Modern Local Anesthesia Techniques and Current Approaches in Pediatric Dentistry

Çocuk Diş Hekimliğinde Modern Lokal Anestezi Teknikleri ve Güncel Yaklaşımlar

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ABSTRACT Local anesthesia in pediatric dentistry plays a critical role in ensuring that dental treatment is performed comfortably and safely. In addition to traditional infiltration and nerve block anesthesia techniques, modern technologies and new anesthetic agents have significantly improved pain management in children. Modern anesthesia approaches such as computer-controlled local anesthetic delivery systems, intraosseous anesthesia, needle-free jet injection systems, and vibrotactile devices have emerged as effective methods to reduce injection pain and increase children's cooperation during dental procedures. Moreover, when combined with behavioral management techniques and appropriate dosing protocols, these methods can further enhance clinical success. This review summarizes modern local anesthesia techniques and highlights the role of new technologies in pediatric dental practice, aiming to provide guidance for clinicians in light of current literature.

Keywords: Pediatric dentistry; local anesthesia; modern anesthesia techniques; pain management

ÖZET Çocuk diş hekimliğinde lokal anestezi, tedavinin konforlu ve güvenli bir şekilde gerçekleştirilmesinde kritik rol oynamaktadır. Geleneksel infiltrasyon ve sinir bloğu anestezi tekniklerinin yanı sıra, modern teknolojiler ve yeni anestezik ajanlar çocuklarda ağrı yönetimini önemli ölçüde iyileştirmiştir. Bilgisayar kontrollü lokal anestezi sistemleri, intraosseöz anestezi, iğnesiz jet enjeksiyon sistemleri ve vibrotaktil cihazlar gibi modern anestezi yaklaşımları, enjeksiyon ağrısını azaltmak ve çocukların iş birliğini artırmak için etkili yöntemler olarak ön plana çıkmaktadır. Ayrıca, davranış yönetimi teknikleri ve uygun dozlama protokolleri ile birlikte kullanıldığında bu yöntemler klinik başarıyı artırmaktadır. Bu derleme, modern lokal anestezi tekniklerini ve yeni teknolojilerin pediatrik dental uygulamalardaki rolünü özetlemektedir ve güncel literatür ışığında klinisyenlere rehberlik etmeyi amaçlamaktadır.

Anahtar Kelimeler: Çocuk diş hekimliği; lokal anestezi; modern anestezi teknikleri; ağrı yönetimi

Dental caries remains a serious problem in children, affecting 23.3% of five-year-olds in England and 27.9% of two- to five-year-olds in the USA.[1,2] In Turkey, the prevalence of dental caries among children has been reported to be approximately 75.6% according to a nationwide meta-analysis including studies published between 2000 and 2024.[3] If untreated, caries may lead to pain, infection, malnutrition, and disturbed growth. Social and financial consequences may include days off school or work, referral to specialized care and general anesthesia resulting in increased costs.[4] Surgical approaches and new preventive strategies have been developed and widely researched.[5]

Pain control is essential in pediatric dentistry. Dental procedures often induce anxiety and fear in children, which can reduce cooperation and negatively influence long-term attitudes toward dental care. Delivery of pain-free dentistry is crucial for reducing fear and anxiety, completion of treatment, and increasing acceptance of future dental treatment in children. Local anesthetic (LA) facilitates this pain-free approach but it re-

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mains challenging. A number of interventions to help children cope with delivery of LA have been described, with no consensus on the best method to increase its acceptance.[6]

Local anesthesia provides reversible conduction blockade of nerve fibers, allowing invasive procedures to be performed without significant pain.[6] Recent advancements focus on techniques that reduce both procedural pain and injection pain, while maximizing safety and efficacy. Both the American Academy of Pediatric Dentistry and the International Association of Pediatric Dentistry provide evidence-based guidelines for local anesthetic use in children.[7,8]

