Administration of Anesthetics Using Metal Syringes. An Ex Vivo Study

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The aim of the present study was to assess injection flow rates of metal syringes, with an emphasis on injection speed and the generation of flow pulsations. A cohort of 64 operators (32 practitioners and 32 students) performed 3 consecutive ex vivo simulated injections (SIs) of 1.8-mL cartridges of anesthetic solution. Two needle diameters were tested (27-gauge and 30-gauge). Each SI was filmed and analyzed using a computer. In most cases, the SI lasted longer than 60 seconds with the 30-gauge needle (75%) but not with the 27-gauge needle (47.9%) ($P < .0001$). Practitioners and men delivered a full cartridge significantly faster than students and women, respectively ($P = .0007$ in both cases). All operators generated 1 pulse in at least 1 of the 3 SIs with both types of needles, especially during the first 3 seconds (254/384; 66.1%). Pulses occurred more frequently with practitioners ($P = .0176$) and with the 27-gauge needle ($P = .005$). Within its methodological limits, the present study showed how difficult it is to control injection pressure when using a metal syringe, especially at the beginning of the injection. Computerized systems may help overcome this problem.

Key Words: Dental anesthesia; Injection speed; Injection pressure.

The use of local anesthesia makes it possible to perform virtually painless dental treatments and surgical procedures. Ironically, the administration of local anesthetics is widely perceived as one of the most painful aspects of a visit to a dentist, and the fear associated with the dental anesthesia has been reported to be a factor in avoiding dental care.^{1–3} Although the pain associated with dental anesthesia depends on many factors, including the injection site,^{4–6} the technique,⁴ and the patient's personality,⁷ it mainly results from the penetration of the mucosa by the needle and the pressure caused when the anesthetic solution is injected into the mucosa, especially during the first few seconds.⁸ Anesthetics should be injected slowly to minimize the painful effects of pressure.^{9–11} However, little is known about the ability of practitioners to control the speed of injection when using metal syringes, especially during the first few seconds of the procedure when the tissue has

not yet been anesthetized. The goal of the present study was to assess injection flow rates of metal syringes, with an emphasis on injection speed and the generation of flow pulsations (pulses), and how they can be influenced or modified by parameters such as the experience of the practitioner and the needle gauge.

METHODS

Population

Sixty-four operators were recruited for our study: 32 randomly selected fifth- and sixth-year students (student group) and 32 practitioners at the University Dental Hospital of Rennes with at least 5 years of experience (practitioner group). Each group was composed of an equal number of men and women. All participants provided informed consent.

Administration of the Anesthetic

The operators had to administer ex vivo the content of a cartridge of anesthetic solution (1.8 mL; mepiva-

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Figure 1. Drop by drop anesthetic flow. The drops exit the flat part of the bevel and exert little pressure on the surrounding tissues.

caine hydrochloride and epinephrine 1 : 100,000; Scandicaine 2% special, Laboratoires Septodont, Saint-Maur des Fossés, France) using a metal syringe in the same way they would inject the solution in vivo. No further instructions were given to the operators. The same metal syringe was used for the entire study. Each cartridge was marked to indicate quarter and half volumes. The experiments were performed in triplicate using 27-gauge (Sterinject 27G 16, Dentsply France, Montigny, France) and 30-gauge (Sterinject 30G 16; Dentsply France), 16-mm-long needles, with 6 simulated injections (SIs) by each operator. To minimize variations related to the internal tolerance of the needles, a single 27-gauge needle was used for the entire study. The 30-gauge needle had to be changed 4 times because of distortion that occurred during cartridge changes.

Each SI was filmed using a video camera (Panasonic NV-GS500 3CCD Mega OJS, 12 $\times$ optical zoom, 4.0 mega; Panasonic France SA, St. Denis, France). The camera lens was mainly focused on the end of the syringe, including the cartridge (to evaluate the volume administered) and the tip of the needle where the anesthetic exited. The video images were transferred to a PC computer and further analyzed by 2 practitioners. The 2 practitioners who analyzed the video images were thus blinded as to the identity of the person using the syringe. In rare cases, a small part of the operator's finger was visible but did not allow the person to be identified.

The following data were recorded for each SI: the time needed to empty the cartridge, and the number, moment of appearance, and duration of pulses that occurred during the SI (Figures 1 and 2). A pulse was considered to occur when a continuous flow or drops of anesthetic that shot out violently and did not fall onto the ground immediately after coming out of the needle tip were observed. Although no special consid-

Figure 2. Pulse during administration that could potentially generate interstitial pressure exceeding the pain threshold.

eration was given to the length or intensity of the pulses to define or differentiate them, all the pulses varied considerably in length and appeared to be at least 1 cm long.

Statistical Analysis

The results were analyzed using the chi-square test. Comparisons were considered significant at $P < .05$.

