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Local Anesthetic Drugs in Dentistry: Clinical, Pharmaceutical, Nursing, and Patient Safety Perspectives-An Updated Review

Nouf Omar Mohammed Hamzi[1], Raed Obaid Awadh Alhirsani[2], Roaa Magbul Hadi Maghfuri[3], Abdulmohsen Eissa Abdulmohsen Aleissa[4], Bashayer Hail Fandi Alruwailli[5], Amani Hassan Ahmed Al Hazmi[6], Tariq Mohammed Rouaished Alrehaily[7], Majed Suliman Alwalie[8], Abdullah Saleh Abdullah Almorshed[9], Abdullah Abdulrahman Mohammed Alrbian[10]

[1]Diriyah Hospital, Riyadh, Ministry of Health, Saudi Arabia
[2]Madinah Health Cluster, Recruitment Department, Saudi Arabia
[3]Eradah Mental Health Hospital, Jazan Health Cluster, Saudi Arabia
[4]Al Ahsa Health Affairs, Ministry of Health, Saudi Arabia
[5]Women and Children Hospital, Sakaka, Ministry of Health, Saudi Arabia
[6]Sabya General Hospital, Jazan Health Cluster, Saudi Arabia
[7]Affiliation not provided
[8]National Guard Health Affairs, Saudi Arabia
[9]National Guard Health Affairs, Saudi Arabia
[10]National Guard Health Affairs, Saudi Arabia

Abstract

Background: Local anesthetic drugs represent a cornerstone in modern dentistry, transforming pain-associated procedures into safe and tolerable clinical interventions. Their introduction has significantly improved patient acceptance, treatment efficiency, and overall oral healthcare delivery. These agents act through reversible blockade of voltage-gated sodium channels, preventing nerve impulse propagation and pain transmission.

Aim: This updated review aims to comprehensively analyze local anesthetic drugs in dentistry from clinical, pharmacological, nursing, and patient safety perspectives, with emphasis on drug classification, mechanisms of action, clinical applications, safety considerations, and technological advancements in delivery systems.

Methods: A narrative review approach was adopted based on synthesis of established pharmacological principles and clinical evidence reported in contemporary dental anesthesia literature. Data were analyzed across major categories of local anesthetics, including ester and amide types, alongside commonly used agents such as lidocaine, articaine, prilocaine, mepivacaine, and bupivacaine. Additional evaluation included topical anesthetics, dosage calculations, toxicity thresholds, and computer-controlled delivery systems.

Results: Findings demonstrate that amide anesthetics dominate modern dental practice due to superior safety and efficacy profiles. Lidocaine remains the reference standard, while articaine offers enhanced diffusion and rapid metabolism. Prilocaine and mepivacaine provide advantages in medically compromised patients, and bupivacaine is reserved for prolonged analgesia. Toxicity remains a critical concern, strongly related to dose, patient factors, and administration technique. Innovations such as computer-controlled local anesthesia delivery systems significantly improve patient comfort and reduce injection-related anxiety.

Conclusion: Local anesthetic agents are essential to contemporary dentistry, requiring careful selection based on pharmacological properties, patient condition, and procedural demands. Safe administration, accurate dosing, and technological advancements collectively enhance clinical outcomes and patient-centered care.

Keywords: Local anesthesia, dentistry, lidocaine, articaine, pharmacology, patient safety, dental anesthesia, vasoconstrictor

Introduction

The introduction of local anesthetic agents represents one of the most significant advancements in modern dentistry, fundamentally transforming dental practice from an experience often associated with considerable pain and patient apprehension into a routine and well-tolerated clinical intervention. Prior to the development and widespread adoption of local anesthesia, many dental procedures were accompanied by substantial discomfort, which frequently limited treatment acceptance and negatively influenced patient experiences. The availability of effective local anesthetic drugs has revolutionized oral healthcare by enabling clinicians to perform a wide range of diagnostic and therapeutic procedures while maintaining patient comfort and cooperation throughout treatment. Local anesthetics exert their pharmacological effects through a reversible mechanism that temporarily interrupts nerve impulse conduction within peripheral nerve fibers. Specifically, these agents act by blocking voltage-gated sodium channels located on neuronal membranes, thereby preventing the influx of sodium ions into nerve cells. Under normal physiological conditions, the movement of sodium ions across the neuronal membrane is essential for initiating and propagating action potentials.

By inhibiting this process, local anesthetic drugs effectively prevent membrane depolarization and subsequently disrupt the transmission of sensory nerve signals, including pain perception, from the operative site to the central nervous system [1][2].

