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Received: 13 June 2023 | Revised: 12 January 2024 | Accepted: 13 February 2024

DOI: 10.1111/ipd.13169

INTERNATIONAL JOURNAL OF PAEDIATRIC DENTISTRY WILEY

ORIGINAL ARTICLE

Overcoming local anesthesia failure during routine dental treatments in children

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Abstract

Background: Local anesthesia (LA) during routine dental treatment in children fails in 5%–35% of first attempts. No data, however, are available on the success rates of subsequent attempts.

Aim: To evaluate the effectiveness of primary, secondary, and tertiary LA attempts (P-LA, S-LA, and T-LA, respectively) for anesthetizing molars during routine dental treatments in children.

Design: We retrospectively analyzed dental records of all children (2–18 years) who had been administered LA for the treatment of primary or permanent molars by a single paediatric dentist, between 2011 and 2022. All LAs were delivered using a computer-controlled local anesthetic delivery (CCLAD) system.

Results: The failure rate of P-LA in 1312 molars was 13% and correlated with age ($p < .001$), type of tooth ($p < .001$), type of treatment ($p < .001$), and treated arch ($p < .001$). The effectiveness of S-LA for buccal infiltration, intrasulcular, inferior alveolar nerve block, greater palatine nerve block (GPNB), posterior superior alveolar nerve block (PSANB), or a combination of the last two was 50%, 87.2%, 66.7%, 63.6%, 33.3%, and 100%, respectively, and was not significantly associated with age or the type of tooth, treatment, or P-LA.

Conclusion: The optimal choice of S-LA for anesthetizing maxillary molars was a combination of PSANB and GPNB, whereas for mandibular molars, it was IS-CCLAD system.

KEYWORDS

extraction, infiltration, intrasulcular, nerve block, pain, restoration

1 | INTRODUCTION

Dental treatment-associated pain resulting from the failure to achieve complete anesthesia is a major cause of both behavior management problems and future dental anxiety, especially when the treatment is continued irrespective of the child expressing indications of experiencing pain.[1] The prevalence of ineffective anesthesia in children after receiving primary local anesthesia (LA; P-LA) varies from 5% to 35%.[2–6] The prevalence can increase up to 67% during invasive treatments, such as restoration by stainless steel crowns (SSCs), pulpal treatments, or extractions.[7,8] No data are available regarding the effectiveness of subsequent LA attempts in children receiving routine dental treatments.

Several factors may affect the effectiveness of P-LAs in routine dental treatment in children. These include the following: (I). **The arch treated:** The success of infiltration is higher in the upper arch than in the lower arch due to less dense bone in the maxilla and easier accessibility.[9] (II).

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The type of treated tooth: LA exhibits lower effectiveness in the primary mandibular second molar following buccal infiltration and intrasulcular computer-controlled local anesthetic delivery (IS-CCLAD) system than its effectiveness in primary first molars, mainly when performing invasive procedures such as pulpotomy, SSC, and extraction.[5,7,8,10] Additionally, IS-CCLAD system shows lower effectiveness in permanent mandibular molars than in primary mandibular molars.[11] (III). **Patient's age, type of injection technique, and operative procedure performed:** The effectiveness of buccal infiltration in primary mandibular molars drops dramatically after the age of 10 years, especially following invasive procedures.[12] Several studies have reported the reduced effectiveness of anesthesia when performing invasive procedures such as SSC, or extraction in primary molars.[2,7,8] The effectiveness of inferior alveolar nerve block (IANB) is higher than that of buccal infiltration regardless of age[10,13] or the type of treatment.[14]

Maljaei et al. found no significant differences between articaine buccal infiltration and lidocaine posterior superior alveolar nerve block (PSANB) in primary maxillary second molars that required vital pulp therapy in children aged 6–9 years.[15]

In this study, our null hypothesis is that the success rate of additional LA attempts would be influenced by the type of injection, the patient's age, and the type of dental procedure. Therefore, this historical cohort study aimed to evaluate various factors associated with the effectiveness of P-LA, secondary LA (S-LA), and tertiary LA (T-LA) in children for routine dental treatment and to evaluate the most effective approaches to overcome the failure of P-LA.

Why this paper is important to paediatric dentists

- The primary anesthesia is highly successful (overall 87% success rate).
- This study provides dentists with tools to manage the failure of LA in mandibular and maxillary molars.
- The optimal choice of S-LA for anesthetizing maxillary molars was a combination of PSANB and GPNB, whereas for mandibular molars, it was IS-CCLAD system.

2 | MATERIALS AND METHODS

This study was performed in accordance with the STROBE guidelines.