RESULTS

The mean age of the students was 24.6 ± 1.2 years. The mean age of the practitioners was 42.7 ± 12.2 years, and their mean length of professional experience was 17.5 ± 12.2 years. The time needed to empty a cartridge varied according to the operator subgroup (Table 1). Significantly more SIs lasted longer than 60 seconds with the 30-gauge needle (75%; 144/192) than with the 27-gauge needle (47.9%; 92/192; $P < .0001$) (Table 2).

All operators generated 1 pulse in at least 1 of the 3 SIs with both the 30-gauge and 27-gauge needles. However, there were 14 (7.3%) SIs with the 30-gauge needle and 14 (7.3%) with the 27-gauge needle with no pulses. A single pulse was recorded in 45 SIs with

Table 1. Mean Emptying Time (in Seconds)*

	N30	N27
Practitioners	85.4 ± 44.1	62.5 ± 38.7
Students	98.6 ± 47.1	83.6 ± 48
Women	101.4 ± 45.3	79.1 ± 41.6
Men	82.7 ± 45	66.9 ± 47.1
All operators	92.0 ± 46	73 ± 44.8

* N30 indicates 30-gauge needle; N27, 27-gauge needle.

Table 2. Distribution of the Simulated Injections With Respect to Duration*

	N30		N27	
	>60 s	<60 s	>60 s	<60 s
Practitioners	67	29	35	61
Students	77	19	57	39
Women	82	14	52	44
Men	62	34	40	56
All operators	144	48	92	100

* Men vs women: statistically significant difference (102 vs 134 exceeding 60 seconds; $P = .0007$). Practitioners vs students: statistically significant difference (102 vs 134 exceeding 60 seconds; $P = 0.0007$). N30 indicates 30-gauge needle; N27, 27-gauge needle.

the 30-gauge (23.4%) and 30 SIs (15.6%) with the 27-gauge needle. Pulses occurred significantly more frequently with practitioners ($P = .0068$) and men ($P < .0001$) than with students and women.

The operators injected significantly more anesthetic with the 27-gauge needle in the first 15 seconds (Table 3). During this initial period, at least 1 pulse was noted in 71.4% of the SIs (274/384).

No gauge-related difference was noted. Practitioners performed significantly more SIs with at least 1 pulse with the 30-gauge needle than students (Table 4). There was no significant difference in the number of pulses between operator subgroups or needle gauges. During the first 15 seconds, men generated significantly more longer-lasting pulses (longer than 3 seconds) than women (53/96 vs 32/96; $P = .0022$) with the 30-gauge needle. In almost two thirds of the SIs, the first pulse occurred during the first 3 seconds (254/384; 66.1%) and was more frequent in the practitioner group than the student group (71.8% vs 60.4%; $P = .0176$). Pulses were significantly more frequent during the first 3 seconds with 27-gauge (140/192; 72.9%) than with 30-gauge needle (114/192; 59.4%), ($P = .0050$).

DISCUSSION

Our results showed that the operators experienced difficulty in controlling the flow rate of the anesthetic (only 14% of the trials were without pulses), particularly during the first few seconds. They also suggested that men inject faster than women and practitioners faster than students.

This experiment was performed ex vivo with no natural tissue resistance. A previous study showed that intracardiac pressures generated when injecting into air are less than those needed to inject into tissue.¹² Furthermore, when tissue resistance increases, the neuromuscular system of the practitioner instinctively reacts by exerting more force on the plunger.¹³ The present study must thus be regarded as prospective and will have to be extended using conditions more closely resembling those encountered in vivo. Our assessments mainly focused on injection speed and pulses generated during the SI.

Injection speed is indicative of the initial needle entry pressure and the needle exit pressure, which is related to the initial pressure, the needle diameter, and the injection site.¹³ Although injection times were significantly shorter with the 27-gauge needle, the mean time for emptying a full cartridge generally exceeded 60 seconds for both gauges, which is longer than recommended and reported in the literature.¹⁴ Only 17% of the operators emptied more than 25% of a cartridge in 15 seconds using the 30-gauge needle, indicating that there was a certain degree of control of the initial pressure with the 30-gauge that was not observed with the 27-gauge needle, where 46% of the operators emptied more than 25% of a cartridge. When the pressure is too high, the drop-by-drop flow turns into pulses of anesthetic solution associated with the high pressure around the site of injection and possibly with pain.