The reversible nature of this pharmacological action is particularly important in clinical dentistry, as it provides temporary analgesia without causing permanent alterations to nerve structure or function. As a result, patients can undergo various dental interventions, including cavity preparation, restorative procedures, periodontal therapy, endodontic treatment, and minor oral surgical procedures, with little to no pain. Furthermore, the use of local anesthetics contributes to improved treatment outcomes by reducing patient anxiety, enhancing procedural efficiency, and facilitating the delivery of comprehensive oral healthcare. Consequently, local anesthesia has become an indispensable component of contemporary dental practice, supporting both patient-centered care and the successful execution of complex dental procedures while minimizing discomfort and improving the overall treatment experience [1][2].

Pharmacology:

Local anesthetic agents constitute a fundamental component of modern dental practice and are indispensable for achieving effective pain control during a wide range of diagnostic and therapeutic procedures. From a pharmacological perspective, local anesthetics are broadly categorized into two principal classes according to the chemical nature of their intermediate linkage: amide-type anesthetics and ester-type anesthetics. Although both categories produce anesthesia through a common mechanism involving the reversible blockade of nerve conduction, they differ significantly in their pharmacokinetic properties, metabolic pathways, duration of action, and potential adverse effects. These distinctions play a critical role in determining the clinical selection of specific anesthetic agents for dental procedures [1]. Ester local anesthetics are generally characterized by a relatively short duration of action, often lasting approximately 15 minutes. Their rapid inactivation occurs primarily through hydrolysis by plasma cholinesterase enzymes circulating within the bloodstream. This metabolic pathway results in a shorter half-life and reduced persistence of the drug within systemic circulation. In contrast, amide local anesthetics demonstrate substantially longer durations of action owing to their greater metabolic stability. These agents undergo biotransformation predominantly within the liver through the action of microsomal enzyme systems, thereby prolonging their anesthetic effect and enhancing their clinical usefulness in dental settings [1][3]. An important exception among amide anesthetics is articaine, which possesses a unique molecular structure containing an additional ester linkage. As a result, despite being classified as an amide local anesthetic, articaine undergoes significant metabolism by plasma esterases in addition to hepatic metabolism, contributing to its distinctive pharmacokinetic profile and favorable safety characteristics [1].

The molecular architecture of local anesthetic agents is composed of three essential structural components that collectively determine their pharmacological behavior. The first component is an aromatic ring, which possesses lipophilic properties and facilitates penetration through the lipid-rich neural membrane. The degree of lipid solubility is directly associated with anesthetic potency, as agents with greater lipophilicity penetrate nerve membranes more efficiently and exhibit stronger anesthetic effects. The second component consists of an intermediate chain containing either an ester or amide linkage, which serves as the basis for the classification of local anesthetics and influences their metabolic fate. The third component is a terminal amine group, which may exist in either a lipid-soluble tertiary form or a water-soluble quaternary form. This dual-state configuration enables local anesthetics to transition between active and inactive forms, thereby influencing membrane penetration, receptor binding, and overall anesthetic efficacy. In contemporary dentistry, the majority of local anesthetic agents routinely employed belong to the amide category because of their favorable pharmacological profiles, predictable clinical performance, and lower incidence of hypersensitivity reactions. Commonly used amide anesthetics include lidocaine, articaine, mepivacaine, and bupivacaine. Lidocaine remains one of the most extensively utilized agents due to its reliable onset and duration of action. Articaine has gained widespread acceptance because of its enhanced tissue diffusion and rapid metabolism. Mepivacaine is often selected when vasoconstrictors are contraindicated, while bupivacaine is preferred for procedures requiring prolonged postoperative analgesia. Conversely, ester-type anesthetics such as procaine, benzocaine, and cocaine are used less frequently in modern dental practice [2]. Among these agents, benzocaine retains a valuable role as a topical anesthetic and is commonly applied to mucosal surfaces before needle insertion to reduce discomfort associated with local anesthetic injections.

