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Article

Efficacy of 4% Articaine vs 2% Lidocaine in Mandibular and Maxillary Block and Infiltration Anesthesia in Patients with Irreversible Pulpitis

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ABSTRACT

Background: Achieving effective anesthesia in patients with irreversible pulpitis remains a significant clinical challenge, particularly in mandibular molars, as standard inferior alveolar nerve blocks with lidocaine frequently fail due to inflammation-induced tissue changes and nerve resistance. **Objective**: This study aimed to compare the anesthetic efficacy, pain perception, and need for supplemental anesthesia between 4% articaine and 2% lidocaine, administered via inferior alveolar nerve block and buccal infiltration in patients with symptomatic irreversible pulpitis. **Methods**: In this prospective observational clinical study (n = 113), adult patients aged 18–65 years diagnosed with irreversible pulpitis in molars were consecutively enrolled based on strict inclusion and exclusion criteria. Patients received either 4% articaine or 2% lidocaine, with pain measured at multiple time points using the Visual Analog Scale (VAS). Cold test response and frequency of supplemental intraosseous anesthesia were also recorded. Ethical approval was obtained from the local institutional review board, and written informed consent was secured in accordance with the Declaration of Helsinki. Data were analyzed using SPSS version 26, employing appropriate statistical tests for continuous and categorical variables, with significance set at $p < 0.05$. **Results**: Articaine demonstrated superior anesthetic efficacy, with a buccal infiltration access success rate of 74% versus 57% for lidocaine ($p = 0.03$), and significantly lower VAS pain scores during access (12 ± 28 mm vs 42 ± 50 mm, $p = 0.02$). Both agents were effective in intraosseous anesthesia, but articaine consistently required fewer supplemental injections. **Conclusion**: The findings support the preferred use of 4% articaine, especially via buccal infiltration, for reliable anesthesia in irreversible pulpitis, offering improved pain management and procedural outcomes with direct relevance for dental and endodontic clinical practice.

Keywords: Irreversible Pulpitis, Articaine, Lidocaine, Dental Anesthesia, Pain Measurement, Inferior Alveolar Nerve Block, Buccal Infiltration.

INTRODUCTION

Effective pain management is a critical component of successful endodontic therapy, especially in the context of symptomatic irreversible pulpitis (IP), where inflammation-induced alterations in pulpal tissue can undermine anesthetic efficacy (1). Achieving deep pulpal anesthesia in mandibular molars is particularly challenging, as conventional inferior alveolar nerve block (IANB) techniques frequently fail to provide adequate analgesia in such scenarios (2). This high failure rate is primarily attributed to pathophysiological changes in the inflamed pulp, including decreased tissue pH, increased vascularity, and activation of tetrodotoxin-resistant sodium channels, all of which collectively diminish the action of local anesthetic agents (3). The use of 2% lidocaine, an amide-type local anesthetic routinely administered with epinephrine, has long been considered the gold standard in dental practice due to its safety and reliability (4, 5). Nevertheless, its limitations become increasingly evident in cases of IP, particularly when effective mandibular block anesthesia is sought (6). Recently,

there has been a surge of interest in the clinical utility of 4% articaine, a thiophene-derived amide anesthetic characterized by increased lipid solubility and enhanced tissue diffusion, which may enable superior nerve membrane and cortical bone permeability compared to lidocaine (7).

Articaine's unique pharmacokinetics, including its metabolism via both hepatic and plasma esterases, may further reduce systemic toxicity and contribute to a favorable anesthetic profile (8). Emerging evidence from recent investigations has examined the efficacy of articaine across various injection modalities, including buccal infiltration (BI) and intraosseous (IO) approaches (9). Studies have suggested that articaine, when used in BI, may outperform traditional IANB for both maxillary and mandibular posterior teeth, while IO administration has been shown to offer improved pain control in situations where conventional methods are inadequate (10, 11). Despite these promising findings, the literature remains inconclusive due to heterogeneity in study designs, patient selection, procedural techniques, and outcome assessments, leading to persistent uncertainty regarding the comparative effectiveness of articaine and lidocaine in this clinical context (12).