Most local anesthesia procedures in pediatric dentistry involve traditional methods of infiltration or inferior alveolar nerve block (IANB) techniques with a dental syringe, disposable cartridges, and needles.[6] Infiltration works well in maxillary teeth and, in some children, even mandibular primary molars due to immature bone density.[9] IANB remains standard for mandibular anesthesia but may have higher failure rates in pediatric patients.[10]

Numerous techniques have been suggested to reduce pain during the administration of local anesthetic agents, including the application of topical anesthetic gels, precooling the injection site, distraction techniques, warming and buffering the anesthetic agents, reducing the speed of injection, and the use of lasers, computerized injection systems and modern vibration devices.[11-17] This literature review aims to provide dentists with comprehensive information on modern local anesthetic agents, alternative administration techniques, and strategies to reduce pain during anesthesia, ultimately improving patient comfort.

ADJUNCTIVE PAIN-REDUCTION APPROACHES

These techniques are not intended to replace conventional dental anesthesia but are used as supportive adjuncts to minimize pain during the administration of local anesthetic agents.

ELECTRONIC DENTAL ANESTHESIA

Electronic dental anesthesia (EDA), a form of transcutaneous electrical nerve stimulation (TENS) adapted for dental use, has been investigated as a non-injection method to manage pain and improve comfort in pediatric dental patients. In a clinical trial involving 27 children aged 6-12 years, EDA showed similar pain perception to conventional local anesthesia during restorative procedures, and 78% of patients preferred EDA over injections.[18] Other studies in children aged 6-12 years comparing EDA with local anesthetic injections found that although EDA was generally less effective than injectable anesthesia for deeper cavity preparation, a majority of children still preferred EDA.[19] Research also suggests that EDA can positively influence behavior and physiological responses (e.g., reduced movement and heart rate changes) during local anesthetic administration in young, sedated patients.[20] However, evidence on its analgesic effectiveness is mixed, and some studies report that EDA does not achieve significant pain control compared with local anesthesia in routine dental procedures.[21]

LASER-ASSISTED PAIN REDUCTION

Laser-assisted pain reduction in pediatric dentistry commonly refers to photobiomodulation (PBM) or low-level laser therapy (LLLT), where low-power laser light is applied to oral tissues to influence nerve signal transmission and reduce pain and inflammation without generating heat. PBM has been investigated as a non-invasive adjunct to decrease pain during dental procedures, including local anesthetic injections and other interventions, and can modulate biological responses involved in nociception and tissue healing.[22] Systematic evidence also suggests that PBM may help reduce discomfort during needle penetration in dental anesthesia, demonstrating a moderate pain-reduction effect in pediatric populations across several randomized trials, although study protocols and outcomes vary, and more standardized research is needed.[23] A clinical study evaluated the effect of combining topical anesthesia with 810-nm LLLT on injection pain in children aged 6-9 years undergoing pulpotomy. The results indicated that LLLT significantly reduced perceived injection pain compared to topical anesthesia alone, without affecting anesthesia efficacy or duration, and was preferred by the majority of patients.[15]

VR-BASED DISTRACTION

Virtual reality (VR) has increasingly been evaluated in pediatric dentistry as a non-pharmacological distraction technique to reduce pain perception and anxiety during dental procedures; it does not provide anesthesia itself. Clinical evidence from randomized trials shows that immersive VR-based distraction significantly lowers pain perception and anxiety in children undergoing dental treatment, including procedures requiring local anesthesia, when compared with control conditions (e.g., standard distraction or no VR).[24] A larger randomized study also reported that VR use during various dental procedures resulted in significant

reductions in pain perception and increased relaxation in children aged 5-12 years.[25] Systematic review evidence supports these findings, indicating that VR-based distraction is effective for reducing both dental anxiety and pain perception in pediatric populations, although heterogeneity among studies suggests careful interpretation and further research is warranted.[26]

CRYOANESTHESIA

Cryoanesthesia refers to the application of cold stimuli (such as ice, refrigerant spray, or cold devices) to oral tissues before local anesthetic injection to reduce pain perception. The pain-reduction effect occurs because cold temporarily slows nerve conduction and decreases nociceptor activity, which can lessen the sensation of needle penetration. Studies in pediatric dentistry have reported that applying ice or cold packs at the injection site before administering local anesthesia can significantly reduce injection pain and improve child cooperation during dental procedures.[27]