2.1 | Study population

We retrospectively analyzed the dental records of children aged 2–18 years who had undergone regular dental treatment in private practices during 2011–2022 or at the paediatric dentistry clinic at the Sheba Medical Center, Israel in 2021 and had been administered LA for routine dental treatment by a single, certified paediatric dentist (MA). The institutional review board of the Sheba Medical Center, Israel approved this study (9764-22-SMC). We excluded the records of uncooperative children who had cried or complained before and/or during all treatments, regardless of the procedure. The records of the included patients were analyzed for several factors that might have affected the effectiveness of P-LA, S-LA, and T-LA. To avoid biases, each child was included only once per group. A structured form was designed to collect demographic and dental variables, which included the patient's age; sex; mode of behavioral management used (behavior modification only, inhalation of N_2O, or sedation); tooth location; and dental treatment procedures (restoration, SSC, pulpotomy, or extraction). For analysis, the children were categorized into groups according to the type of treated tooth, treatment mode, and to their age, as follows: Group 1, 2–5 years; Group 2, 6–12 years; and Group 3, 12–18 years.

2.2 | Mode of treatment

The children's cooperation was achieved by the following three approaches: (i) behavior modification (BM), (nonpharmacological) techniques only, such as desensitization, empathy, giving control by raising the left hand, retraining, behavior shaping, reframing, distraction, and tell–show–do; (ii) inhalation of N_2O/oxygen (up to 50% N_2O) in combination with BM; and (iii) sedation (per-rectal or per-oral midazolam, 0.4 mg/kg, up to a maximal dose of 12 mg) combined with N_2O inhalation and BM. The last approach was mainly used in young children.

2.3 | Types of local anesthesia used

All types of local anesthetics were delivered using a CCLAD system (STA; Milestone Scientific, Inc., Deerfield, IL, USA); therefore, the reported injected amount of local anesthetic is higher by approximately 20% than the actual volume that the patient received. The partial volumes of the injected cartridges were determined based on the scale of the STA device. Buccal infiltration, IANB, lingual nerve, and buccal nerve blocks were all started with

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an injected velocity of the STA and proceeded in regular mode. The default anesthesia of primary and permanent maxillary molars was buccal infiltration (mepivacaine 3%, one cartridge divided between the treated tooth and the adjacent tooth for the application of the rubber dam clamp) with the addition of intrasulcular (IS)-CCLAD system (0.2–0.4 cartridges of lidocaine 2% 1:100000 adrenaline) to anesthetize the palatal mucosa of the treated teeth. Children who complained regarding the sensation of the initial anesthesia were anesthetized in all subsequent treatments using only IS-CCLAD.[7] The default anesthesia for primary mandibular molars was IS-CCLAD system (approximately 1–1.2 cartridges of lidocaine 2% 1:100000 adrenaline was equally distributed among two adjacent primary molars) as previously described.[7] Children who needed treatment in their primary and permanent mandibular molars were routinely anesthetized by IANB (1.4 cartridges of mepivacaine 3% divided into the inferior alveolar, lingual, and long buccal nerves). Each injection was preceded by an application of topical gel (benzocaine 20% for 50 s). Mepivacaine or lidocaine was replaced with articaine in the S-LA and T-LA groups. When unsuccessful anesthesia was identified in conjunction with pulp exposure, intra-pulpal anesthesia was administered by slowly rinsing the pulp exposure points using 1–2 cartridges of lidocaine. The amount of all types of LAs used did not exceed a dose of 6.6 mg/kg body weight. A tooth clamp and rubber dam were applied immediately after LA delivery and preoperatively.

2.4 | Evaluating the effectiveness of anesthesia

The dentist assessed the effectiveness of anesthesia in the presence or absence (noncontiguous) of pain-disruptive behavior during treatment, as previously described.[7,13] Briefly, each sign of discomfort (even mild) was rated as a positive presence of pain. Signs of discomfort included visual or acoustic changes such as tensed or moving hands or body, eye movements, verbal complaints, or tears. Anesthesia was rated as adequate only when the child was completely relaxed during treatment.

2.5 | Statistical analysis

Pearson's chi-squared test was used to evaluate the possible associations between effectiveness, sex, age, mode of behavioral management, dental procedure performed, and effectiveness of anesthesia. Additionally, the odds ratios (OR) were calculated, and Cramer's V values were assessed to determine the strength of the correlation.

3 | RESULTS

The effectiveness of LA delivered to 1312 molars in 679 children (aged 7.68 ± 10.03, range: 2–18 years, 51.5% boys) was analyzed. The dental treatments included 903 restorations, 237 SSCs, 53 pulp treatments, and 119 extractions. Of these, 150 of 1312 (11.43% of all P-LA) teeth required S-LA, and 13 of 150 (8.67% of the S-LA) or 13 of 1312 (0.991% of P-LA) required T-LA.

3.1 | Effect of age on the effectiveness of LA

The effectiveness of P-LA negatively correlated with the age at the treatment of the primary mandibular first molar ($p = .02$), the permanent mandibular first molar ($p = .033$), and the primary maxillary second molar ($p = .034$). The mean age for effective anesthesia was 7.5 years, and for ineffective anesthesia, it was 9 years ($p < .001$). The mean age of patients receiving treatment for the permanent first molars was significantly higher than that of those receiving treatment for primary first and second molars ($p < .001$ and $p < .001$, respectively). Differences in age during treatment were statistically significant ($p < .001$; $Eta^2 = 0.246$, very large effect). The distribution of patients' ages at the time of treatment according to the treated tooth, type of treatment, and mode of behavioral management is shown in Tables 1–3.