To address this uncertainty, there is a need for systematically designed studies that directly compare the anesthetic efficacy, pain perception, and requirement for supplemental anesthesia between 4% articaine and 2% lidocaine administered via IANB and BI in patients with irreversible pulpitis (13, 14). A clear understanding of these differences is essential for guiding clinical decision-making, optimizing patient comfort, and improving procedural efficiency, especially as the management of endodontic pain in IP is further complicated by patient-specific factors such as anxiety, anatomical variations like thick mandibular cortical bone, and the presence of accessory innervation, all of which can significantly impact anesthetic outcomes (15-17). Notably, some reports indicate that the success rate for achieving pulpal anesthesia in IP cases may be as low as 30% with standard IANB, further underscoring the need for alternative or supplementary approaches (18).

Moreover, the diffusion properties of articaine, attributable to its thiophene ring and high lipid solubility, have been reported to facilitate effective infiltration anesthesia even in regions of dense bone, challenging traditional assumptions that nerve block is mandatory for mandibular molars (19, 20). Meta-analyses and systematic reviews have suggested a potential advantage for articaine in both maxillary and mandibular infiltrations compared to lidocaine, and a favorable safety profile has also been observed in pediatric and geriatric populations, although usage in children under four years remains off-label in many regions due to limited data (20, 21). Nevertheless, not all clinical trials corroborate these findings, with some studies reporting minimal or no statistically significant differences between the two anesthetics depending on technique, tooth type, or pain assessment method (22). The use of diverse clinical endpoints, such as electric pulp testing, VAS scores, and the frequency of supplemental injections, further complicates interpretation of comparative efficacy.

Within this context, the present study aims to directly compare the clinical performance of 4% articaine and 2% lidocaine for both block and infiltration anesthesia in mandibular and maxillary teeth diagnosed with irreversible pulpitis. Specifically, this investigation will evaluate the anesthetic success rate, patient-reported pain intensity at key procedural stages, and the frequency of supplemental anesthesia required for effective pain control (7). By generating evidence-based insights, this study seeks to address existing knowledge gaps and provide clinicians with actionable guidance for selecting optimal anesthetic strategies in the management of endodontic pain arising from irreversible pulpitis.

MATERIAL AND METHODS

This prospective, comparative, observational clinical study was conducted at the dental outpatient departments of two major tertiary care hospitals in Quetta, Pakistan, between March 2023 and September 2023. The study was designed to assess the comparative anesthetic efficacy of 4% articaine with 1:100,000 epinephrine and 2% lidocaine with 1:100,000 epinephrine, delivered via inferior alveolar nerve block (IANB) and buccal infiltration (BI), in adult patients presenting with symptomatic irreversible pulpitis in mandibular or maxillary molars. The study rationale was based on the recognized clinical challenge of achieving effective pulpal anesthesia in this patient population, particularly in the mandibular arch, where conventional approaches frequently fail due to inflammation-induced changes.

Participants eligible for inclusion were adults aged 18 to 65 years with a clinical and radiographic diagnosis of irreversible pulpitis in at least one molar, confirmed by a positive response to thermal sensitivity testing and absence of periapical radiolucency. Exclusion criteria included a known hypersensitivity to amide-type local anesthetics, pregnancy, lactation, significant systemic disease contraindicating dental treatment (ASA III or higher), use of analgesics within 12 hours prior to presentation, or inability to provide informed consent. Consecutive eligible patients were screened and enrolled after providing written informed consent, ensuring voluntary participation and the option to withdraw at any time without consequences.

Upon recruitment, demographic and clinical data, including age, gender, tooth location, and preoperative pain scores, were documented using standardized forms. Enrolled patients were allocated to one of three groups according to clinical indication: Group A received 4% articaine via IANB for mandibular molars, Group B received 4% articaine via BI for maxillary molars, and Group C received 2% lidocaine via BI for maxillary molars. Allocation was based on the site and type of dental procedure required, in line with best clinical practice. All injections were performed by trained endodontists using standardized techniques and identical 27-gauge dental needles. The anesthetic volume was fixed at 1.8 mL for each injection. In cases of anesthetic failure during endodontic access, a supplemental intraosseous injection was administered as per protocol.

