effect of other analgesics. Discovered by Humphrey Davy and with depressant effects on the axial neuromuscular plate identified by Claude Bernard, its analgesic properties have been known since the early 20th century, where its use with ether to produce deep anesthesia was suggested. It is considered a neuronal depressant that acts on the CNS and neuromuscular reflexes at the neuromuscular junction, and when applied directly, it depresses the electrical function of nerve tissue. Another fact mentioned by Gutiérrez et al. is that magnesium sulfate is also used to generate hypnosis and analgesia in intravenous anesthesia because it reduces the requirements for sevoflurane, desflurane, propofol, and opioids (24).
- **Ropivacaine:** Ropivacaine, introduced in 1996 as an alternative to bupivacaine due to its toxicity, has a similar structure but is a levorotatory (L) isomer. L-isomers are generally more potent, less toxic, and have a shorter half-life. Ropivacaine is an amino-amide local anesthetic, composed of an amino residue (polar/hydrophilic) and an aromatic group (hydrophobic) joined by an amide bond (24).

4.3. Continuous Infusion Pumps for Prolonged Blocks

Perineural administration of local anesthetic (LA) is preferably performed with infusion pumps due to clinical and logistical benefits over manual boluses. There is no ideal pump, and the choice depends on the clinical context, although they should generally be precise, reliable, portable, and programmable. Vacuum and spring-powered pumps are not very precise for routine practice. Electronic pumps are the most accurate (5% variation), allow for customization of basal infusion, boluses, and lockout times, optimizing dosage and featuring alarms and refill/reuse capability. Elastomeric pumps are simpler, lighter, quieter, and more economical, ideal for outpatient use. However, their basal infusion rate is more variable (10-30% above the initial expected rate, then stabilizes and increases again at the end), and the rate depends on temperature and altitude. Refilling them is not recommended (25).

5. Safety and Complication Management

Despite its numerous benefits, advanced regional anesthesia presents risks of nerve injury (minimized with proper technique and volume), hematomas and infections (preventable with asepsis and technique), and local anesthetic toxicity (avoidable with correct doses and monitoring); the management of these complications, such as lipid emulsion for systemic toxicity, requires in-depth knowledge to ensure patient safety and block efficacy (26).

Regional anesthesia techniques, although with low complication rates, require early identification for appropriate patient-centered management. Complications are classified in various ways (immediate, intermediate, late; anatomical, physiological; mild, moderate, severe), although their reporting may be underestimated. Nerve injuries and local anesthetic toxicity are the major complications, which may be due to neurotoxicity, cardiotoxicity, hypersensitivity, mechanical complications, or infection. Major complications (severe damage, disability, increased costs and hospital stay) include dural puncture, cardiorespiratory arrest, permanent neurological injury, and death, while minor complications include failed blocks, paresthesias, and vascular punctures. A significant percentage of procedures use neuroaxial regional anesthesia. The learning curve is important, with a higher risk of failures and complications at the beginning, highlighting the role of the instructor. Postoperative nerve injuries can be difficult to attribute to a specific cause (anesthetic, surgical, positional, etc.). Local anesthetic systemic toxicity (LAST) is a serious but infrequent complication. Adverse events in general anesthesiology occur mostly in scheduled surgeries and in the PACU, with failures in pre-anesthetic evaluation, informed consent, protocols, and communication. Anesthesiologist fatigue is associated with errors. Post-dural puncture headache is frequent, benign, and self-limited, while epidural and spinal hematomas are more serious but less common neuroaxial complications (27).

5.1. Contraindications

Regional anesthesia has absolute contraindications such as patient refusal, infection at the injection site, sepsis, circulatory insufficiency, increased intracranial pressure, and severe coagulopathy (due to the risk of epidural hematoma and neurological damage). Increased intracranial pressure is a contraindication due to the risk of brain herniation from cerebrospinal fluid loss. In sepsis, sympathetic blockade can worsen hypoperfusion. Relative contraindications include infection distant from the puncture site (risk of meningitis), undefined or evolving neurological disease, and hypovolemic patients. The decision to use the technique should be based on medical judgment considering advantages and disadvantages. Disadvantages include anesthetic failures (lack of level or intensity, although the failure rate is low), possible prolongation of surgery, patient anxiety, need for operator experience, longer latency compared to general anesthesia, inability to use it in all types of surgeries, side effects of drugs, and risk of permanent neurological complications (28).