3.2 | Effect of the injected volume of LA

The mean total volumes of LA delivered to anesthetize the primary first and second molars and the permanent first molars were 1.18, 1.19, and 1.37 cartridges, respectively. Differences were considered statistically significant ($p < .001$); they had, however, a very small effect ($Eta^2 = 0.04$). Similarly, the volumes injected into the infiltration, IS-CCLAD system, and IANB groups (per treatment) were 1.25, 1.1, and 1.44, respectively, ($p < .001$); the magnitude of this difference, however, was small ($Eta^2 = 0.1$).

3.3 | Effect of different types of LA delivery on the effectiveness of P-LA

Infiltration, IS-CCLAD system, and IANB induced mean effectiveness of 86.5%, 89.7%, and 81%, in primary and permanent mandibular molars, respectively, when delivered as P-LA ($p = .007$, Cramer = 0.08). This indicates a small difference. Intrasulcular computer-controlled local anesthetic delivery system as a P-LA was significantly more effective

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TABLE 1 Effect of the type of treated tooth in different age groups on the effectiveness of local anesthesia.

	Age group (years)	Total ineffective anesthesia	Total effective anesthesia	Total ineffective anesthesia	Total effective anesthesia	The mean age of the treated child	Range age	*p*-value	Size magnitude of the effect: >0.15 = big 0/1–0.15 = medium >0/1 = small
Permanent maxillary first molars	2–5	0 (0%)	0 (0%)	38 (34.9%)	71 (65.1%)	10.54 ± 3.1	6–18	.81	0.04
	6–12	29 (33.7%)	57 (66.3%)						
	13–18	9 (39.1%)	14 (60.9%)						
Primary maxillary second molars	2–5	8 (9.3%)	78 (90.7%)	30 (11%)	243 (89%)	6.8 ± 2.2	2.8–15	.034	0.17
	6–12	19 (10.6%)	161 (89.4%)						
	13–18	3 (42.9%)	4 (57.1%)						
Primary maxillary first molars	2–5	3 (4.5%)	63 (95.5%)	13 (5.8%)	211 (94.2%)	7 ± 2.2	2.10–13.11	.79	0.05
	6–12	10 (6.5%)	145 (93.5%)						
	13–18	0 (0%)	3 (100%)						
Permanent mandibular first molars	2–5	0 (0%)	3 (100%)	29 (20.1%)	115 (79.9%)	11 ± 3.6	5.3–18	.033	0.21
	6–12	15 (15.2%)	84 (84.8%)						
	13–18	14 (33.3%)	28 (66.7%)						
Primary mandibular second molars	2–5	21 (16.4%)	107 (83.6%)	43 (14.2%)	259 (85.8%)	7 ± 2.8	2.9–15	.73	0.05
	6–12	21 (12.7%)	145 (87.3%)						
	13–18	1 (12.5%)	7 (87.5%)						
Primary mandibular first molars	2–5	10 (9.3%)	98 (90.7%)	20 (7.7%)	240 (92.3%)	7.31 ± 2.4	2.9–15	.02	0.21
	6–12	8 (5.4%)	140 (94.6%)						
	13–18	2 (50%)	2 (50%)						

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TABLE 2 Effect of the type of treatment in different age groups on the effectiveness of local anesthesia.

Age group (years)	Type of treatment	Total ineffective anesthesia	Total effective anesthesia	Total number of teeth	*p*-value	Size magnitude of the effect >0.15 = big 0/1–0.15 = medium >0/1 = small
2–5	Restoration	17 (6.7%)	238 (93.3%)	255	$p < .001$	0.22
	SSC^{+}	15 (15%)	85 (85%)	100		
	Pulpotomy +SSC	8 (30.8%)	19 (69.2%)	26		
	Extraction	2 (20%)	8 (80%)	10		
Total		42 (10.7%)	349 (89.3%)	391		
6–12	Restoration	59 (10.1%)	523 (89.9%)	582	$p = .002$	0.14
	SSC	20 (14.8%)	115 (85.2%)	135		
	Pulpotomy +SSC	8 (34.8%)	15 (65.2%)	23		
	Extraction	15 (16%)	79 (84%)	94		
Total		102 (12.2%)	732 (87.8%)	834		
13–18	Restoration	21 (31.8%)	45 (68.2%)	66	$p = .026$	0.33
	SSC	0 (0%)	2 (100%)	2		
	Pulpotomy +SSC	4 (100%)	0 (0%)	4		
	Extraction	4 (26.7%)	11 (73.3%)	15		
Total		29 (3.3%)	58 (66.7%)	87		

Note: + Preformed stainless steel crown.

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TABLE 3 Effect of the age and management approach on the effectiveness of local anesthesia.