The historical development of local anesthetic agents has significantly influenced modern pain management strategies in dentistry. Cocaine was the first local anesthetic to be identified and introduced into clinical practice. Its discovery represented a major breakthrough in medical and dental treatment because of its ability to produce profound local anesthesia. Nevertheless, cocaine was eventually abandoned for routine clinical use due to its substantial adverse effect profile. The drug exhibited potent stimulatory effects on both the cardiovascular and central nervous systems, frequently causing tachycardia, hypertension, euphoria, and a high potential for psychological dependence. Furthermore, cocaine demonstrated an increased risk of systemic toxicity, particularly involving neurological and cardiovascular complications, rendering it unsuitable for widespread medical application [2]. Following the decline in cocaine use, procaine was introduced in 1905 and rapidly gained popularity, particularly in the United States. Procaine provided a safer alternative and became one of the most widely used anesthetic agents of its era. However,

subsequent clinical experience revealed a relatively high incidence of allergic reactions associated with its metabolism. These hypersensitivity responses were largely attributed to para-aminobenzoic acid derivatives produced during ester hydrolysis. The recognition of these limitations ultimately contributed to the transition toward amide local anesthetics, which offered improved efficacy, enhanced safety profiles, and a significantly lower risk of allergic complications [2]. Overall, the pharmacology of local anesthetic drugs reflects a complex interplay between molecular structure, metabolic characteristics, and clinical performance. Understanding the distinctions between ester and amide anesthetics, as well as the structural features governing their activity, is essential for optimizing anesthetic selection, maximizing patient safety, and ensuring effective pain management in contemporary dental practice [1][2][3].

Lidocaine

Lidocaine remains the most extensively utilized local anesthetic agent in contemporary dental practice and is widely recognized as the benchmark against which newer anesthetic drugs are assessed. Since its introduction into clinical use, lidocaine has established an exceptional reputation for safety, efficacy, and predictability, making it the preferred choice for a broad range of routine dental procedures. As a member of the amide class of local anesthetics, lidocaine possesses a chemical structure that includes a benzene aromatic ring, which contributes to its lipid solubility and facilitates effective penetration of neural membranes. Its favorable pharmacological characteristics, rapid onset of action, and reliable anesthetic effect have contributed significantly to its enduring popularity among dental practitioners worldwide [3]. One of the major advantages of lidocaine is its low incidence of severe hypersensitivity reactions compared with ester-type local anesthetics. Allergic responses to lidocaine are exceedingly uncommon, enhancing its suitability for widespread clinical application. Nevertheless, as with all local anesthetic agents, adverse effects may occur under certain circumstances. Neurotoxicity represents a potential complication when lidocaine is administered at excessively high concentrations or doses, emphasizing the importance of adhering to recommended dosage guidelines and maintaining careful patient monitoring during treatment [3].

In dental practice, lidocaine is most commonly formulated in combination with the vasoconstrictor adrenaline (epinephrine). The addition of adrenaline enhances the clinical effectiveness of the anesthetic by stimulating α1-adrenergic receptors located within the smooth muscle of arteriolar walls. This stimulation results in localized vasoconstriction, which reduces blood flow at the injection site. Consequently, the absorption of lidocaine into the systemic circulation is slowed, allowing higher concentrations of the anesthetic to remain in the target tissues for an extended period. This prolongs the duration of anesthesia, improves procedural comfort, and reduces the risk of systemic toxicity by limiting rapid plasma uptake [4]. The vasoconstrictive properties of adrenaline provide an additional clinical benefit through the promotion of hemostasis. Reduced local blood flow minimizes bleeding during dental procedures, thereby improving visibility within the operative field and facilitating more precise treatment. These advantages are particularly valuable during surgical and periodontal interventions where adequate control of bleeding is essential for optimal outcomes [4]. Despite its benefits, the use of adrenaline-containing anesthetic solutions requires careful consideration in patients with underlying cardiovascular disease. Even at the relatively low concentrations employed in dentistry, adrenaline may produce systemic effects, including increased heart rate, enhanced cardiac output, and peripheral vasodilation. In medically compromised individuals, these physiological responses may increase the risk of serious cardiovascular events, including hypertensive crises, cardiac arrhythmias, and myocardial infarction. Therefore, comprehensive medical assessment and appropriate dose modification are critical when treating patients with significant cardiovascular conditions [5].

Lidocaine undergoes extensive hepatic metabolism, with only a small proportion of the administered dose, approximately 10%, being excreted unchanged in the urine. The average elimination half-life is approximately 90 minutes, although this may vary according to individual patient characteristics. In particular, patients with advanced liver disease may exhibit impaired drug metabolism, resulting in prolonged systemic exposure and an increased risk of toxicity. Similarly, renal dysfunction may affect the elimination of metabolites and influence overall drug clearance. Consequently, reduced dosages and enhanced clinical vigilance are recommended when administering lidocaine to patients with significant hepatic or renal impairment to ensure safe and effective anesthetic management [6].