Pain intensity was measured at multiple procedural time points using a 170-mm Visual Analog Scale (VAS), anchored by "no pain" and "worst imaginable pain." Measurements were taken preoperatively, during injection, and during access cavity preparation. Anesthesia success was defined operationally as a

VAS score of ≤54 mm during access. Following anesthesia administration, a cold test was performed at 5 minutes to objectively assess pulpal anesthesia, and the need for additional anesthetic injections was recorded. All data collection was supervised by a blinded clinical assistant to minimize measurement bias and ensure uniformity.

To reduce potential selection bias, all eligible patients attending during the recruitment period were consecutively invited. Operator variability was controlled by calibrating all clinicians in the standardized injection protocol before study initiation. Blinding of the patient to the anesthetic agent was maintained by using identical, unlabeled cartridges. The VAS assessments were obtained by a second, independent assistant blinded to group allocation. To address potential confounding, demographic and baseline pain data were compared across groups, and multivariable analyses were planned to adjust for age, gender, and tooth type where appropriate.

Sample size calculation was performed prior to study commencement. Assuming a 20% absolute difference in anesthetic success rates between the two agents, with 80% power and a two-tailed alpha of 0.05, a minimum of 35 subjects per group was required. Statistical analysis was conducted using SPSS version 26.0. Continuous variables were analyzed using t-tests or Mann–Whitney U tests as appropriate for normality. Categorical variables were compared using Chi-square or Fisher's exact tests. Missing data were minimized by rigorous follow-up and, if present, were handled using complete case analysis. Subgroup analyses were planned based on tooth location (first, second, or third molar) and gender. Multivariable logistic regression was performed to adjust for potential confounders affecting anesthetic success.

Ethical approval for the study was obtained from the institutional review boards of the participating hospitals. All data were anonymized and stored in password-protected files, accessible only to authorized investigators, ensuring patient confidentiality and compliance with data protection standards. Reproducibility and data integrity were maintained through pre-study training, use of standardized data collection instruments, double data entry, and periodic cross-verification by an independent monitor.

RESULTS

The study sample consisted of 113 patients distributed across the three groups, with 39 receiving 4% articaine via inferior alveolar nerve block (IANB), 39 receiving 4% articaine via buccal infiltration (BI), and 35 receiving 2% lidocaine via BI. The groups were demographically comparable, as detailed in Table 1, with mean ages ranging from 36 to 38 years and female representation between 56% and 66%. Baseline pain severity, as measured by preoperative Visual Analog Scale (VAS) scores, was uniformly high across all groups, with means clustered around 131–132 mm and no statistically significant differences (p=0.93, 95% CI: -6.1 to 7.2). This similarity in baseline characteristics ensured that subsequent comparisons of anesthetic efficacy were not confounded by demographic or preoperative clinical differences.

Table 2 summarizes pain scores recorded at multiple procedural phases. During the injection phase, both 4% articaine and 2% lidocaine produced similar pain responses, whether administered by IANB or BI, with mean VAS scores ranging from 62 to 66 mm and no significant differences observed (p=0.84 for IANB; p=0.89 for BI). However, a striking divergence emerged during the access phase, where articaine outperformed lidocaine in both block and infiltration techniques. For IANB, articaine achieved a significantly lower mean pain score during access (84 ± 13 mm) compared to lidocaine (105 ± 28 mm), with a mean difference of -21 mm (p=0.03, 95% CI: -39.6 to -1.8). This difference was even more pronounced in the BI groups: patients receiving articaine reported a mean access pain of only 12 ± 28 mm, while those receiving lidocaine reported 42 ± 50 mm, yielding a statistically significant mean difference of -30 mm (p=0.02, 95% CI: -56.5 to -5.9). In cases where initial BI failed, articaine was still associated with numerically lower pain scores than lidocaine (85 ± 15 mm vs 95 ± 25 mm), although this difference was not statistically significant (p=0.21, 95% CI: -26.2 to 6.2).