- **Patients with chronic diseases:** The effects of regional anesthesia should be carefully evaluated in patients with conditions such as diabetes, hypertension, heart, lung, or kidney diseases (29).
- **Patients with vascular diseases:** Regional anesthesia may not be suitable for patients with peripheral vascular diseases, as they may have an increased risk of complications such as ischemia (30).
- **Patients with allergies:** Allergy to local anesthetics is an absolute contraindication for regional anesthesia (30).
- **Patients with infections:** The presence of a local infection in the area to be anesthetized may contraindicate regional anesthesia (31).
- **Patients with coagulation disorders:** Patients with coagulation disorders may have an increased risk of bleeding after regional anesthesia (32).
- **Elderly patients:** Regional anesthesia may have a greater effect in elderly patients, so caution should be exercised and side effects considered (33).
- **Patients with cognitive impairment:** Patients with cognitive impairment may have difficulty understanding regional anesthesia instructions and may require more sedation (30).

To decrease complications in regional anesthesia, adequate assessment, management, and thorough documentation are crucial, including pre-operative evaluation, maneuvers, and postanesthetic notes for potential legal defense. Alertness and adherence to protocols are essential; training, supervision, avoiding working alone, maintaining order, and labeling drugs are recommended. Regional anesthesia is associated with lower perioperative mortality than general anesthesia. Care strategies include reviewing anticoagulated patients for neuroaxial anesthesia, controlling perfusion pressure in the sitting position, and improving postoperative opioid management. Preventive measures for injuries by the anesthesiologist include vigilance of position, fractional injection, use of a nerve locator and ultrasound for peripheral blocks, and fine needles. The use of ultrasound, new needles, and local anesthetics in lower concentrations and volumes has decreased local anesthetic systemic toxicity (LAST), and lipid emulsion has improved its treatment. In neuroaxial blocks, rapid diagnosis of high block, advanced monitoring, and low blocks are important. Other strategies include teamwork, training, standardization, and error reporting. Staying updated in regional anesthesia is fundamental. Medico-legal claims are a concern, so knowing the legal framework and correctly completing the anesthetic record are vital (27).

6. Perspectives of Regional Anesthesia in Outpatient Orthopedic Surgery

6.1. Hip

In hip surgery, the most commonly used anesthetic technique is typically subarachnoid anesthesia, which allows for good pain control and adequate muscle relaxation, reaching a metameric level of T10. Additionally, it is frequently complemented with peripheral nerve blocks, such as the femoral, iliofascial, or PENG block, to further improve postoperative analgesia and reduce the need for opioids. The choice between general anesthesia and the regional technique depends on the patient's history. Basic monitoring, including ECG, non-invasive blood pressure, and SpO_2, is routine, and in cases of general anesthesia, additional monitoring such as BIS is added. Antibiotic prophylaxis with cefazolin is administered beforehand, and in some cases, tranexamic acid is used to reduce the risk of bleeding. This strategy seeks to minimize complications, optimize pain control, and promote a safer and more comfortable recovery (34).

6.2. Shoulder and Upper Extremities

Regional anesthesia (RA) is frequently used in shoulder and upper extremity surgery due to its ability to provide both anesthesia and postoperative analgesia, which is crucial for pain management, as it can be significant after these interventions. RA techniques, such as the interscalene block (ISB), supraclavicular block, infraclavicular block, and axillary block, allow anesthesiologists to block specific nerves or groups of nerves that innervate the surgical area. The use of ultrasound guidance (USG) has become essential to increase the accuracy of these techniques, allowing real-time visualization of nerve structures and the placement of local anesthesia, which improves the effectiveness of the block and reduces the risk of complications. Compared to general anesthesia, RA offers advantages such as reduced postoperative pain, decreased need for opioids, decreased postoperative nausea and vomiting, and faster patient recovery (35, 36).