Prilocaine

Prilocaine is an amide-type local anesthetic that occupies an important position in dental anesthesia due to its favorable safety profile and relatively low systemic toxicity. Compared with lidocaine, prilocaine exhibits reduced vasodilatory activity, a characteristic that contributes to its clinical usefulness in situations where the use of potent vasoconstrictors may be undesirable or contraindicated. Because of these properties, prilocaine is frequently selected for patients with certain cardiovascular conditions, particularly those with unstable angina, severe uncontrolled hypertension, or other medical circumstances in which minimizing cardiovascular stimulation is a primary concern [7]. A distinctive feature of prilocaine formulations used in dentistry is their frequent combination with felypressin, a synthetic vasoconstrictor that differs substantially from adrenaline in both structure and pharmacological action. Felypressin is chemically related to vasopressin and exerts its effects primarily by reducing venous outflow rather than producing intense arterial vasoconstriction. As a result, its cardiovascular impact is generally less pronounced than that of adrenaline, making it a valuable alternative for patients who may not tolerate conventional adrenergic vasoconstrictors. Although felypressin possesses weaker vasoconstrictive properties than adrenaline, the relatively low vasodilatory effect of prilocaine

compensates for this limitation, allowing adequate concentrations of the anesthetic to remain at the site of administration for a sufficient duration to achieve effective pain control [7]. The combination of prilocaine and felypressin provides satisfactory anesthesia for many routine dental procedures while reducing the likelihood of significant cardiovascular stimulation. This characteristic has made prilocaine a preferred option in selected patient populations requiring special medical consideration. Nevertheless, the use of felypressin requires caution in pregnant patients. Due to its structural similarity to vasopressin and its ability to mimic certain physiological actions of oxytocin, felypressin may potentially stimulate uterine smooth muscle contraction. Consequently, its administration during pregnancy is generally discouraged unless the anticipated clinical benefits clearly outweigh potential risks [3].

Another important advantage of prilocaine is its reduced systemic toxicity compared with several other amide local anesthetics. This lower toxicity is largely attributed to its unique metabolic pathway. While many amide anesthetics depend predominantly on hepatic metabolism, prilocaine undergoes biotransformation not only in the liver but also within the lungs and kidneys. This distributed metabolic process reduces the metabolic burden placed on hepatic tissues and contributes to a more efficient elimination profile. Furthermore, prilocaine and its metabolites are cleared from the body more rapidly through renal excretion than many other amide anesthetic agents, reducing the likelihood of drug accumulation during routine clinical use [3]. The favorable pharmacokinetic and pharmacodynamic properties of prilocaine have contributed to its continued relevance in modern dental practice. Its combination of effective anesthetic action reduced vasodilatory effects, lower systemic toxicity, and suitability for patients with specific cardiovascular concerns makes it a valuable alternative to lidocaine in selected clinical situations. For these reasons, prilocaine remains an important component of the dental anesthetic armamentarium, offering clinicians a reliable and comparatively safe option for achieving effective local anesthesia while accommodating the unique medical needs of individual patients [3][7].

Articaine

Articaine represents one of the most significant developments in modern dental local anesthesia since its first synthesis in 1969. It has rapidly achieved widespread clinical acceptance across global dental practice due to its unique chemical structure, enhanced tissue penetration, and favorable pharmacokinetic profile. Unlike conventional amide local anesthetics that contain a benzene ring, articaine is characterized by the presence of a thiophene ring. This structural modification significantly increases its lipid solubility, allowing improved diffusion through neuronal lipid membranes. As a result, articaine demonstrates superior penetration into hard and soft tissues, which is particularly advantageous in dental procedures requiring effective anesthesia of dense structures such as mandibular bone [8].

Another important pharmacological characteristic of articaine is its formulation at a relatively high concentration of 4%, which further enhances its clinical efficacy. The combination of increased lipid solubility and higher concentration contributes to improved diffusion of the anesthetic agent, enabling more reliable pulpal anesthesia in challenging anatomical regions, including the mandible. This makes articaine especially valuable in situations where other local anesthetics may exhibit reduced effectiveness or incomplete nerve blockade. From a pharmacokinetic perspective, articaine exhibits an efficient and rapid clearance profile. Following administration, the drug is absorbed into the systemic circulation and distributed throughout body tissues. However, unlike most amide local anesthetics that rely primarily on hepatic metabolism, articaine possesses an additional ester side chain within its molecular structure. This feature allows rapid inactivation by plasma esterases in the blood. Consequently, approximately 90% of the administered dose is metabolized into articainic acid within the plasma and subsequently eliminated via renal excretion. The remaining fraction, approximately 10%, undergoes hepatic metabolism. This dual metabolic pathway contributes to a significantly reduced elimination half-life of approximately 20 minutes, which is considerably shorter than that of lidocaine and other hepatically metabolized amide anesthetics [9].