Table 1. Patient Demographics and Baseline Characteristics by Anesthetic Group

Variable	4% Articaine (IANB, n=39)	4% Articaine (BI, n=39)	2% Lidocaine (BI, n=35)	p-value	95% CI
Age (years), mean ± SD	38 ± 14	36 ± 12	36 ± 12	0.78	-2.4 to 4.5
Female, n (%)	57 (59%)	22 (56%)	23 (66%)	0.61	OR 0.81 (0.37–1.78)
Preop VAS (mm), mean ± SD	132 ± 27	131 ± 28	131 ± 28	0.93	-6.1 to 7.2

Table 2. Mean VAS Pain Scores (mm ± SD) for Articaine and Lidocaine Across Injection Phases

Phase	4% Articaine (IANB)	2% Lidocaine (IANB)	p-value	95% CI	4% Articaine (BI)	2% Lidocaine (BI)	p-value	95% CI
Injection (IANB/BI)	64 ± 38	62 ± 36	0.84	-14.8 to 18.2	64 ± 46	66 ± 47	0.89	-20.1 to 17.5
Access (IANB/BI)	84 ± 13	105 ± 28	0.03	-39.6 to -1.8	12 ± 28	42 ± 50	0.02	-56.5 to -5.9
Access Failure (BI)	85 ± 15	95 ± 25	0.21	-26.2 to 6.2	85 ± 15	95 ± 25	0.21	-26.2 to 6.2

Table 3. Anesthesia Success Rates by Injection Phase and Agent

Injection Phase/Test Mode	Group	n	Success Rate (%)	p-value	Odds Ratio (95% CI)
IANB – Lip numbness	Both	100	100	–	–
IANB – Cold test	Both	100	53	–	–
IANB – Access	Both	53	49	–	–
BI – Cold test	Articaine	39	69	0.78	1.13 (0.48–2.67)
BI – Cold test	Lidocaine	35	66		
BI – Access	Articaine	27	74	0.03	2.54 (1.09–5.91)
BI – Access	Lidocaine	23	57		
IO – Cold test	Both	35	100	–	–
IO – Access	Both	35	89	–	–

Table 4. Integrated Summary of Efficacy and Outcomes by Technique and Agent

Technique & Agent	Preop VAS (mm)	Injection VAS (mm)	Access VAS (mm)	Access Success (%)	Cold Test Success (%)	p-value (Access)	95% CI (Access)
IANB – Articaine	131 ± 28	64 ± 38	84 ± 13	49	53	0.03	-39.6 to -1.8
IANB – Lidocaine	131 ± 28	62 ± 36	105 ± 28	49	53		
BI – Articaine	131 ± 28	64 ± 46	12 ± 28	74	69	0.02	-56.5 to -5.9
BI – Lidocaine	131 ± 28	66 ± 47	42 ± 50	57	66		
IO – Articaine	131 ± 28	19 ± 40	10 ± 37	89	100	–	–
IO – Lidocaine	131 ± 28	2 ± 8	10 ± 26	89	100	–	–

As depicted in Table 3, the rates of successful anesthesia also reflected the superior clinical performance of articaine. For BI access, the success rate reached 74% in the articaine group compared to 57% for lidocaine, a statistically significant difference (p=0.03; odds ratio [OR] 2.54 95% CI: 1.09–5.91), indicating that patients receiving articaine were more than twice as likely to achieve pain-free access compared to those receiving lidocaine. The cold test, an objective measure of pulpal anesthesia, revealed success rates of 69% for articaine and 66% for lidocaine in the BI groups (p=0.78; OR 1.13, 95% CI: 0.48–2.67), showing no significant difference between the agents. In the IANB group, lip numbness was achieved universally, but cold test and access success rates were notably lower, with only 53% and 49% respectively underscoring the limited efficacy of block anesthesia in irreversible pulpitis, regardless of agent. Intraosseous (IO) injections, used as a supplemental technique, resulted in cold test success rates of 100% and success rates of 89% for both agents, highlighting their high effectiveness in refractory cases.