6.3. Knee

Different regional anesthesia techniques exist for knee arthroscopy (KA). While epidural analgesia (EA) and intrathecal morphine are options, special attention is paid to the femoral nerve block (FNB) and the adductor canal block (ACB). The FNB is noted to provide good pain control but can cause quadriceps weakness, increasing the risk of falls. In contrast, the adductor canal block is presented as an alternative that provides sensory analgesia with minimal effect on quadriceps strength, facilitating faster recovery and decreasing opioid consumption and the risk of falls (37). Local anesthesia for the knee is a simple and safe technique, suitable for outpatient arthroscopic surgeries, involving anesthetic infiltration and sedation, useful in patients with contraindications to other anesthetics, although limited for long surgeries and with potential risks of cartilage cytotoxicity. Peripheral nerve blocks, guided by ultrasound, offer analgesia with fewer complications, where the femoral block is common for the anterior aspect (with the risk of quadriceps motor block) and the adductor canal block is an alternative with less motor block; the sciatic nerve block is used for the posterolateral aspect, and although nerve blocks have risks such as nerve injury, infection, or toxicity, they allow for effective analgesia, whether short-term or prolonged with catheters, balancing benefits and potential complications (38).

6.4. ERAS Protocol

The ERAS (Enhanced Recovery After Surgery) protocol, developed by Dr. Olle Ljungqvist, is introduced as a multimodal program that seeks to attenuate the loss of functional capacity and improve postoperative recovery. The objectives of ERAS include enhancing patient safety and quality, reducing morbidity, shortening recovery time, decreasing surgical stress, and optimizing pain control, early mobilization, and diet. As a result, the aim is to reduce hospital length of stay and costs. The text also mentions the creation of the ERAS group and Society in 2001, and the development of the ERAS project, a multimodal rehabilitation program with preoperative, intraoperative, and postoperative strategies based on scientific evidence to improve patient recovery and minimize the response to surgical stress (39).

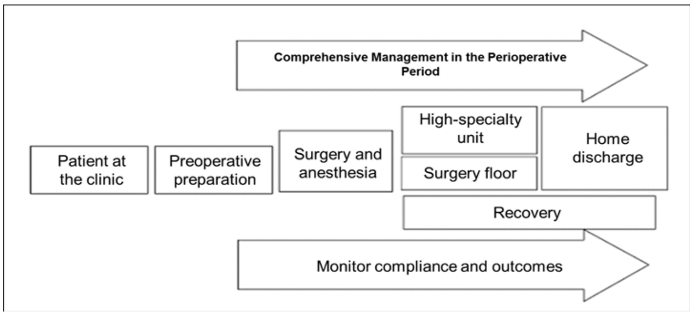

Figure 2. Perioperative care process based on the ERAS protocol

Source: Carrillo Esper & Mejía Terrazas (39).

The flowchart illustrates the perioperative care process under the ERAS protocol, starting with patient admission and progressing through preoperative preparation, surgery and anesthesia, hospital stay (either in a specialized unit or surgical ward), to home discharge, with "recovery" as a continuous process throughout the postoperative phase. This scheme highlights comprehensive patient management and the importance of monitoring protocol compliance and the outcomes obtained.

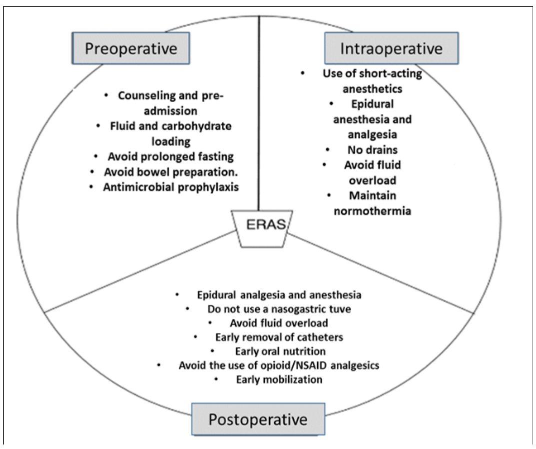

Figure 3. Recommended strategies ERAS protocol

Source: Carrillo Esper & Mejía Terrazas (39).

The anesthesiologist plays a crucial role in optimizing postoperative outcomes, addressing three fundamental pillars of the ERAS protocol: control of the surgical stress response, adequate fluid therapy, and effective analgesia. Central regional anesthesia, such as epidural, has demonstrated the ability to mitigate the activation of the neuroendocrine system and prevent surgery-induced immunosuppression, offering immunological and metabolic advantages compared to general anesthesia. Regarding pain management, while intravenous opioids are common, they are associated with longer hospital stays. Epidural anesthesia and analgesia with short-acting agents attenuate the stress response, relieve pain (improving respiratory function), and promote intestinal recovery, although caution is required due to potential side effects such as hypotension and urinary retention. The optimal analgesic strategy should allow for early and safe mobilization, and in orthopedic surgery, regional anesthesia combined with paracetamol, NSAIDs, and gabapentinoids is prioritized to minimize opioid use, with local infiltration being a promising technique for effective pain control with less impact on mobility (40).

