



Physical, chemical, mechanical, and micromorphological characterization of dental needles

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Background: In anesthetic techniques, touching bones can cause needle bending. Theoretically, a needle should support such deflection without fracturing. However, it is possible that a needle may fracture depending on the quality and type of needle used. This study evaluated the physical, chemical, and micromorphological characteristics of long and short dental anesthetic needles, as well as the mechanical properties of flexural load and bending resistance when needles are subjected to different bending angles.

Methods: Long and short needles (30G, Jets, Misawa, Selektro, Terumo, Unoject and 27G, Dencojet, Injex, Jets, Misawa, Procure, Setoject XL, Terumo) were evaluated. Scanning electron microscopy was used to evaluate the needle bevels and energy-dispersive X-ray spectroscopy was used for the chemical analysis of needle compositions. Flexural loading and bending strength assessments were performed using a universal testing machine by bending the needles ($n = 5$) to angles of 30°, 60°, or 90°, or until fracture occurred.

Results: The Injex 27G, Jets 27G, and Septoject XL 27G needles were all less than 30 mm in length. There were small percentage variations in the chemical compositions of the needles. Superior smoothness was observed for the Unoject 30G needle, which exhibited the highest fracture resistance at 60°. The Jets 30G needle exhibited greater resistance to fractures at 90°. The Procure 27G needle exhibited the highest load resistance to bending, followed by the Septoject XL 27G needle, and both needles were tied for the lowest fracture resistance. No needle fractured when bent to 30° or at less than three bends to 60° or 90°.

Conclusions: Greater needle resistance to bending increases the probability of early fracturing. Thinner and shorter needles are more resistant than longer and thicker needles. Performing a single bend does not result in any significant risk of fracture or obliterate the lumen, allowing for the continued passage of anesthetic liquid.

Keywords: Dental Anesthesia; Flexural Strength; Local Anesthesia; Needles.



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INTRODUCTION

The use of disposable dental needles has made the occurrence of needle fracturing a rare event [1]. However, this complication continues to occur occasionally, typically based on the use of improper technique when

handling very thin and long needles [2], excessive pressure, unexpected sudden movements by patients, or a combination of these factors [3]. Such scenarios compromise the effectiveness of anesthetic techniques [2-4].

The needles used in dentistry have special characteristics based on the ANSI/ADA [5] and ISO [6]

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Table 1. Specifications of dental needles used in this study according to their manufacturers

Trademark	Country	Gauge	Type / Classification	Length (in millimeters)	Diameter (in millimeters)	Lot
Dentojet	Italy	27G	Long	38	0.4	17080578
Injex	Brazil	27G	Long	30	0.4	515/18
Jets	Korea	30G	Extra short	12	0.3	3091098
Jets	Korea	27G	Long	30	0.4	3091098
Misawa	Japan	30G	Extra short	12	(*)	170120
Misawa	Japan	27G	Long	42	(*)	130705
Procure	China	27G	Long	(*)	(*)	280817L
Selekto	Germany	30G	Short	21	0.3	8H170403
Septoject XL	France	27G	Long	30	0.4	F05202AA
Terumo	Japan	30G	(*)	21	0.3	171226
Terumo	Japan	27G	(*)	35	0.4	151015
Unoject	Japan	30G	Short	25	0.3	150317

(*) Manufacturer does not indicate information on packaging.

standards. Malamed [4] considered extra-short needles to have lengths of approximately 10 to 12 mm, short needles to have lengths of approximately 20 mm (20 to 25 mm), and long needles to have lengths of approximately 32 mm (30 to 35 mm). In contrast, the ANSI/ADA standard [5] allows for greater variations by setting lengths for various nominal sizes: extra short (8 to 14 mm), short (24 ± 4 mm), long (34 ± 4 mm), and extra-long (41 ± 4 mm). Overall, the ANSI/ADA standard [5] is more meticulous and complete because it accounts for the purpose (type of nerve block) for which each needle size is intended, despite the apparent significant variations between minimum and maximum values. Thin needles (27 or 30 caliber) are very fragile and flexible, making them susceptible to fractures or deviations in direction. Additionally, the lumens of these needles are even smaller in diameter, which can make aspiration difficult [7–13].