The rapid metabolism and clearance of articaine are associated with a relatively low systemic toxicity profile, making it suitable for use in a wide range of dental procedures, including those requiring prolonged or repeated administration of local anesthesia. Its safety profile, combined with its potent anesthetic properties, supports its use as an effective agent for achieving reliable pain control in both routine and complex dental interventions [10]. In pediatric dentistry, articaine has been investigated extensively to evaluate its safety and efficacy. Evidence from clinical studies, including findings by Gulenko et al., indicates that articaine is an effective and safe alternative to lidocaine in children, including those under four years of age. These findings support its use across pediatric age groups when administered with appropriate dosing considerations. The recommended pediatric dosage is approximately 5 mg/kg, and precise dose calculation is essential at each clinical appointment to avoid potential toxicity. Despite supporting evidence for its safety, cautious use is still advised in very young children, particularly those aged four years and below, to ensure optimal risk management [11]. In clinical practice, articaine has been extensively evaluated for both efficacy and safety. While some concerns have been raised regarding potential neurotoxicity, particularly cases of paraesthesia following inferior alveolar nerve blocks or prolonged postoperative numbness, the overall body of evidence suggests that these occurrences are rare and not conclusively linked to inherent neurotoxicity of the drug. Multiple systematic investigations have concluded that articaine remains a safe and highly effective local anesthetic agent for patients across all age groups when used appropriately in dental practice [12]. Overall, articaine stands out due to its superior diffusion properties, rapid metabolism, short half-life, and strong clinical efficacy. These characteristics have positioned it as one of the most valuable and widely used local anesthetic agents in contemporary dentistry.

Mepivacaine

Mepivacaine is a widely utilized amide local anesthetic in dental practice and is valued for its rapid onset of action and intermediate duration of anesthesia. It shares structural and pharmacological similarities with other amide agents such as lidocaine and prilocaine; however, it is distinguished by its relatively low vasodilatory activity. This property allows mepivacaine to be effectively administered without the addition of a vasoconstrictor in many clinical situations. As a result, a higher concentration formulation, commonly 3% plain mepivacaine, can be delivered directly to the target tissue while still achieving satisfactory anesthetic depth and duration [13]. The absence of a vasoconstrictor in mepivacaine formulations provides a significant clinical advantage, particularly in patients where vasoconstrictor use may present potential risks. It is frequently selected for medically compromised individuals, especially those with cardiovascular disease, arrhythmias, or hyperthyroidism. In such populations, the avoidance of exogenous vasoconstrictors reduces the likelihood of undesirable systemic effects such as tachycardia, elevated blood pressure, and increased myocardial oxygen demand. Consequently, mepivacaine serves as a safer alternative to anesthetic solutions containing adrenaline, particularly in elderly patients and those with limited physiological reserve [14].

Despite these advantages, it is important to recognize that the anesthetic potency of mepivacaine is generally considered slightly lower than that of lidocaine when used in comparable conditions. Nevertheless, its pharmacokinetic properties and favorable safety profile maintain its clinical relevance in a wide range of dental procedures. The onset of action of local anesthetics, including mepivacaine, is influenced by physicochemical properties such as ionization constant (pKa), lipid solubility, and tissue pH. Local anesthetics are typically prepared as hydrochloride salts to ensure chemical stability in solution. In this ionized, water-soluble form, the molecules are unable to cross lipid-rich nerve membranes. Effective anesthesia occurs only when a portion of the drug exists in its non-ionized, lipid-soluble form, which allows diffusion across neuronal membranes and subsequent blockade of sodium channels [1]. The proportion of anesthetic molecules in the active lipid-soluble state is strongly influenced by physiological pH. Agents with a higher pKa value tend to have a smaller fraction of non-ionized molecules at physiological pH, resulting in a slower onset of action. This effect is further exacerbated in inflamed or infected tissues, where the local environment is more acidic, thereby reducing the availability of lipid-soluble anesthetic molecules and impairing diffusion into nerve fibers. These conditions often lead to incomplete or delayed anesthesia with certain local anesthetics [1].

Mepivacaine presents a notable advantage in such clinical scenarios due to its relatively favorable physicochemical properties. Its lower pKa and reduced dependence on tissue alkalinity enable a greater proportion of the drug to exist in a diffusible form, even in acidic environments associated with infection or inflammation. Consequently, mepivacaine may demonstrate improved anesthetic effectiveness compared with other agents such as lidocaine under these challenging conditions. This makes it particularly useful in emergency dental care or procedures involving acutely inflamed tissues. In addition, patient-specific physiological factors must be considered when selecting and administering local anesthetic agents. Elderly individuals often exhibit reduced renal and hepatic function, along with diminished physiological reserve, which can affect drug metabolism and elimination. Similarly, underlying cardiac conditions may impair systemic clearance of anesthetic agents, increasing the risk of accumulation and toxicity. Therefore, careful dose adjustment and clinical monitoring are essential when using mepivacaine in medically compromised patients to ensure both safety and efficacy in dental anesthesia [14].