6.5. Benefits in Older Adults and Patients with Comorbidities

In elderly patients undergoing traumatological surgery, particularly orthopedic procedures like knee and hip arthroplasty or hip fracture repair, the presence of multiple comorbidities elevates their risk profile, making pre-existing conditions and the nature of the surgery more critical than age itself in determining functional recovery (41). Inadequate perioperative pain management in this population, whose physiological reserves and homeostatic mechanisms are diminished with aging, leading to altered pharmacokinetics and pharmacodynamics of pain medications and increased sensitivity to stressors, can result in complications that negatively impact the final outcome (41). Regional anesthesia in older adults requires specific considerations, including potentially more challenging epidural techniques with the need for lower local anesthetic volumes due to increased cephalad spread and faster onset with greater motor block intensity, and prolonged spinal block duration with greater cephalad spread of hyperbaric solutions and increased risks with intrathecal opioids and bleeding; while peripheral blocks are useful, caution is advised due to vascular and nerve fragility, potential pre-existing neuropathy, and a higher risk of local anesthetic systemic toxicity necessitating total dose reduction (41). Epidural anesthesia/analgesia is an effective technique for perioperative pain management in the elderly, offering superior relief compared to systemic opioids and potentially reducing postoperative morbidity, although with a higher risk of pruritus and motor block, requiring careful titration due to age-related changes in opioid requirements and reduced renal function affecting metabolite clearance, while age also influences the diffusion and effective concentration of local anesthetics in the neuroaxial space, necessitating adjustments in volume and concentration to avoid adverse effects like hypotension (42).

7. Proposals for Improvement and Future Research Directions

7.1. Standardized Protocols According to Type of Surgery

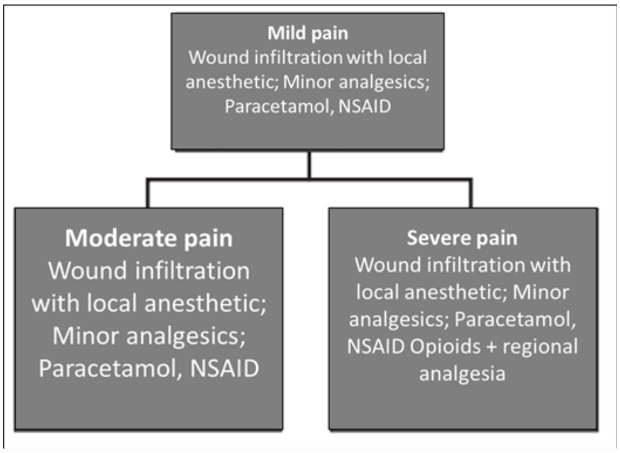

Figure 4. Postoperative Acute Pain Protocol

Source: Hernández-Hernández (43).

Table 2. Electronic Pumps: Continuous Infusion

Local Anesthetic	Concentration	Infusion Rate
Bupivacaine	125%	Initial 4-6 mL/h, increase by 2 mL/h based on response
L-bupivacaine	Same as Bupivacaine implicitly	Same as Bupivacaine implicitly

Source: Hernández-Hernández (43).

Table 3. Epidural Analgesia Protocols

Indication	Puncture Level	Punta-catéter Level
Thorax, upper and middle	T6-T9	T6-T7
Thorax, lower and abdomen	T11-T12	T9-T10
Lower limbs	L2-L3 or L3-L4	L2-L3

Source: Hernández-Hernández (43).

Table 4. Elastomeric Infusers

Local Anesthetic	Concentration
Bupivacaine	0.125% + fentanyl 5 µg/mL
L-bupivacaine	2 mg/mL + fentanyl 4 µg/mL
Ropivacaine	Not specified in this table

Source: Hernández-Hernández (43).