	Variables	Age group (years)	Total ineffective anesthesia	Total effective anesthesia	*p*-value	Size magnitude of the effect: >0.15 = big 0/1–0.15 = medium >0/1 = small
Methods of behavior management	BM[a]	2–5	0 (0%)	1 (100%)	$p = .001$	0.27
		6–12	11 (10.3%)	96 (89.7%)		
		13–18	20 (31.7%)	43 (68.3%)		
	Total		31 (18.1%)	140 (81.9%)		
	N_2O	2–5	20 (11.6%)	153 (88.4%)	$p = .02$	0.1
		6–12	78 (12.9%)	529 (87.1%)		
		13–18	7 (33.3%)	14 (66.7%)		
	Total		105 (13.1%)	696 (86.9%)		
	Sedation	2–5	22 (10.1%)	195 (89.9%)	$p = .043$	0.17
		6–12	13 (10.8%)	107 (89.2%)		
		13–18	2 (66.7%)	1 (33.3%)		
	Total		37 (10.9%)	303 (89.1%)		
Total			173 (13.2%)	1139 (86.8%)		

[a]Behavior management only.

TABLE 4 Distribution of the effectiveness of primary, secondary, and tertiary anesthesia in relation to the types of treated teeth in the **mandibular** arch.

Type of local anesthesia	Mode of injection	Type of treated tooth	Number of treated teeth	Effectiveness (%)	
Primary local anesthesia **(*n* = 706)**	IANB	Primary first molar	36	33/36	92%
		Primary second molar	44	34/44	77%
		Permanent first molar	129	102/129	79%
		Total number	**209**	169/209	81%
	IS-CCLAD	Primary first molar	224	207/224	92%
		Primary second molar	258	225/258	87%
		Permanent first molar	15	13/15	87%
		Total number	**497**	445/497	90%
Secondary local anesthesia **(*n* = 79)**	IS-CCLAD	Primary first molar	13	12/13	92%
		Primary second molar	32	25/32	78%
		Permanent first molar	24	22/24	92%
		Total number	**69**	59/69	86%
	IANB	Primary first molar	1	1/1	100%
		Primary second molar	3	2/3	64%
		Permanent first molar	2	1/2	50%
		Total number	**6**	4/6	67%
	Intra-pulpal	Primary second molar	2	2/2	100%
		Permanent first molar	2	2/2	100%
		Total number	**4**	4/4	100%
Tertiary local anesthesia **(*n* = 4)**	IS-CCLAD	Primary second molar	2	2/2	100%
		Permanent first molar	1	1/1	100%
		Total number	**3**	3/3	100%
	Intra-pulpal	Primary second molar	1	1/1	100%

Abbreviations: IANB, inferior alveolar nerve block; IS-CCLAD, intrasulcular computer-controlled local anesthetic delivery system.

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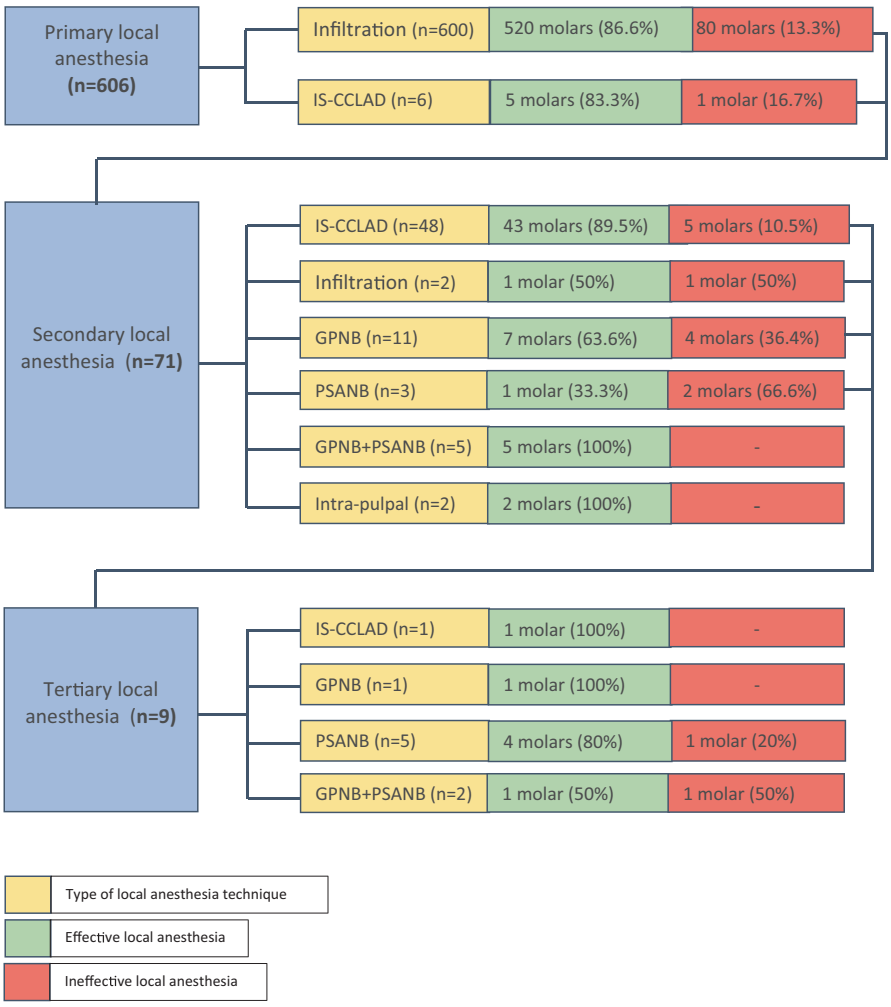