Bupivacaine

Bupivacaine is a long-acting amide local anesthetic widely recognized for its potent and sustained analgesic effects in dental and surgical practice. It is a water-soluble agent with high lipid solubility and strong protein-binding capacity, properties that significantly contribute to its extended duration of action. These pharmacological characteristics allow bupivacaine to provide profound anesthesia of pulp, bone, and soft tissues, making it particularly valuable in dental procedures that require prolonged operative time or are associated with significant postoperative pain. Because of its long duration, it is frequently selected for complex treatments such as endodontic therapy, surgical extractions, and other invasive dental interventions where extended pain control is clinically beneficial [15]. One of the key pharmacodynamic features of bupivacaine is its relatively slow onset of action compared with other commonly used local anesthetics. Clinical studies indicate that its onset typically ranges between 5 to 8 minutes in both maxillary and mandibular regions. In contrast, agents such as lidocaine demonstrate a faster onset, generally occurring within 2 to 4 minutes. This delay in anesthetic effect is an important consideration in clinical practice, particularly when immediate pain control is required at the beginning of a procedure. To overcome this limitation, a commonly adopted clinical strategy involves the initial administration of lidocaine to achieve rapid anesthesia, followed by supplementation with bupivacaine to maintain prolonged analgesia during and after the procedure. This combined approach allows clinicians to benefit from both rapid onset and extended duration of action [16].

The extended duration of bupivacaine-induced anesthesia is one of its most significant clinical advantages. When formulated with adrenaline at a concentration of 0.5% bupivacaine with 1:200,000 epinephrine, soft tissue anesthesia can persist for approximately 4 to 9 hours, as reported by Malamed. In comparison, 2% lidocaine with 1:100,000 epinephrine typically provides soft tissue anesthesia lasting approximately 3 to 5 hours. This prolonged effect contributes to improved postoperative comfort and reduced need for additional analgesic medications in many patients [15]. However, despite these benefits, the prolonged anesthetic effect of bupivacaine may not always be desirable.

Extended soft tissue numbness can increase the risk of accidental self-inflicted trauma, particularly in pediatric patients or individuals with special healthcare needs who may have difficulty recognizing or avoiding biting injuries. For this reason, bupivacaine is generally reserved for procedures that are expected to produce significant postoperative pain or require extended analgesic coverage rather than routine short-duration dental treatments [11]. From a safety perspective, bupivacaine, while effective, has a relatively higher cardiotoxic potential compared to other local anesthetics. Although systemic toxicity from local anesthetics is rare in dental practice when appropriate dosing guidelines are followed, bupivacaine is associated with more pronounced cardiovascular effects in cases of overdose or inadvertent intravascular injection. Toxic concentrations can interfere with cardiac conduction pathways, reduce myocardial contractility, and disrupt vascular tone due to its vasodilatory effects. These effects may lead to serious complications such as arrhythmias, hypotension, and in severe cases, cardiovascular collapse [15]. Overall, bupivacaine remains a highly valuable local anesthetic in dentistry due to its long duration of action and strong analgesic properties. Its use requires careful patient selection, precise dosing, and clinical awareness of its delayed onset and potential cardiotoxicity to ensure safe and effective outcomes in dental anesthesia.

Topical Anesthetics

Topical anesthetics are widely used in dental practice to reduce superficial pain associated with minor procedures, particularly needle insertion during local anesthetic administration. Their primary mechanism of action involves reversible inhibition of peripheral nerve endings located in the superficial layers of the oral mucosa, thereby reducing sensory transmission from the site of application. In selected clinical situations, topical anesthetics may also eliminate the need for injection anesthesia for very superficial procedures. In addition, they are commonly applied to the soft palate to suppress gag reflexes during impression taking, intraoral radiography, and other diagnostic or restorative procedures that may stimulate pharyngeal sensitivity. These agents are available in several pharmaceutical formulations, including gels, sprays, and ointments, allowing flexibility in clinical application depending on the treatment requirement and anatomical site. Compared with injectable local anesthetics, topical formulations are generally prepared at higher concentrations to compensate for the limited penetration across mucosal surfaces. The oral mucosa acts as a protective barrier, and therefore effective topical anesthesia requires sufficient drug concentration and appropriate application technique. In clinical practice, the targeted area is typically dried first to enhance drug adherence, followed by careful application using a cotton swab, applicator, or spray device to ensure even distribution over the mucosal surface.