In anesthetic techniques for the lower alveolar nerve, touching the bone can cause bending of the needle. Theoretically, a needle should sustain this deflection without fracturing. However, it is possible that a needle may fracture [14,15]. Failure to remove needle fragments can cause trismus, infections, and damage to local and vital structures [8–13]. Malamed [4] recommended a maximum of four insertions for each needle, acknowledging that needles are commonly used for multiple injections in dental practice. However, it should be considered that needle fractures can also occur as a

result of flaws in the metal alloys from which they are fabricated, as well as inadequate flexibility, internal bubbles, or low resistance to deflection and fracturing [16–19].

Needles should not be bent [15–17], but they do experience some deflection when penetrating oral tissues, particularly the thinnest needles (30 gauge). The more deeply a needle penetrates, the greater the probability of permanent deformation and fracturing [7]. The goal of this study was to verify the number of folds or bends that dental gingival needles can sustain before fracturing, as well as evaluating their dimensions, chemical compositions, and surface morphological characteristics.

METHODS

1. Specifications of the analyzed dental needles

Twelve different types of needles were analyzed in this study. Table 1 lists the relevant information regarding caliber, type of needle, length, and diameter in millimeters. Batch numbers were obtained from needle packages when possible.

2. Macromorphological physical characterization

Ten samples of each commercial brand were evaluated for the physical characterization of the needles. Lengths and diameters were measured using a digital caliper (King

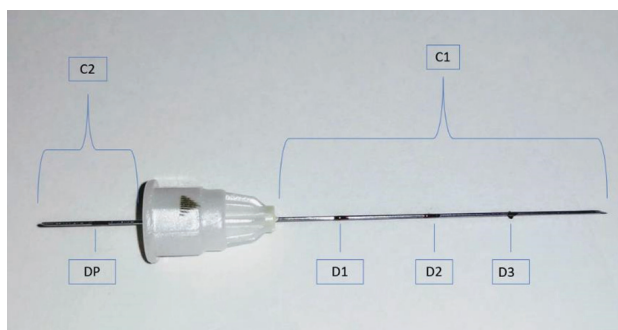


Fig. 1. Needle measurement locations. C1, anterior length; C2, posterior length; D1, diameter closest to the hub (cannon); D2, central diameter of the anterior part; D3, diameter closest to the bevel; DP, posterior diameter.

Tools, model 502.L150 BL, Guangzhou, Guangdong, China) with a resolution of 0.01 mm or 0.0005 inches and measurement range of 0–150 mm with an accuracy of up to two decimal places.

Measurements of C1 (anterior length of the cannula that penetrates the tissue), C2 (length of the cannula that pierces the tube), D1 (diameter closest to the hub/cannon), D2 (diameter in the center of the anterior part of the needle), D3 (diameter closest to the bevel), and DP (diameter in the center of the posterior part of the hub) (Fig. 1) were obtained in duplicate. To this end, the needles were fixed in a polyurethane sponge (Dexter, China) on a black fabric background with artificial lighting and bilateral fixtures under a magnifying glass (Lorben, China) with six-fold magnification. The measured values were recorded in a spreadsheet. The average diameters of the needles were obtained from double measurements performed using the aforementioned digital caliper at locations D1, D2, D3, and DP.

3. Micromorphological physical characterization

The bevel of each needle was positioned horizontally on a stub for micromorphological evaluation using a scanning electron microscope (Jeol, model JSM IT 300, Tokyo, Japan) order to evaluate the active tip in the lateral view. The bevel of a new needle from each manufacturer was analyzed. The seal was carefully broken and the needle was carefully positioned for analysis at a magnification of 430 times. Bevels were characterized by

the absence or presence of deformations such as bends, uneven edges, porosity in the metal, cracks in the metal, and an external metallic layer with detachment or the presence of foreign bodies (filings or metal powder adhered to the surface).

4. Chemical characterization using energy-dispersive X-ray spectroscopy (EDS)

By using the same scanning electron microscope mentioned above (Jeol, model JSM IT 300, Tokyo, Japan), the EDS technique was applied to perform chemical analysis of the metallic compositions of the needles in backscattered mode. In this analysis, a needle from each commercial brand was evaluated under 60-fold magnification in one area. The transition region corresponding to the beginning of the needle bevel was selected for analysis. The chemical elements used in the manufacturing processes of the needles are presented as percentages.