FIGURE 1 Flowchart presenting the distribution of types of primary, secondary, and tertiary local anesthesia delivered in the **maxilla.**

than IANB (OR = 2.06, 95% confidence interval [CI]: 1.31–3.24; $p < .05$). Inferior alveolar nerve block induced approximately 50% less effectiveness in mandibular molars than IS-CCLAD system (OR = 0.484, 95% CI: 0.31, 0.76; $p = .001$). The different modes of LA delivery and their effects on successfully achieving LA during P-LA, S-LA, or T-LA are shown in Tables 4 and 5, and Figures 1 and 2.

3.4 | Effect of the type of treated tooth on the effectiveness of P-LA

The distributions of teeth receiving P-LAs, S-LAs, or T-LAs are presented in Tables 4 and 5. The statistically significant differences between the treated teeth following P-LA are summarized in Tables 1 and 6. The effectiveness of anesthesia in the primary first and second molars and in the permanent first molars was 93.2%, 87.3%, and 73.5%, respectively. These differences were statistically significant, with a moderate degree of association ($p < .001$, Cramer = 0.2).

The effectiveness of P-LA in the permanent mandibular first molar was 2.12-fold higher than that associated with the permanent maxillary first molar (95% CI: 1.2–3.75; $p = .01$). In contrast, the effectiveness of P-LA did not differ between the maxillary and mandibular first and second primary molars (94.2% vs. 92.3%; $p = .47$) or between the maxillary and mandibular primary second molars (89% vs. 85.8%; $p = .26$).

In the **maxillary** molars, the effectiveness of P-LAs in the primary first and second molars and the permanent first molars was 94.2%, 89%, and 65.1%, respectively ($p < .001$; Cramer = 0.3). The effectiveness in the primary second molar was slightly lower than that of the primary first molar (OR = 0.5, 95% CI: 0.25–0.98, $p = .03$), whereas the effectiveness of P-LA in the primary maxillary first and second molars was significantly (fivefold and threefold) higher than that of the maxillary permanent first molars (OR = 5.65, 95% CI: 3.4–9.34, $p < .001$; and OR = 3.24, 95% CI: 2.3–4.56, $p < .001$, respectively; Figure 1).

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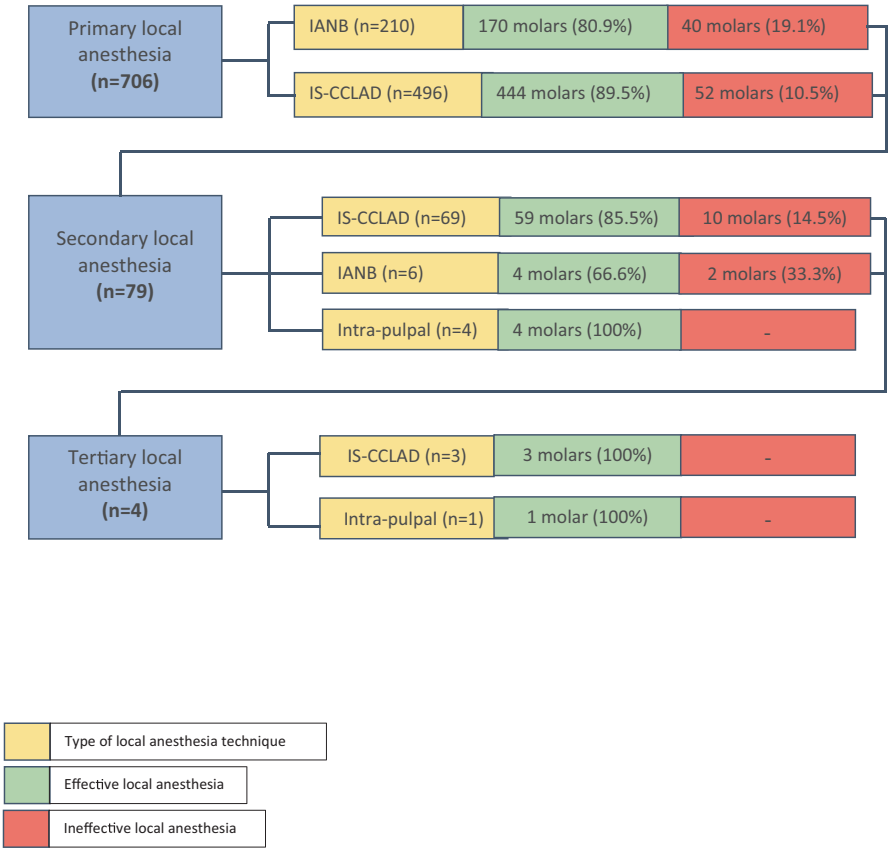