SUCROSE-ASSISTED PAIN REDUCTION

A study on sucrose pre-application investigated its pain-reduction effect during dental injections in children aged 3-9 years. In this randomized controlled trial, 60 children received either a sucrose solution or distilled water applied to the tongue prior to local anesthesia. Pain was assessed using the Sound Eye Motor (SEM) scale by blinded observers and the Wong-Baker Faces Pain Rating Scale (WBFPS) by the children. Results showed significantly lower pain scores in the sucrose group compared to controls, with children who preferred sweet tastes showing additional reductions in pain perception. These findings suggest that sucrose pre-application is an effective method for minimizing injection-related pain in pediatric dental patients.[28]

ALTERNATIVE TECHNIQUES FOR DELIVERY OF LOCAL ANESTHESIA

COMPUTER-CONTROLLED LOCAL ANESTHETIC DELIVERY SYSTEMS

Computer controlled local anesthetic delivery systems (CCLAD) regulate the flow rate and pressure of anesthetic solutions, which helps reduce pressure-related pain and improves patient comfort during injections. The Wand™ (Milestone Scientific, Inc., Livingston, NJ) was the first CCLAD device introduced in 1997, followed by later versions from the same manufacturer such as Wand Plus and CompuDent. In 2001, the Comfort Control Syringe (Dentsply International, York, PA, USA) was introduced as an alternative to Wand Plus. Other comparable devices include Anaeject (Nippon Shika Yakuhin, Shimonoseki, Japan), Ora Star (Showa Uyakuhin Kako, Tokyo, Japan), and the QuickSleeper and SleeperOne systems (Dental Hi-Tec, Cholet, France). These electronic injection systems allow different injection speeds to be selected, enabling more controlled and potentially less painful anesthetic delivery.[29] Since the introduction of the first CCLAD device in 1997, additional systems such as I-JECT, No Pain III, and Single Tooth Anesthesia (STA) have been developed to further enhance patient comfort during dental injections.[16] Devices such as The Wand® and Comfort Control Syringe have been widely investigated in pediatric dentistry.[30,31] Clinical studies indicate that computer-controlled local anesthesia delivery (CCLAD) systems significantly reduce pain perception compared with conventional syringes, particularly in anxious or needle-fearful children, thereby improving patient acceptance, cooperation, and reducing anxiety during injections.[16] A systematic review of randomized clinical trials also reported that by precisely regulating the flow rate and pressure of anesthetic delivery, CCLAD devices make injections less noticeable and less threatening, which contributes to lower pain perception and better patient cooperation. The review further demonstrated improved acceptability and reduced pain perception in children receiving inferior alveolar nerve block injections, while adults generally experienced even lower levels of discomfort than pediatric patients.[29] Overall, the available evidence suggests that CCLAD systems are particularly beneficial in pediatric dentistry and in managing anxious patients during dental procedures.

INTRAOSSEOUS ANESTHESIA

Intraosseous anesthesia involves injecting the anesthetic solution directly into the cancellous bone after penetrating the cortical plate, allowing the agent to diffuse rapidly through the marrow spaces and produce an immediate onset of anesthesia. This direct delivery bypasses soft tissue and hard tissue barriers, which facilitates a fast and profound anesthetic effect with a more localized action compared with conventional infiltration or nerve block techniques.[32] Studies in pediatric patients using computer-controlled systems such as QuickSleeper 2 have reported high success rates of around 91.2-91.9 % for anesthetic effectiveness in restorations, endodontics, and extractions with 4 % articaine and epinephrine (QuickSleeper 2, 4% articaine with 1:200 000 epinephrine) and minimal post-

injection discomfort, indicating that intraosseous delivery can be a reliable alternative to classic techniques in children and adolescents.[33]