Pulse frequency and moment of onset may influence the pain felt by the patient. Tissue overpressure—

Table 3. Distribution of Simulated Injections With Respect to the Volume Administered During the First 15 Seconds*

	Fraction of Cartridge Administered							
	N30				N27			
	≤0.25	0.25–0.50	>0.50	Full Cartridge	≤0.25	0.25–0.50	>0.50	Full Cartridge
Women	88	8	0	0	60	31	5	0
Men	73	13	7	3	43	35	7	11
Practitioners	71	19	5	1	35	43	9	9
Students	90	2	2	2	68	23	3	2
All operators	161	21	7	3	103	66	12	11

The volume ejected is expressed as a percentage of the initial volume (1.8 mL) in the cartridge. Men vs women: statistically significant difference (N30, $P = .0032$; N27, $P = .0139$). Practitioners vs students: statistically significant difference (N30, $P = .0001$; N27, $P < .0001$). N30/N27: statistically significant differences for volume administered ≤ 0.25 ($P < .0001$), volume administered = 0.25 to 0.50 ($p = 0.0179$), and volume administered > 0.50 ($P = .0293$). N30 indicates 30-gauge needle; N27, 27-gauge needle.

Table 4. Simulated Injections With at Least 1 Pulse During the First 15 Seconds

	N30		N27	
	Simulated Injections	%	Simulated Injections	%
Women	59	61.5	72	75
Men	71	74	72	75
Practitioners	72	75	73	76
Students	58	60	71	74
All operators	130	67.7	144	75

* Differences between practitioners and students, between women and men, and between N30 and N27 not significant except for practitioners vs students with N30: statistically significant ($P = .0307$). N30 indicates 30-gauge needle; N27, 27-gauge needle.

related pain may appear, especially at the beginning of the injection before the anesthesia has taken effect. The early pulses are thus those that may trigger injection pain. In nearly two thirds of the SIs, the first pulse occurred during the first 3 seconds whereas no pulses were observed in the first 15 seconds in less than one third of the SIs, irrespective of the needle gauge. This may be due to the higher force required to mobilize the plunger at the beginning of the injection compared to the force needed to maintain its motion.⁸ Furthermore, at the beginning of an injection, the plunger is completely out of the body of the syringe, leading to poorer manual control of the pressure. However, the threshold of interstitial overpressure associated with pain is difficult to determine.

A recent study conducted using a computerized anesthesia delivery system (the Wand) suggests that 306 mm Hg of pressure is the threshold for triggering pain, but with major variations depending on the patient's stress level.⁹ The level of pain may also depend on the injection site. Injections in high-density tissues, such as intraligamentary and palatal infiltrations (palatal approach to the anterior superior alveolar nerve block [P-ASA], palatal approach to the anterior middle superior alveolar nerve block [A-MSA]), potentially generate more pain because of higher pressures required for the injection.^{4,13,15–17} The use of computer-assisted injection systems might be a solution for these problems of overpressure,^{8,11,18} although the potential improvement may be less evident in anxious patients.^{10,19} These computer-assisted systems administer anesthetic drop by drop during the initial stages of the injection, with a slow increase in the injection rate over time.

In the present study, given the limits imposed by the experimental conditions, the practitioners performed faster SIs than the students, with significantly more

pulses during the first few seconds. The lack of experience likely made the students more careful. It cannot be ruled out that some of the students and practitioners understood the hidden nature of the study and tried to change the way they injected, thus introducing bias into the study. On average, men emptied a cartridge faster than women and performed more SIs with pulses.

These results are in agreement with previous findings indicating that men generated higher pressures than women during periodontal ligament injections.¹⁷ Other studies have also shown that female students have a different attitude toward dental anesthesia and tend to be more stressed.^{20,21} In addition, female dentists are more concerned about causing pain to patients²² and are more motivated by human-oriented factors than their male counterparts.²³ The present study also revealed gauge-related differences, with higher injection speeds and more frequent pulses during the first 3 seconds with the 27-gauge needle. Given that we performed an *ex vivo* study, we did not assess the intensity of the pulses and, consequently, we could not verify whether the pressure generated by the pulses would have caused pain. However, the larger gauge would distribute the pressure over a larger area (30-gauge, 0.071 mm², compared to 27-gauge, 0.126 mm²), which would reduce the risk of generating interstitial overpressure. As such, the larger volume injected with the 27-gauge needle might be compensated by the higher pressure generated by the 30-gauge needle. This complexity might partially explain why studies on the relationship between needle gauge and pain and, as a result, recommendations on the appropriate needle gauge, are contradictory.^{4,9,24,25}

Within its methodological limits, the present study showed that it is difficult to control injection pressure with a metal syringe, especially during the first few seconds of injection. The intensity of the pulses and thus the putative intratissular pressure was not evaluated. It is likely that a powerful stream of anesthetic solution is potentially more likely to generate intratissular pain than a steady stream at fairly low pressure. More studies are needed to determine whether all pulses can induce overpressure-related pain. Pulses occurred most frequently during the first 3 seconds, which is when the tissues are unlikely to be anesthetized. These pulses thus appear more likely to cause pain-generating interstitial overpressure. The injection mode and rate varied widely among operators and with needle size. Practitioners, especially men, emptied the cartridges more rapidly, which, *in vivo*, would increase the risk of generating high interstitial pressure, thus causing pain. These problems might be overcome by injecting the anesthetic solution using

computer-assisted systems to ensure a steady flow rate.

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