FIGURE 2 Flowchart describing the distribution of the types of primary, secondary, and tertiary local anesthesia delivered in the **mandible.**

In **mandibular** molars, the effectiveness in the primary first and second molars and the permanent mandibular first molars was 92.3%, 85.8%, and 79.9%, respectively ($p < .001$ Cramer = 0.137). The effectiveness of anesthesia in the primary second molar was slightly lower than that in the primary first molar (OR = 0.5, 95% CI: 0.29–0.88, $p = .015$), whereas that in the primary molars was significantly (threefold) higher than that in the permanent first molar (OR = 3.24, 95% CI: 2.3–4.56, $p < .001$). The effectiveness of IANB was 50% less than that of IS-CCLAD system (OR = 0.484, 95% CI: 0.31–0.76, $p = .001$). Nevertheless, in each tooth group, the differences in the effectiveness of P-LA between IANB and IS-CCLAD system were not significant (permanent first molar: OR = 0.58, p = not significant [NS]; primary second molar: OR = 0.5, p = NS; and primary first molar: OR = 0.86, p = NS; Figure 2).

3.5 | Effect of type of treatment on the effectiveness of P-LA

The effectiveness of P-LA when performing restoration, SSC, pulp treatment, and extraction was 89.3%, 85.2%, 62.3%, and 82.4%, respectively. $p < .001$ and Cramer = 0.16 indicated a moderate difference. The distribution of the types of treatment and their effectiveness in relation to age is shown in Table 2.

3.6 | Effect of sex, arch treated, and mode of management on the effectiveness of LA

No significant relationship was found between sex and the effectiveness of P-LA (girls: OR = 0.83, $p = .24$). Similarly, no relationship was found between the treated arch and the effectiveness of anesthesia. The total effectiveness of P-LA in children managed with BM, N_2O, and SED was 81.9%, 86.9%, and 89.1%, respectively ($p = .073$, Cramer = 0.06).

3.7 | Factors affecting the effectiveness of S-LA

The effectiveness of S-LA with infiltration, IS-CCLAD system, IANB, GPNB, PSANB, a combination of GPNB and PSANB, and intra-pulpal anesthesia was 50%, 87.2%, 66.7%, 63.6%, 33.3%, 100%, and 100%, respectively (Tables 4 and 5). A strong correlation was observed between the type of S-LA administered and its efficacy ($p = .02$, Cramer = 0.32),

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TABLE 5 Distribution of the effectiveness of primary, secondary, and tertiary anesthesia in relation to the types of treated teeth in the **maxillary** arch.

Type of local anesthesia	Mode of injection	Type of treated tooth	Number of treated teeth	Effectiveness (%)	
Primary local anesthesia (***n*** **= 606)**	Infiltration	Primary first molar	220	207/220	94%
		Primary second molar	271	242/271	89%
		Permanent first molar	109	71/109	65%
		Total number	**600**	520/600	87%
	IS-CCLAD	Primary first molar	4	4/4	100%
		Primary second molar	2	1/2	50%
		Total number	**6**	5/6	83%
Secondary local anesthesia (***n*** **= 71)**	IS-CCLAD	Primary first molar	8	8/8	100%
		Primary second molar	20	19/20	95%
		Permanent first molar	20	16/20	80%
		Total number	**48**	43/48	90%
	Infiltration	Primary first molar	2	1/2	50%
	GPNB	Primary first molar	1	1/1	100%
		Primary second molar	1	1/1	100%
		Permanent first molar	9	5/9	56%
		Total number	**11**	8/11	73%
	PSANB	Primary second molar	1	0/1	0%
		Permanent first molar	2	1/2	50%
		Total number	**3**	1/3	33%
	GPNB+PSANB	Primary second molar	1	1/1	100%
		Permanent first molar	4	4/4	100%
		Total number	**5**	5/5	100%
	Intra-pulpal	Primary second molar	1	1/1	100%
		Permanent first molar	1	1/1	100%
		Total number	**2**	2/2	100%
Tertiary local anesthesia (***n*** **= 9)**	IS-CCLAD	Primary second molar	1	1/1	100%
	GPNB	Permanent first molar	1	1/1	100%
	PSANB	Permanent first molar	5	4/5	75%
	GPNB+PSANB	Permanent first molar	2	1/2	50%

Abbreviations: GPNB, greater palatine nerve block; IS-CCLAD, intrasulcular computer-controlled local anesthetic delivery system; PSANB, posterior superior alveolar nerve block.

indicating a significant difference. No correlation was observed between the P-LA and S-LA injection modes (p = NS).