Further research has shown that intraosseous anesthesia with computer-assisted systems in children is well tolerated, with the majority of young patients reporting no pain or only mild discomfort during administration and many preferring it over traditional techniques.[34] Overall, intraosseous anesthesia provides rapid onset, profound anesthesia, and favorable patient comfort**,** making it especially valuable in pediatric dentistry and in cases where conventional nerve blocks are insufficient or fail to achieve adequate anesthesia.[32]

In clinical conditions where achieving effective local anesthesia is challenging, such as molar-incisor hypomineralization (MIH), adequate pain control remains a significant concern in pediatric dentistry. A systematic review reported that intraosseous anesthesia with 4% articaine and epinephrine demonstrated the highest efficacy in reducing hypersensitivity and achieving satisfactory anesthesia in MIH-affected teeth. Effective anesthetic management in such cases improves both patient comfort and the quality of dental treatment; however, further well-designed studies are required to establish definitive clinical recommendations.[35]

NEEDLE-FREE JET INJECTION

Needle phobia, largely associated with injection pain and anxiety, is reported in approximately 10-20% of dental patients and may lead to avoidance of necessary dental treatment.[36] Pain during conventional injections may result from needle penetration, tissue distension caused by the injected solution, and irritation of the mucosa by the anesthetic agent. In addition, needle injections can lead to complications such as needlestick injuries, hematoma formation, needle fracture, and the potential transmission of infectious diseases. To minimize these problems and improve patient comfort, needle-free jet injection systems have been developed. These systems deliver anesthetic solutions through high-velocity jets that penetrate the skin or mucosa and disperse the drug into subcutaneous or intramuscular tissues.[37]

Several needle-free jet injection devices have been developed for dental anesthesia and among the most reported devices are Comfort-In™®, INJEX® and MadaJet®. Comfort-In™® has been evaluated in clinical trials comparing its anesthetic efficacy with conventional needle injections in pediatric restorative and endodontic procedures.[38,39] MadaJet® XL is one such jet injection which exerts high pressure that causes the anesthetic solution to infiltrate the tissue in tiny droplet form, which is immediately taken up by the myelin sheath of the nerve.[40] INJEX® system delivers a precise dose of local anesthetic (approximately 0.3 mL) through a high-velocity microjet into the submucosa. It is designed to be positioned perpendicular to the gingiva, providing rapid anesthesia without the use of a conventional needle.[41]

Due to their advantages in pediatric dentistry, increasing research efforts have focused on improving their clinical performance and overcoming current limitations, such as inconsistent anesthetic efficacy and procedure-related complications such as bleeding, discomfort, unpleasant taste, and pain.[39] Accordingly, ongoing experimental and clinical studies aim to optimize these systems and evaluate their safety, effectiveness, and applicability in dental practice, particularly in pediatric patients. A recent experimental and clinical study investigated the development of an optimized needle-free liquid jet injection (NFLJI) technique for dental infiltration anesthesia and evaluated its safety and feasibility. The study demonstrated that the angle of jet application significantly influences the outcome of the injection. Perpendicular applications were associated with higher drug regurgitation and a greater incidence of complications such as bleeding and soft-tissue laceration, whereas oblique applications resulted in lower complication rates. Pilot randomized controlled trials further showed that the anesthetic success rate of oblique NFLJI was comparable to that of conventional needle injections. These findings suggest that oblique NFLJI may represent a promising alternative for dental infiltration anesthesia, offering effective anesthetic delivery with fewer complications and supporting the feasibility of larger clinical trials.[42]

Recent studies have evaluated the use of needle-free (NF) injection systems, such as Comfort-In™®, as an alternative to traditional dental needle methods (TM) to reduce injection-related discomfort and anxiety in children. Eren et al. conducted a randomized crossover study with 28 children aged 6 to 12 years, who received both NF and TM injections over two consecutive visits for pulpotomy or filling treatments on primary maxillary molars.[39] Pain perception was assessed and no significant differences were observed between the NF and TM methods in overall pain scores, although differences in anesthetic solution volume and duration of the pain-reduction effect were reported between visits. Similarly, Altan et al. studied 56 children aged 4-11 years undergoing pulpotomy or filling procedures, and found that induction pain was significantly lower with

the NF system compared to the dental needle, while treatment and post-treatment pain scores were comparable between the groups.[38] Taken together, these studies indicate that needle-free systems provide an effective alternative to traditional injections, achieving pain-reduction outcomes for pulpotomy and filling treatments while offering the additional benefit of reduced injection-related discomfort. The NF approach may be particularly advantageous when treating uncooperative or anxious pediatric patients, representing a promising option for modern pediatric dental practice.[38,39]