The protocolization of treatments is fundamental to standardize postoperative analgesia and reduce therapeutic variability, necessitating the development of specific guidelines per surgical procedure to optimize care and outcomes, and further research into their impact (43). Effective postoperative pain management relies on multimodal analgesia, combining various agents like NSAIDs, opioids, and regional anesthesia, and the principles of balanced analgesia which prioritize opioid-sparing techniques (43). Patient preferences are crucial in selecting analgesic management, alongside protocols to minimize common and serious side effects; regional analgesia, particularly continuous epidural or PCEA, proves highly effective for major surgeries, offering superior pain control and reduced opioid use, potentially attenuating surgical stress and improving recovery (43). When regional techniques are not feasible, PCA or IV infusions with scheduled paracetamol and NSAIDs, within a multimodal approach, are recommended, emphasizing the role of acute pain units in ensuring consistent care and communication (43). Peripheral nerve blocks and local infiltrations effectively reduce postoperative pain and opioid consumption in orthopedic surgery, with oral multimodal analgesia being an option for minor procedures, while the role of adjuvant modalities like cryotherapy and TENS requires further investigation, and intravenous dexmedetomidine shows promise as an opioid-sparing adjunct (44). However, significant knowledge gaps regarding optimal protocols and long-term outcomes highlight the ongoing need for high-quality research to refine postoperative pain management in orthopedic surgery (44).

7.2. Training and Learning Curve for Anesthesiologists

Over the last two decades, Regional Anesthesia (RA) has experienced a technology-driven revitalization, although fundamental anatomical knowledge remains essential to avoid sonoanatomy errors. RA training has significantly advanced through simulation, offering a safe environment for developing technical and non-technical skills via practice and expert feedback. Simulation, combined with didactic teaching, provides an effective balance of learning and cost. Organizations like the ASA and ASRA have established minimum experience requirements and certification programs in ultrasound-guided regional anesthesia (UGRA), highlighting the importance of supervised practice. Ultrasound guidance has improved success rates and reduced block onset times. RA simulation includes various modalities, from in vitro models to virtual reality and crisis simulation. The future of RA training is geared towards evaluating the cost-effectiveness of different simulation techniques and their impact on patient safety, within a competency-based medical education framework. Establishing a standardized RA curriculum is crucial for ensuring training quality and improving patient access to this technique, integrating it into basic anesthesia training and continuous professional development (45).

The American Society of Anesthesiologists (ASA) has established minimum experience thresholds for neuroaxial anesthesia (50 blocks for epidural and spinal), but recommendations for peripheral nerve blocks (40 for blocks and 25 for pain management) are less specific and do not detail block types, potentially leading to superficial training. These recommendations are based on learning curve studies, such as Kopacz and Neal's, which demonstrated an initial improvement in procedural success around 20-25 attempts, followed by a potential decrease and recovery with 50 or more procedures. However, the quality of execution is not guaranteed by quantity. Learning curves vary by procedure, with regional anesthesia being more complex than basic general anesthesia skills, and epidural particularly challenging, requiring a high number of attempts to achieve competency. Analyzing these curves is crucial for residency program supervision, individual learning assessment, determining the appropriate number of cases for training, adopting new techniques, and planning program capacity, considering faculty-to-resident ratios and the need to maintain medical staff skills (46).

7.3. Evaluation of Long-Term Impact on Postoperative Chronic Pain

Postoperative chronic pain (PPCP) in orthopedic surgery varies significantly (15%-65%) and is associated with factors such as surgical technique, acute postoperative pain (APOP), prior opioid use, smoking, and mood disorders. One study found unusual factors like "excessive" clinical follow-up, teaching institutions, and insurance type. Orthopedic trauma surgery presents the highest incidence of PPCP (65%), with risk factors including female sex, prior trauma surgery, and preoperative pain intensity, which impacts functionality, causes disability, and increases resource utilization. In total knee arthroplasty, up to 34% persist with moderate to severe PPCP at three months, with preoperative pain, APOP intensity, anxiety, and expected pain being important risk factors. Surprisingly, up to 32.7% of patients undergoing knee arthroscopy, a procedure to treat chronic pain, experience moderate to severe PPCP at 18 months, with preoperative pain and preoperative analgesic use being identified risk factors (47).