5. Evaluation of the mechanical properties of bending loads and resistance to bending

Five needles from each commercial brand were evaluated at bending angles of 30°, 60°, and 90°. These angles were selected after a pilot study with different bending angles, which revealed that they are the most representative of the different scenarios that occur during the application of local anesthetics. For this analysis, the needles were attached to a carpule syringe (Golgran, São Caetano do Sul, SP, Brazil) accompanied by a glass anesthetic tube (Alphacaine 2%, DFL, Rio de Janeiro, RJ, Brazil). The tube was changed every five needles. The needles were fixed in a needle flexibility measurement device (NFMD, Odeme Dental Research, Luzerna, SC, Brazil) that was developed specifically for this work. The NFMD allowed the syringe and corresponding needle to be positioned parallel to the horizontal plane for testing in the universal testing machine (Emic DL 2000, Sao Jose dos Pinhais, PR, Brazil) such that the needle would not be displaced during testing. To validate our measurements, a digital angle meter (Insize Digital Level and

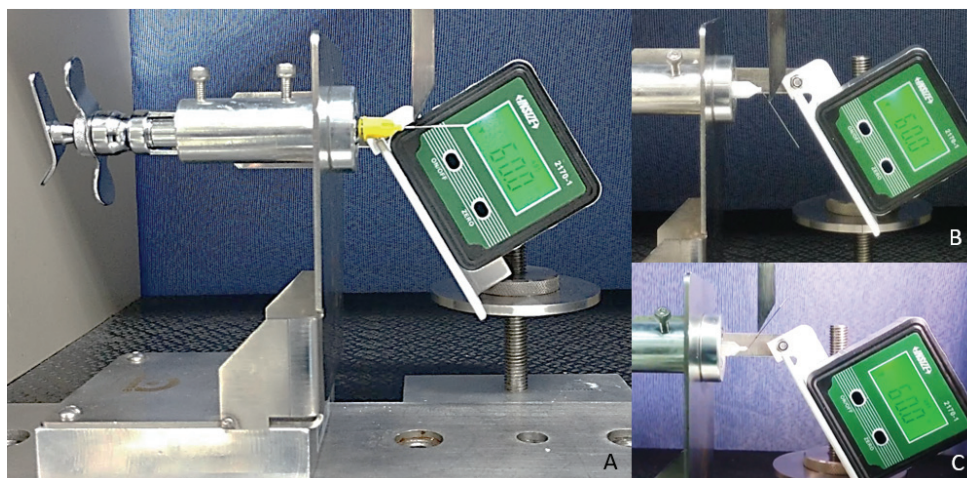


Fig. 2. NFMD. (A) Carpule syringe positioned and locked in the NFMD. The chisel coupled to the testing machine is positioned to induce the first bend in the gingival needle. (B) Flexion of the needle with a 60° inclination. (C) After bending, the syringe is rotated by 180° such that the needle is facing upward and the chisel is positioned to induce the second bend of 60°.

Protractor 4 × 90°, Sao Paulo, SP, Brazil) was used to verify an angle of 0° parallel to the ground before testing each needle. The digital angle meter was then positioned at 30°, 60°, or 90° depending on the test to be performed. The bevel of each needle was placed facing the observer. The NFMD made it possible to obtain the angle of each gingival needle using a digital angle meter. A mechanical stop unit was carefully positioned to guarantee the standardized angulation of all tested needles at different bend angles.

Prior to testing, each needle was marked at a distance of 5 mm from the hub using a digital caliper (King Tools, model 502.150 BL, Guangzhou, Guangdong, China) with a resolution of 0.01 mm or 0.0005 inches and measurement range of 0–150 mm. The chisel-shaped force applicator tip of the universal testing machine was positioned at this location to begin load application on each needle. We used a 20 kgf load cell at a speed of 15 mm/min to obtain flexural loads measured in Newtons (N). This speed allowed the universal testing machine to be stopped at the desired angles of 30°, 60°, and 90° with sufficient accuracy for this study, as evaluated in our preliminary tests.