In contrast to P-LA, the effectiveness of S-LA was not correlated with patient's age ($p = .37$). The mean age for the successful effectiveness of S-LA was 9.4, and failure of S-LA was 8.6 years. Similarly, the effectiveness of S-LA was not correlated with the type of molars (primary first or second molars or permanent molars, $p = .46$); type of treatment (effectiveness of S-LA when performing restoration, SSC, pulp therapy, and extraction was 87.5%, 66.7%, 87.5%, and 93.8%, respectively, $p = .08$); or the treated arch.

In mandibular molars, IS-CCLAD system as an S-LA was 3.4 times more effective than IANB. This difference, however, was not statistically significant ($p = .20$).

3.8 | Effectiveness of T-LA

Similar to the effectiveness of the S-LA, no relationship was found between the effectiveness of the T-LA and type of P-LA, age, type of tooth, type of treatment, or arch treatment.

4 | DISCUSSION

This study aimed to evaluate the most effective approaches for overcoming P-LA failure in children during routine dental treatment. We found that following IANB to anesthetize mandibular molars, the most effective mode of S-LA was the addition of IS-CCLAD system, followed by infiltration into the upper molars and a combination of

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TABLE 6 Summary of statistically significant differences between treated teeth following primary local anesthesia.

Percent effectiveness in different treated teeth					OR (95% CI)	*p*-value
Permanent mandibular first molars	(79.9%)	vs.	Permanent maxillary first molars	(65.1%)	2.12 (1.21–3.75)	$p = .01$
Permanent maxillary first molars	(65.1%)	vs.	Primary maxillary first and second molars	(91.6%)	5.65 (3.4–9.34)	$p < .001$
Permanent mandibular first molars	(79.9%)	vs.	Primary mandibular first and second molars	(89.0%)	3.24 (2.3–4.56)	$p < .001$
Primary maxillary first molars	(94.2%)	vs.	Primary maxillary second molars	(89.0%)	0.5 (0.25–0.98)	$p = .03$
Primary mandibular first molars	(92.3%)	vs.	Primary mandibular second molars	(85.8%)	0.5 (0.29–0.88)	$p = .015$
Primary maxillary first molars	(94.2%)	vs.	Primary mandibular first molars	(92.3%)	–	$p = $ NS
Primary maxillary second molars	(89.0%)	vs.	Primary mandibular second molars	(85.8%)	–	$p = $ NS

Abbreviations: CI, confidence interval; NS, not significant; OR, odds ratio.

PSANB and GPNB. Interestingly, two upper molars could not be anesthetized following three attempts, even though PSANB and GPNB were delivered in different attempts, probably as a result of tachyphylaxis.[16] These molars were effectively anesthetized at the next appointment when buccal infiltration, PSANB, and GPNB were delivered simultaneously as P-LA. These findings are important to discontinue treatment when anesthesia is ineffective and to prevent future dental trauma in children.

Previously, the effectiveness of S-LA was studied only in adults with acute pulpitis.[17–20] To our knowledge, this is the first cohort study to evaluate the effectiveness of S-LA and T-LA in children undergoing routine dental treatment. The failure rate of 13% in P-LA in shown in the present study, which was in accordance with Nakai et al. who found 11.6% failure in a clinical setting.[2] The slightly higher rate of failure in our study might have resulted because we also included older children up to the age of 18 years, whereas Nakai et al. included children only up to the age of 13 years. In this study, we identified several factors associated with the effectiveness of the P-LA. These included age, arch, type of tooth, and type of treatment. In contrast, the patient's sex and behavioral management approach did not affect the effectiveness of the P-LA. These results correspond with those of previous studies.[2,3,5,7–10,13,14] Interestingly, in the present study, the effectiveness of P-LA was higher when performing primary molar extraction than that associated with pulp treatment. This may be attributed to the fact that when anesthetizing a tooth for extraction, the operator switched the mode of delivery from the STA to the regular mode to verify complete anesthesia.

In the present study, the failure rate of P-LA in the permanent maxillary molars was 34.9%, which is significantly higher than that in the first and second primary molars (5.8% and 11%, respectively). This is a novel finding of this study. This high failure rate may be attributed to the anatomy of the maxilla at the age of the treated patients, the anatomy of the upper molars, and the presence of developmental disturbances in the treated teeth.[9] In younger ages, the roots of the molar are located deep under the zygomatic process, resulting in a thick bone overlying the maxillary molar, thus delaying the diffusion of the LA agents to the apexes of the treated teeth.[9] Additionally, as the maxillary molars have three roots, infiltration through the two buccal roots may delay infiltration into the flared palatal root.