Postoperative chronic pain (PPCP) is a common complication in various orthopedic surgeries, with an overall prevalence of around 20%, although it varies by surgery type. In hip arthroplasty, the patient's preoperative status is a significant predictor of postoperative outcome, while iliac crest graft harvesting can cause persistent pain. In knee arthroplasty, a considerable proportion of patients experience PPCP, often with a neuropathic component, and pre-existing pain and central sensitization are important risk factors. Knee arthroscopy, paradoxically, can also lead to PPCP. Similarly, in shoulder surgery, preoperative pain is a key predictive factor for postoperative pain, and in shoulder arthroplasty, various clinical and demographic variables influence the chronicity of pain. Rotator cuff repair is particularly associated with postoperative pain, where preoperative pain also plays a crucial role. In general, preoperative pain emerges as a consistent risk factor for the development of PPCP in multiple types of orthopedic surgery (48).

8. Analysis of New Technologies.

8.1. Artificial Intelligence-Controlled Blocks

Artificial Intelligence (AI) is revolutionizing postoperative pain management by offering personalized predictions based on patient history, allowing for adjustments in analgesic doses to avoid overmedication or insufficient relief. AI-powered monitoring devices track pain in real-time and automatically adjust medication, improving the patient experience. AI is also integrated with biofeedback and virtual reality to distract and reduce pain perception. However, excessive reliance on technology and the importance of maintaining doctor-patient communication are cautioned (49).

Specific AI techniques, such as predictive algorithms based on machine learning and deep neural networks, analyze large amounts of data to forecast pain intensity and response to analgesics, thereby personalizing treatment. Natural Language Processing (NLP) is used to interpret patients' descriptions of pain, offering additional insights. The accuracy of these systems depends on the quality of the training data, and ensuring their interpretability is crucial (49).

AI-based tools and platforms include mobile applications for pain logging and monitoring that alert to intense episodes and offer reminders and exercises. Wearable devices detect physiological changes correlated with pain, allowing for real-time adjustments. Patient-controlled analgesia systems with AI automatically adjust medication. In research, AI analyzes large datasets to identify biomarkers and future therapies. Despite its potential, challenges such as data privacy and the need for adequate training must be addressed, emphasizing AI's complementary role in patient care to achieve more precise and personalized treatment (49).

8.2. Portable Ultrasound and Color Doppler

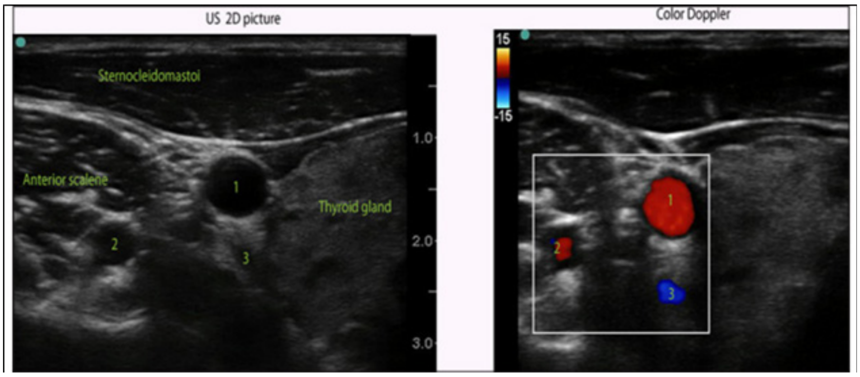

Figure 5. Color Doppler superimposed on 2D ultrasound of the anterolateral area of the neck at the C6/C7 level. Observing only the 2D ultrasound image, one might confuse the vertebral artery (2) with a nerve root. Both can appear similar on 2D ultrasound. Color Doppler helps to distinguish nerve roots from blood vessels. 1) Carotid artery; 2) Vertebral artery; 3) Inferior thyroid vein

Source: Boezaart & Ihnatsenka (50).

Color Doppler assists in distinguishing moving structures, such as blood flow within vessels, which is particularly useful as hypoechoic proximal nerves can be mistaken for blood vessels (50). While 2D ultrasound can be ambiguous, color Doppler helps differentiate nerve roots from blood vessels and determine blood flow direction (50). However, color Doppler is most effective when ultrasound waves are nearly parallel to the flow, and may produce false negatives at near-90° angles or with low flow; tilting the probe and using power Doppler can improve vessel recognition in such cases (50).