The needles from each commercial brand were bent until they reached angles of 30°, 60°, and 90°. When reaching one of these selected angles, the syringe/needle

set was inverted on the NFMD for subsequent application of a load by the testing machine at the same angle. This maneuver was repeated 10 times and interrupted if needle fracture occurred before 10 repetitions (Fig. 2).

6. Micromorphological evaluation of the fractured needle area

For this analysis, a scanning electron microscope (Jeol, model JSM IT 300, Tokyo, Japan) was used with 200-fold magnification. Two fractured needles from each commercial brand were selected and bent to 90°. The criteria for choosing the two fractured needles from each brand were as follows: a needle that fractured with a bend of less than 90° was selected and a needle that took a relatively long time to fracture was selected (i.e., sustained the most bends to 90° before fracturing). If there was a tie in the number of bends, then the needle that sustained the smallest load before fracturing in the final bend was selected. The fractured area of the needle was analyzed by observing the integrity of the external cover of the needle, obliteration of the needle lumen, flaws and manufacturing defects in the metal, and the presence of foreign bodies in the fractured area.

7. Statistical analysis

For macromorphological physical characterization, the

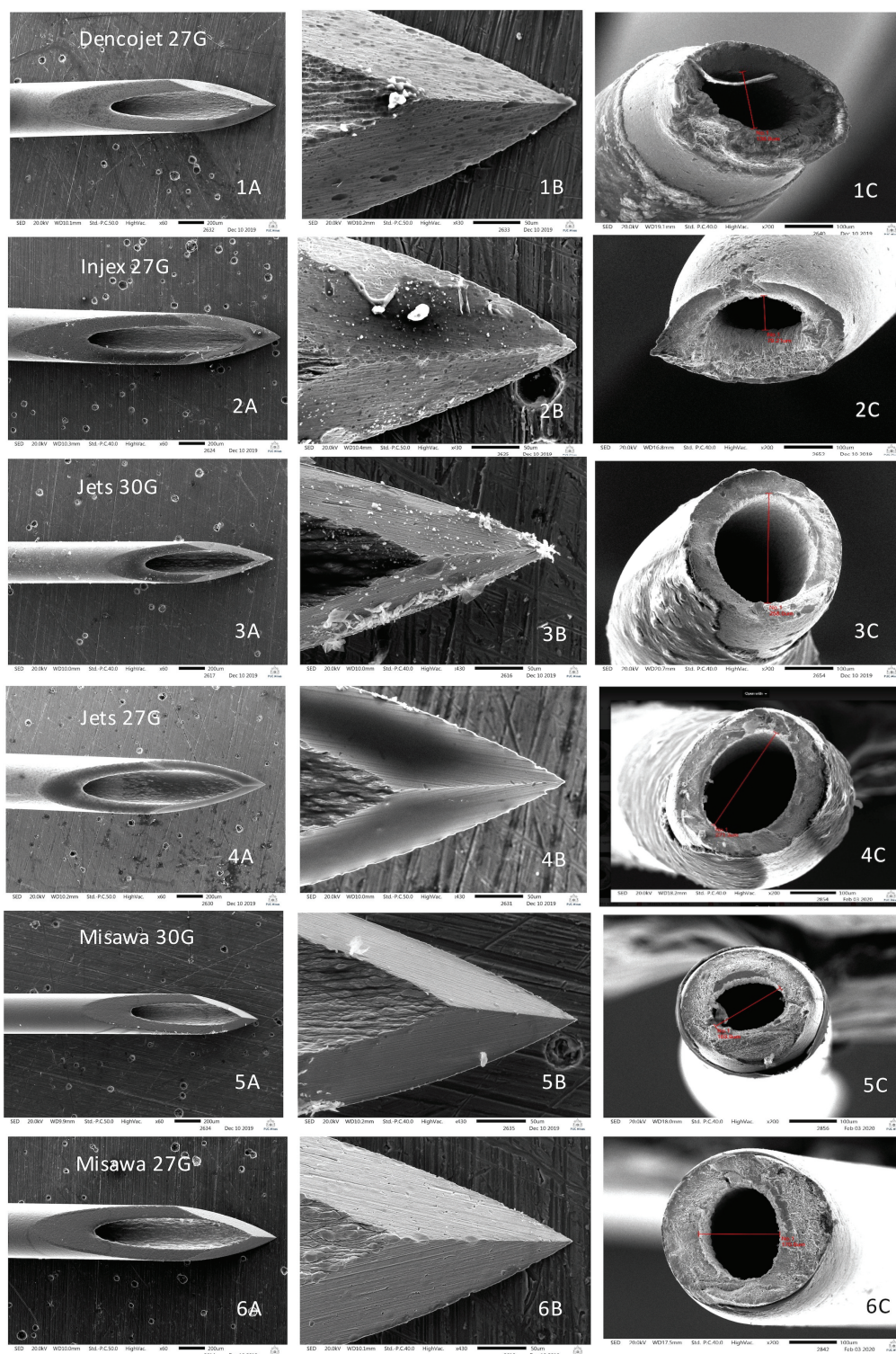
Table 2. Average anterior and posterior lengths, and average diameter of extrashort, short and long dental needles