Among the most commonly used topical anesthetic agents is benzocaine, which is an ester-type local anesthetic available in concentrations ranging from 6% to 20%. Benzocaine is formulated in different delivery systems, including ointments, gels, and sprays, making it suitable for a variety of clinical indications. At higher concentrations, particularly 20%, benzocaine demonstrates a rapid onset of action, typically within approximately 30 seconds, with clinically adequate depth of anesthesia achieved within 2 to 3 minutes. Its fast onset and ease of application make it especially useful for reducing discomfort prior to needle insertion, improving patient acceptance of dental procedures. In addition, benzocaine ointments are frequently used for symptomatic relief in patients suffering from localized oral lesions such as aphthous ulcers, where temporary pain control is required. Lidocaine is another widely used topical anesthetic agent in dentistry, available in multiple formulations including 2% and 5% gels as well as a 10% spray. Compared with benzocaine, lidocaine also provides effective mucosal anesthesia with a slightly longer onset time, typically ranging from 1 to 2 minutes, with adequate anesthetic effect achieved within approximately 3 minutes. Its versatility and established safety profile contribute to its frequent use in both adult and pediatric dental care. Overall, topical anesthetics play an essential role in modern dental practice by improving patient comfort, reducing procedural anxiety, and facilitating smoother clinical workflows. Their proper use enhances the overall quality of dental care by minimizing pain perception and increasing patient cooperation during treatment procedures.

Maximum Dose

Local anesthetic agents are generally safe when administered within recommended dosage limits; however, exceeding the maximum permissible dose can result in serious systemic toxicity affecting both the nervous and cardiovascular systems. Toxicity develops due to elevated plasma concentrations of the anesthetic agent, which may lead to direct neuronal dysfunction, neural ischemia, and inflammatory responses triggered by the drug itself or associated vasoconstrictors. The clinical presentation of local anesthetic systemic toxicity typically follows a predictable progression. Early manifestations are primarily excitatory neurological symptoms, including visual disturbances, sensory abnormalities, circumoral numbness, dizziness, tinnitus, and in more severe cases, generalized seizures. If plasma concentrations continue to rise, these excitatory signs may transition into central nervous system depression, characterized by reduced consciousness, coma, respiratory depression, and potentially respiratory arrest [18]. Cardiovascular toxicity represents a more severe and potentially life-threatening complication. It may present as alterations in cardiac rhythm, including both tachyarrhythmias and bradyarrhythmias, as well as impaired myocardial contractility. In extreme cases, cardiovascular collapse and cardiac arrest may occur. The severity of these effects depends on multiple factors, including the specific anesthetic agent used, the total administered dose, the rate of systemic absorption, and patient-related physiological conditions [18].

Prevention of local anesthetic toxicity is primarily achieved through strict adherence to established maximum dosage guidelines, which are typically calculated based on patient body weight. The concentration of a local anesthetic solution is expressed as a percentage, indicating the number of grams of active drug per 100 milliliters of solution. For example, a 2% lidocaine solution contains 2 grams of lidocaine per 100 milliliters, which is equivalent to 20 mg per milliliter. This standard conversion allows clinicians to accurately determine the total drug content administered during a procedure [18]. To calculate the total dose delivered in a single dental cartridge, the concentration in milligrams per milliliter is multiplied by the volume of the cartridge, which is commonly either 1.8 mL or 2.2 mL depending on the delivery system used. For instance, a 2% lidocaine solution (20 mg/mL) in a 2.2 mL cartridge contains 44 mg of lidocaine. This calculation provides a practical basis for determining safe administration limits in clinical settings. For a healthy adult weighing 70 kilograms, the maximum recommended dose of lidocaine with a vasoconstrictor is approximately 7 mg/kg, resulting in a total allowable dose of 490 mg (7 mg/kg × 70 kg = 490 mg). Based on this value, the maximum number of cartridges that can be safely administered is determined by dividing the total permissible dose by the amount of drug per cartridge. In this example, 490 mg divided by 44 mg per cartridge yields approximately 11 cartridges [18]. Several additional factors influence the risk of toxicity, including drug potency, total dose administered, and duration of exposure. Patient-specific variables such as age, body weight, hepatic and renal function, and overall physiological reserve play a critical role in determining safe dosage limits. Pediatric patients, elderly individuals, and medically compromised patients often require reduced doses due to decreased metabolic capacity and increased sensitivity to local anesthetic agents. Furthermore, accidental intravascular injection represents a major cause of acute systemic toxicity, as it results in rapid elevation of plasma drug concentrations. Clinical signs of early toxicity should be carefully recognized to prevent progression to severe complications. These include slurred speech, visual disturbances such as diplopia, tinnitus, muscle twitching, and agitation. Early identification and prompt intervention are essential to prevent progression to life-threatening neurological and cardiovascular outcomes. Therefore, careful patient assessment, correct dose calculation, aspiration prior to injection, and awareness of anatomical injection sites are essential components of safe local anesthetic administration in dental practice [18].