The advent of portable ultrasound devices has enabled point-of-care (POC) diagnostics, bringing imaging to the patient's bedside rather than a separate lab (51). Studies show that adding portable ultrasound to routine clinical exams changes, adds, or confirms a significant diagnosis in one out of three patients, making it indispensable for diagnostic purposes (51). This bedside accessibility also facilitates faster diagnosis and immediate treatment initiation, improving patient outcomes (51). Furthermore, it can reduce the need for invasive tests by aiding in diagnosis at the bedside (51). Portable devices are especially beneficial in out-of-hospital settings like remote medical camps and low-income treatment centers (51).

Applications

Portable ultrasound devices have various applications. In musculoskeletal issues, they can diagnose conditions like partial or full rotator cuff tears with sensitivity comparable to arthroscopy, potentially avoiding unnecessary MRIs and saving time and money (51). They are also used in knee joints to rule out meniscus tears and in emergency departments to detect inflamed joints, helping exclude joint effusion (51). Furthermore, portable ultrasound guides treatments in the operating room, such as administering regional anesthetic blocks and detecting lesions/masses for ultrasound-guided biopsies. In vascular surgery, they aid in identifying relevant blood vessels (51).

8.3. Automated Infusion Systems for Continuous Regional Analgesia

Figure 6. Automated Infusion Systems. Electronic Infusion Pump (left). Variable Rate Infuser + PCA (right)

Source: Eimil Rúa (52).

Benefits:

- Prolongs postoperative analgesia time.
- Increases analgesic quality.
- Minimizes opioid-related side effects.
- Allows for the successful incorporation of new surgical procedures.
- Improves patient satisfaction.
- Decreases sleep disturbances.
- Shortens hospital stay.
- Facilitates early rehabilitation (52).

Features:

- Lightweight and comfortable to wear
- .Easy to handle and understand for the patient and caregiver.
- Possibility of continuous infusion and/or boluses.
- Adaptation to analgesic needs.
- Ability to administer different doses.
- Infusion time adjusted to patient needs, duration 2-5 days.
- Sufficient capacity for the required local anesthetic.
- Possibility of reprogramming to adjust to analgesia requirements.
- Variable basal flow rate (maximum possible flow range).
- Adequacy between the programmed and administered dose.
- Consistency in perfusion.
- Lowest possible cost (52).

The viability of an automated continuous infusion system in different clinical contexts depends on several factors, including the technology used, the ability to integrate into the hospital environment, patient safety, and cost-effectiveness.

Potential Advantages:

- **Precision and Control:** Allows for precise administration of medications or nutrients, adapting to the specific needs of the patient.
- **Consistency:** Reduces human errors in dosage and infusion control.

- **Real-time Monitoring:** Facilitates the early detection of complications or changes in the patient's condition.
- **Efficiency:** Can decrease the workload of healthcare personnel and optimize resources (53).

Clinical Contexts Where It May Be Viable:

- **Intensive Care:** For continuous administration of vasoactive drugs, sedatives, or parenteral nutrition.
- **Neonatology:** For infants with precise and delicate requirements.
- **Surgery:** During procedures requiring controlled and precise infusions.
- **Oncology:** For continuous or frequently administered chemotherapy.
- **Rehabilitation and Pain Management:** With analgesics or sedatives in automated infusion pumps (53).

9. Comparison of Strategies.

Ultrasound-Guided Blocks vs. General Anesthesia:

- **Precision and Safety:** Ultrasound guidance allows real-time visualization of nerves, vessels, and the needle, enabling precise local anesthetic placement and reducing complications like vascular or nerve puncture compared to anatomical landmark-based techniques. General anesthesia, inducing unconsciousness, necessitates comprehensive airway and cardiovascular control with inherent risks related to intubation, mechanical ventilation, and systemic effects of anesthetic drugs (19, 54–56).
- **Recovery:** Patients receiving ultrasound-guided blocks often experience faster recovery with fewer systemic side effects (e.g., nausea, vomiting) than those under general anesthesia. This is due to the localized nature of regional anesthesia, avoiding whole-body exposure to anesthetic drugs. General anesthesia can lead to a longer recovery period due to residual drug effects (19, 54–56).
- Postoperative Analgesia: Ultrasound-guided peripheral nerve blocks can provide excellent postoperative pain relief in the blocked region, often decreasing the need for systemic analgesics, including opioids, and their associated side effects. Analgesia after general anesthesia typically relies on systemic medications (19, 54–56).
- Suitability: General anesthesia is necessary for extensive surgeries, procedures requiring complete immobility, or in patients who cannot tolerate regional anesthesia. Ultrasound-guided blocks are ideal for surgeries on extremities, the abdominal wall, and other specific areas where selective nerve blockade is possible (19, 54–56).