Gazal et al. found that teeth with multiple roots showed slower pulp anesthesia than that exhibited by single-rooted teeth. Accordingly, they recommended the administration of an extra local anesthetic to these teeth or an intraseptal injection. Nevertheless, in children, interseptal anesthesia may damage the underlying developing tooth buds of the corresponding permanent teeth.[21] In the present study, the palatal mucosa of the upper molars was routinely anesthetized using IS-CCLAD system injected into the palatal gingival sulcus, although the injected volume was about third the volume administered for buccal infiltration. Another factor that could have contributed to the high failure rate in the present study was the presence of molar incisor hypomineralization (MIH) among the treated teeth, which are more difficult to anesthetize.[22] In our country, the prevalence of MIH is approximately 17.1% and 18% in Jewish and Arab children, respectively.[23] In adults, as these teeth are already treated at younger ages, they do not affect the failure rate of P-LA. Information regarding the presence and severity of MIH, however, was not collected regularly in the present

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study; therefore, the contribution of MIH to the failure of anesthesia could not be evaluated. The failure rate in this study was significantly higher than that reported by Stiagailo (in Russian and was cited by Malamed)[9] who reported a failure rate of 16.5% in the first attempt to anesthetize permanent maxillary molars with pulpitis. Our higher failure rate in routine dental treatments could have been attributed to the fact that the effectiveness of anesthesia was documented in real time, in younger patients, whereas Stiagailo evaluated it retrospectively in adults by questionnaires to several dentists.

To overcome the failure of LA in upper molars, Malamed suggested adding PSANB.[9] Conversely, Broering et al.[24] reported similar (95%–100%) effectiveness of anesthesia with GPNB and PSANB in permanent maxillary posterior teeth. In the present study, GPNB was more effective as S-LA than the effectiveness of PSANB (63.6% vs. 33.3%, respectively). The lower effectiveness of PSANB compared with that of GPNB in the present study might have been attributed to the fact that we used these modes to overcome the failure of P-LA, whereas Broering et al. used a pulp tester to evaluate the effectiveness of anesthesia in healthy permanent molars.

Several other approaches have been suggested by Malamed to overcome the failure of LA in permanent maxillary molars. These include the use of a buffered LA solution or articaine, which diffuses more reliably through soft and hard tissues and into nerves, and adding PSANB.[10] In the present study, infiltrations during P-LA and S-LA were delivered using mepivacaine and articaine, respectively. Only the combination of PSANB and GPNB, however, resulted in 100% effective anesthesia.

The rate of 79.9% effectiveness of IANB to anesthetize the permanent first molar is similar to that reported by others (63%–87%),[9,13,25–27] but higher than that mentioned by Malamed (44.7%–59%).[9] The reason for these discrepancies can be attributed to the lack of definitive and consistent anatomy in the patients,[9] the presence of a developmental issues such as MIH, or acute pulpitis in the treated teeth. Malamed proposed several approaches to overcome the failures of IANB. Among them are the slow administration of the local anesthetic solution[28] and the use of a buffered local anesthetic solution. In the present study, we primarily used buffered LA (mepivacaine) for IANB and delivered it using CCLAD systems. For S-LA, we used articaine for the addition of IANB, as suggested by others,[14,29] or lidocaine 2% for administering IS-CCLAD system, which resulted in 66.6% and 85.5% effectiveness, respectively. This difference was not significant because of the small number of teeth. These results also correspond with those of Childers et al.[26] We did not use infiltration in lower molars in S-LA.

Another novel finding of this study was that only the effectiveness of P-LA correlated with age, type of treatment, type of tooth, and the treated arch, whereas S-LA and T-LA correlated only with the type of injection.

A limitation of the present study is that the primary, secondary, and tertiary attempts to anesthetize the teeth were chosen by the treating dentist arbitrarily and not methodologically and that behavioral issues in younger patients could have been mistaken for anesthesia failure. Nevertheless, these limitations do not affect the applicability of the conclusion. Moreover, 16 children were not included in the present study since they had cried during the entire dental treatment; therefore, it was impossible to determine whether they were crying because of pain or fear. In general, such children were referred to complete their dental treatment under general anesthesia. The strengths of the present study are that the analysis of the effectiveness of the S-LA required a relatively high number of primary anesthesia procedures, all documented in real time. We evaluated 1312 molars in 679 children who received primary anesthesia, and to rule out biases, we included only one tooth per group from each child. The selection of a specific tooth within each group of teeth was conducted randomly using Microsoft Excel's "remove duplicates" command.

In conclusion, in case of LA failure in the maxillary molars, we recommend a combination of PSANB and GPNB, and in case of LA failure in mandibular molars, we recommend IS-CCLAD system.

AUTHOR CONTRIBUTIONS

MY collected the data for the statistical analysis, helped in presenting and analyzing the data, and wrote and reviewed the manuscript. **NY** helped in analyzing the results and reviewed the manuscript. **MA** conceived the idea, delivered all the local anesthesia, analyzed the data, and led the writing.

FUNDING INFORMATION

This study was funded by the authors.

CONFLICT OF INTEREST STATEMENT

All authors do not have a conflict of interest in publishing this manuscript.

DATA AVAILABILITY STATEMENT

Research data are not shared.

ETHICS APPROVAL

The Institutional Review Board at the Sheba Medical Center (research number: 9764-22-SMC) approved the study.

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How to cite this article: Yagudaev M, Yarom N, Ashkenazi M. Overcoming local anesthesia failure during routine dental treatments in children. *Int J Paediatr Dent*. 2024;00:1-12. doi:10.1111/ipd.13169

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