Computer-Controlled Local Anesthesia Delivery (CCLAD) Systems

Computer-Controlled Local Anesthesia Delivery systems represent a significant advancement in dental anesthesia techniques, designed specifically to improve patient comfort and reduce the psychological and physical discomfort associated with traditional injection methods. Conventional local anesthetic injections often generate pain due to several factors, including the mechanical trauma of tissue penetration, rapid expansion of tissues caused by high-pressure fluid delivery, and the chemical properties of anesthetic solutions such as temperature and acidity. These factors collectively contribute to patient anxiety and avoidance of dental care, particularly among children and individuals with heightened dental fear. CCLAD technology addresses these challenges by modifying the way anesthetic agents are delivered into the tissue environment [19]. The core principle of CCLAD systems is the controlled and consistent delivery of local anesthetic solution at a predetermined slow rate and stable pressure. Unlike manual syringe injection, where variability in hand pressure can lead to fluctuations in flow rate and discomfort, computer-controlled systems maintain precise regulation throughout the injection process. This gradual administration allows the anesthetic solution to diffuse more evenly through the tissues, reducing sudden pressure changes that typically cause pain. As a result, the injection experience can become nearly imperceptible for many patients, significantly improving tolerance and cooperation during dental procedures [19].

A typical CCLAD system consists of a computerized control unit connected to a pen-like handpiece, which replaces the traditional syringe design. The handpiece is ergonomically designed to resemble a dental instrument rather than a conventional needle syringe, thereby reducing patient anxiety associated with visual cues of injection. This design also enhances operator control and precision, particularly in areas requiring delicate infiltration or nerve block techniques. The system enables clinicians to maintain accurate needle placement while ensuring a consistent flow rate of anesthetic solution, improving both safety and effectiveness of delivery. Despite its clinical advantages, CCLAD systems have certain limitations that may restrict their widespread adoption. One of the primary drawbacks is the relatively high cost of acquisition and maintenance compared to conventional syringe systems. Additionally, these devices require dedicated space within the dental operatory, which may be challenging in smaller clinical settings. Another limitation is the increased time required to administer local anesthesia compared to manual injection techniques. The slow, controlled delivery that enhances patient comfort also extends the duration of the procedure, which may impact clinical workflow efficiency in high-volume dental practices [20].

Nevertheless, the benefits of CCLAD systems in improving patient experience are particularly valuable in pediatric dentistry, special care dentistry, and anxiety management. By minimizing pain perception and reducing fear associated with injections, these systems contribute to better patient compliance and more positive attitudes toward dental treatment. Over time, improved patient cooperation can lead to more effective treatment outcomes and reduced behavioral management challenges for clinicians. Overall, Computer-Controlled Local Anesthesia Delivery systems represent an important innovation in modern dental practice. They reflect a shift toward patient-centered care, where comfort, precision, and psychological well-being are prioritized alongside clinical effectiveness.

Conclusion

Local anesthetic drugs are fundamental to modern dental practice, enabling pain-free execution of diagnostic and therapeutic procedures while improving patient cooperation and clinical efficiency. Their pharmacological behavior is determined by chemical structure, metabolism, and tissue interaction, which directly influences onset, duration, and safety profiles. Amide anesthetics such as lidocaine, articaine, prilocaine, mepivacaine, and bupivacaine remain the mainstay of dental anesthesia due to their predictable performance and reduced allergic potential compared with ester compounds. Safe clinical use depends on accurate dose calculation, awareness of maximum permissible limits, and careful consideration of patient-specific factors such as age, weight, and systemic health. Toxicity remains a critical risk, particularly in cases of overdose or intravascular injection, requiring strict adherence to safety protocols. Advances in delivery systems, especially computer-controlled anesthesia devices, have further enhanced patient comfort and reduced procedural anxiety. Overall, optimal outcomes in dental anesthesia rely on integrating pharmacological knowledge with clinical precision, patient safety principles, and technological innovation in practice.

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