Continuous Catheters vs. Systemic Analgesia:

- **Prolonged Pain Control:** Continuous catheters, placed near peripheral nerves or in the epidural space, allow for continuous or intermittent administration of local anesthetic for several days. This provides more sustained and effective pain control compared to systemic analgesia (oral or intravenous), which often results in fluctuations in pain levels (19, 54–56).
- **Opioid Reduction:** Continuous regional analgesia can significantly reduce the need for systemic opioids, which in turn decreases opioid-related side effects such as sedation, constipation, nausea, and the risk of respiratory depression. Systemic analgesia often relies on opioids for moderate to severe pain, with their consequent adverse effects (19, 54–56).
- **Functional Recovery:** Better pain control with continuous catheters facilitates early mobilization, physical therapy,

and ultimately, faster functional recovery compared to inadequate systemic analgesia (19, 54–56).

- **Personalized Management:** Continuous catheters allow for adjustment of the local anesthetic dose and administration regimen according to individual patient needs and pain intensity over time. Systemic analgesia is often based on fixed doses or patient demand, which may not always match changing pain needs (19, 54–56).
- **Risks:** Continuous catheters carry a risk of infection at the insertion site and the possibility of catheter displacement, which could compromise analgesia. Systemic analgesia, especially with opioids, has its own risks, such as the side effects mentioned above (19, 54–56).

Table 5. Comparative Table

Feature	Ultrasound-Guided Blocks (Single Dose)	Ultrasound-Guided Continuous Catheters
Block Duration	Limited (hours to a day, depending on the drug)	Prolonged (days, while the catheter is active)
Need for Rescue Analgesia	Higher, as the block effect diminishes	Lower, with adjustable continuous analgesia
Complications	Lower risk of systemic complications, risk of nerve/vascular puncture | Risk of infection, catheter displacement, complications similar to single dose	
Time to Ambulation	Potentially faster (without prolonged motor block) | May be slower initially (if motor block is present), but better long-term due to better pain control	

Source: Arévalo Gutiérrez; Prat Calero et al; Ramírez Flores; Vera, Lorenti, López, Ron, Solis, Zambrano, Romina, et al (19,54–56).

Additional Considerations:

- The duration of the block with single-dose techniques depends on the local anesthetic used (e.g., lidocaine vs. bupivacaine vs. ropivacaine) and can be extended with adjuvants.
- The need for rescue analgesia is inversely related to the duration and effectiveness of the initial block. Catheters allow for the administration of additional boluses or infusions to maintain analgesia.
- Complications from ultrasound-guided blocks are generally low when performed correctly. Catheters introduce additional risks but can avoid the need for multiple injections.
- The time to ambulation may be initially affected by motor block, but better long-term pain control with catheters can facilitate earlier rehabilitation (19, 54–56).

Conclusions

The optimization of regional anesthesia (RA) in orthopedic surgery, through the implementation of modern techniques such as ultrasound-guided blocks and continuous catheters, represents a significant advancement in postoperative pain management with multiple proven benefits. Compared to general anesthesia and traditional systemic analgesia, modern RA offers greater precision and safety in the administration of local anesthetics, resulting in more effective and specific pain control in the surgical region.

Ultrasound-guided peripheral nerve blocks allow for real-time visualization of nerve structures, minimizing the risk of complications and facilitating early and high-quality postoperative analgesia, often with a significant reduction in the need for opioids and their associated side effects. This translates to faster recovery, early mobilization, and greater patient satisfaction.

For their part, continuous catheters extend the analgesic benefits of RA for several days, providing sustained and adjustable pain control tailored to the individual patient's needs over time. This prolonged analgesia facilitates rehabilitation, decreases the incidence of postoperative chronic pain, and contributes to a potentially shorter hospital stay.

While the successful implementation of these techniques requires specialized training and well-defined protocols, current evidence strongly supports their value in optimizing postoperative pain management in orthopedic surgery. Modern RA, by minimizing exposure to general anesthetics and reducing dependence on systemic opioids, not only improves the patient experience but can also have a positive impact on healthcare costs and long-term outcomes. Consequently, the integration and continuous improvement of image-guided RA techniques should be a priority in contemporary orthopedic practice.

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