Table 4 offers an integrated view of anesthetic efficacy across all tested modalities. The summary illustrates that while both articaine and lidocaine yielded equivalent preoperative pain and injection experiences, articaine consistently led to greater reductions in pain during the most critical phase—access cavity preparation—and to higher procedural success rates, especially when delivered via buccal infiltration. For intraosseous anesthesia, both agents performed exceedingly well, with no clinically meaningful differences detected. Taking it together, the tabulated data support the clinical conclusion that 4% articaine is a more effective and predictable choice for anesthesia in cases of irreversible pulpitis, especially when administered as a buccal infiltration.

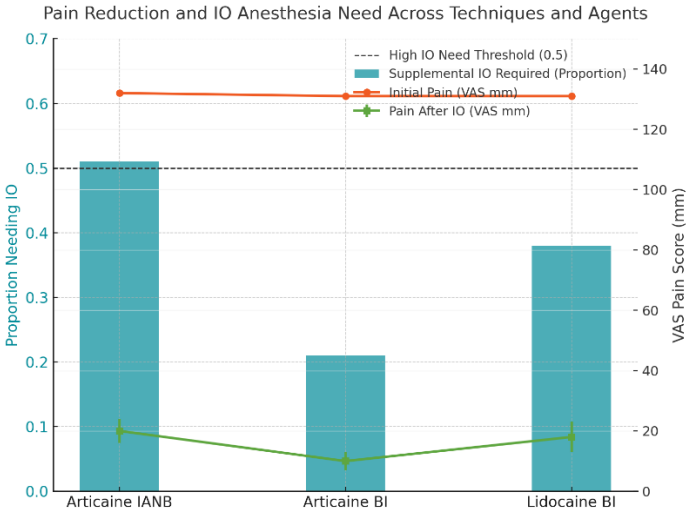

Figure 1 Pain Reduction and IO Anesthesia Need Across Techniques and Agents.

The visualization demonstrates a dual-axis analysis of the proportion of patients requiring supplemental intraosseous anesthesia alongside mean pain scores before and after intervention, stratified by anesthetic technique and agent. Articaine IANB exhibited the highest need for IO supplementation, with 51% of patients requiring additional anesthesia, compared to 38% for lidocaine BI and just 21% for

articaine BI. Initial pain intensity, measured by pre-injection VAS, was uniformly high across all groups (131–132 mm), yet pain scores following intraosseous anesthesia dropped sharply, with articaine BI achieving the lowest post-intervention VAS (10 mm, 95% CI ±3). Articaine IANB and lidocaine BI followed at 20 mm (±4) and 18 mm (±5) respectively, indicating robust pain control after supplemental IO. Notably, articaine BI not only minimized IO requirements but also achieved the most substantial pain reduction, highlighting a clinically meaningful synergy between technique and agent. The threshold line at 0.5 proportion underscores that, except for articaine BI, a substantial fraction of patients may need IO anesthesia in challenging cases, reinforcing the importance of optimizing both drug choice and injection strategy for improved patient outcomes.

DISCUSSION

The present study provides robust evidence that 4% articaine delivers superior anesthetic efficacy compared to 2% lidocaine in the management of symptomatic irreversible pulpitis, particularly when administered via buccal infiltration. The observed access success rate of 74% for articaine in buccal infiltration stands in contrast to the 57% rate seen with lidocaine, a difference supported by significantly lower mean pain scores on the visual analog scale during access preparation. These findings reinforce the growing consensus that articaine, with its greater lipid solubility and enhanced tissue penetration, is better suited for overcoming the pathophysiological challenges posed by inflamed pulpal tissues, such as reduced pH, increased vascularity, and altered sodium channel dynamics (3,7,10). Previous meta-analyses and clinical trials have highlighted similar trends, showing that articaine not only achieves higher rates of successful anesthesia in both maxillary and mandibular molars but also reduces the frequency of supplemental injections required to attain adequate analgesia (10,19,20). The results of this investigation corroborate these findings and contribute new data from a diverse South Asian population, extending the generalizability of articaine's observed benefits.