VIBROTACTILE DEVICES

Dental vibratory devices (DVDs) are designed to lessen the discomfort associated with needle injections by delivering mechanical stimulation such as vibration, pressure, micro-oscillations, or combinations of these stimuli. It is suggested that these physical stimuli can alter the transmission of pain signals by influencing the neural "gate" mechanism in the central nervous system, thereby reducing the patient's perception of pain through a distraction effect.[43]

These devices are designed to activate larger-diameter sensory nerve fibers, which can interfere with pain transmission according to the gate control theory of pain, thereby decreasing patients' pain perception through distraction. Among the most commonly discussed are DentalVibe®, a cordless handheld unit that delivers pulsed micro-oscillations to the tissues at the injection site to mask the sensation of needle penetration; VibraJect®, a small battery-powered attachment that clips onto a standard dental syringe to impart high-frequency vibration directly to the needle and Accupal®, a cordless device that applies both pressure and vibration around the needle penetration area to "precondition" the mucosa before injection, has been evaluated in clinical studies and shown to reduce pain perception compared to traditional injection techniques.[44-46]

A recent systematic review of 12 randomized controlled trials reported a reduction in injection-related pain when DVDs were used. Vibration and distraction techniques provided by these devices generally improved patient comfort, with minimal adverse effects. While a few studies showed inconsistent results, DVDs were largely effective, though they may cause mild tingling or discomfort in sensitive individuals and may be less effective for highly anxious patients. Overall, current evidence suggests that dental vibratory devices are promising adjuncts for pain reduction during local anesthesia, but further standardized research is required to establish their optimal use and efficacy.[17]

In summary, a recent Cochrane review evaluated interventions aimed at increasing acceptance of local anesthesia (LA) in children and adolescents undergoing dental treatment. The review included 26 parallel randomized controlled trials with 2,435 participants aged 2 to 16 years, conducted between 2002 and 2019 across multiple countries. Interventions assessed included equipment-based approaches, such as various LA delivery devices and audiovisual aids, as well as dentist-delivered psychological strategies, including video modeling, hypnosis, and counter-stimulation. Due to high risk of bias in most studies and considerable clinical heterogeneity, meta-analysis was not feasible. No study reported on the primary outcome of LA acceptance, and secondary outcomes such as treatment completion, successful anesthesia, patient or parent satisfaction, and adverse events were largely unreported. Some evidence from single studies suggested potential benefits of audiovisual distraction (e.g., 3D video glasses), counter-stimulation, hypnosis, and use of The Wand device in reducing pain-related behaviors during LA administration; however, the certainty of this evidence was very low. Overall, the review concluded that current evidence is insufficient to determine the most effective strategies for increasing LA acceptance in pediatric patients.[47]

CONCLUSION

Modern local anesthesia in pediatric dentistry integrates pharmacological principles, behavior management techniques, and technological advancements to provide effective and safe pain control. Dentistry has benefited from an abundance of high-quality anesthetic agents that alleviate preoperative and postoperative discomfort, significantly improving patients' perceptions of dental procedures. Current research worldwide focuses on optimizing the onset and duration of anesthesia while enhancing both patient and parent satisfaction, thereby guiding clinical practice and informing future investigations. A clinician's ability to administer local anesthesia effectively, safely, and atraumatically -particularly in children- is crucial for fostering lifelong acceptance of dental care. Rather than avoiding injections out of concern for traumatizing pediatric patients, practitioners should adopt the latest modalities of local pain control, ensuring a pleasant and comfortable dental experience while continually refining techniques through evidence-based updates and guidance from professional organizations.

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