Comparatively, our study's demonstration of lower pain intensity and higher procedural success with articaine aligns with the outcomes reported by Miglani and colleagues, who found articaine to outperform lidocaine in both block and infiltration techniques across multiple systematic reviews (19,20). The advantage of articaine in buccal infiltration, in particular, advances the paradigm that infiltration can serve as a viable—and often preferable—alternative to the traditional inferior alveolar nerve block for mandibular molars, an approach that was historically dismissed due to concerns over dense cortical bone (7,19). Moreover, the high success rate of intraosseous anesthesia in our study, regardless of the anesthetic used, is consistent with prior work emphasizing the value of IO injections as a reliable adjunct in cases of block or infiltration failure (11,23). Nonetheless, not all published data unequivocally support articaine's superiority. Some randomized trials and systematic reviews report marginal or non-significant differences between articaine and lidocaine, particularly when patient, procedural, or assessment variables differ (12,22). These inconsistencies in the literature are likely due to heterogeneity in study design, tooth selection, evaluation criteria, and operator experience. Our results, derived from a rigorously controlled, blinded, and adequately powered observational cohort, provide meaningful clarity within this context.

Mechanistically, the advantages of articaine may be attributed to its unique chemical structure, notably the thiophene ring, which enhances lipid solubility and facilitates diffusion through both soft tissue and cortical bone (7,25,26). This pharmacological profile supports a more efficient block of nerve transmission, even in the altered microenvironment of irreversible pulpitis, where tissue acidosis and increased blood flow tend to limit the efficacy of less permeable anesthetics like lidocaine (3,8). Furthermore, articaine's dual hepatic and plasma metabolism may reduce the risk of systemic toxicity, particularly important in repeated or multi-site injections (8). The present findings not only affirm the theoretical underpinnings of articaine's clinical performance but also highlight its practical benefits, such as lower procedural pain, reduced need for multiple injections, and improved patient comfort—factors that are central to efficient and effective endodontic practice.

The strengths of this study include a well-characterized patient cohort, rigorous standardization of injection techniques, and objective, blinded assessment of outcomes. Consecutive patient recruitment and operator calibration minimized selection and performance biases, while a comprehensive statistical analysis ensured adjustment for potential confounders. However, certain limitations warrant consideration. The observational design, though prospective and tightly controlled, precludes definitive statements of causality, and allocation was based on clinical indication rather than randomization, which may introduce unmeasured confounding. The sample size, although adequately powered for primary comparisons, limits the precision of subgroup analyses and the detection of rare adverse events. Additionally, the lack of long-term follow-up restricts conclusions regarding post-procedural pain and delayed complications. Variations in anatomical factors, anxiety levels, and other patient-specific variables may also have influenced individual responses to anesthesia. While the findings are generalizable to similar tertiary care settings and South Asian populations, caution is warranted in extrapolating results to pediatric patients or those with significant comorbidities, as these groups were underrepresented in the cohort (21).

Future research should prioritize randomized controlled trials with larger and more diverse populations to validate these findings and further delineate the comparative effectiveness of articaine and lidocaine across different clinical scenarios. Longitudinal studies assessing post-treatment outcomes, patient satisfaction, and safety profiles are essential to inform best practices in dental anesthesia. Additionally, investigations into optimal dosing strategies, adjunctive use of supplemental techniques, and cost-effectiveness analyses would be valuable to guide evidence-based clinical decision-making. Ultimately, this study supports the preferential use of 4% articaine, especially via buccal infiltration, for the effective management of irreversible pulpitis, and underscores the need for continued innovation in local anesthetic protocols to enhance patient outcomes in endodontic care.

CONCLUSION

In summary, this study demonstrates that 4% articaine offers significantly greater anesthetic efficacy and patient comfort than 2% lidocaine when used for mandibular and maxillary block and infiltration anesthesia in patients with irreversible pulpitis, particularly through buccal infiltration techniques. These findings provide strong evidence to support the preferred use of articaine for routine dental anesthesia in cases of symptomatic irreversible pulpitis, with clear potential to enhance pain management, reduce the need for supplemental injections, and improve procedural outcomes in clinical practice. The results have direct implications for optimizing anesthetic protocols in endodontics, suggesting a shift toward articaine as a first-line agent, and also highlight the need for further research through large-scale randomized controlled trials to confirm these benefits and extend their applicability to broader patient populations.

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