Variable	Needle type	Needle trademark	Mean (standard deviation)
Anterior needle length (C1)	Extra short	Jets 30G	11.28 (0.18) a
		Misawa 30G	10.99 (0.25) b
	P-value		¹ P = 0.0083
	Short	Selekto 30G	21.23 (0.64) b
		Terumo 30G	20.36 (0.26) c
		Unoject 30G	24.31 (0.12) a
	P-value		² P < 0.0001
	Long	Dencojet 27G	37.83 (0.30) b
		Injex 27G	28.78 (0.60) f
		Jets 27G	29.44 (0.23) e
		Misawa 27G	42.44 (0.18) a
		Procure 27G	35.94 (0.41) c
Septoject XL 27G		29.33 (0.23) e	
Terumo 27G		35.16 (0.22) d	
P-value		² P < 0.0001	
Posterior needle length (C2)	Extra short	Jets 30G	11.58 (0.13) a
		Misawa 30G	11.01 (0.10) b
	P-value		¹ P < 0.0001
	Short	Selekto 30G	11.37 (0.22) a
		Terumo 30G	10.53 (0.20) b
		Unoject 30G	9.53 (3.24) b
	P-value		² P < 0.0001
	Long	Dencojet	10.92 (0.21) d
		Injex 27G	11.39 (0.44) c
		Jets 27G	11.39 (0.15) c
		Misawa 27G	10.44 (0.20) e
		Procure 27G	12.08 (0.42) b
Septoject XL 27G		13.29 (0.15) a	
Terumo 27G		10.54 (0.14) e	
P-value		² P < 0.0001	
Average needle diameter	Extra short	Jets 30G	0.31 (0.01) a
		Misawa 30G	0.30 (0.01) a
	P-value		¹ P = 0.2163
	Short	Selekto 30G	0.30 (0.01) b
		Terumo 30G	0.31 (0.00) a
		Unoject 30G	0.31 (0.00) a
P-value		³ P = 0.0013	
Long	Dencojet 27G	0.40 (0.01) ab	
	Injex 27G	0.39 (0.01) c	
	Jets 27G	0.40 (0.01) ab	
	Misawa 27G	0.40 (0.01) ab	
	Procure 27G	0.41 (0.01) a	
	Septoject XL 27G	0.40 (0.01) ab	
	Terumo 27G	0.40 (0.00) bc	
	P-value		³ P = 0.0232

Different letters within each classification represent statistically significant differences ($P \leq 0.05$). ¹T-test, ²one-way ANOVA, and ³generalized linear models.

needles were classified according to their types as extra short, short, and long. A student's t-test was used to compare the extra-short needles. For the other types, one-way analysis of variance (ANOVA), Tukey's test,

and generalized linear models were used in cases where the data exhibited asymmetric distributions. Chemical analysis of the needles was performed using EDS according to the percentage of each chemical element



(continued)

present in each needle. Regarding the assessment of bending loads and bending strength, exploratory analyses revealed that the data did not meet the assumptions of

ANOVA. Generalized linear models were used with consideration for the mark angle and repeated measurements over two bends as factors for the variable

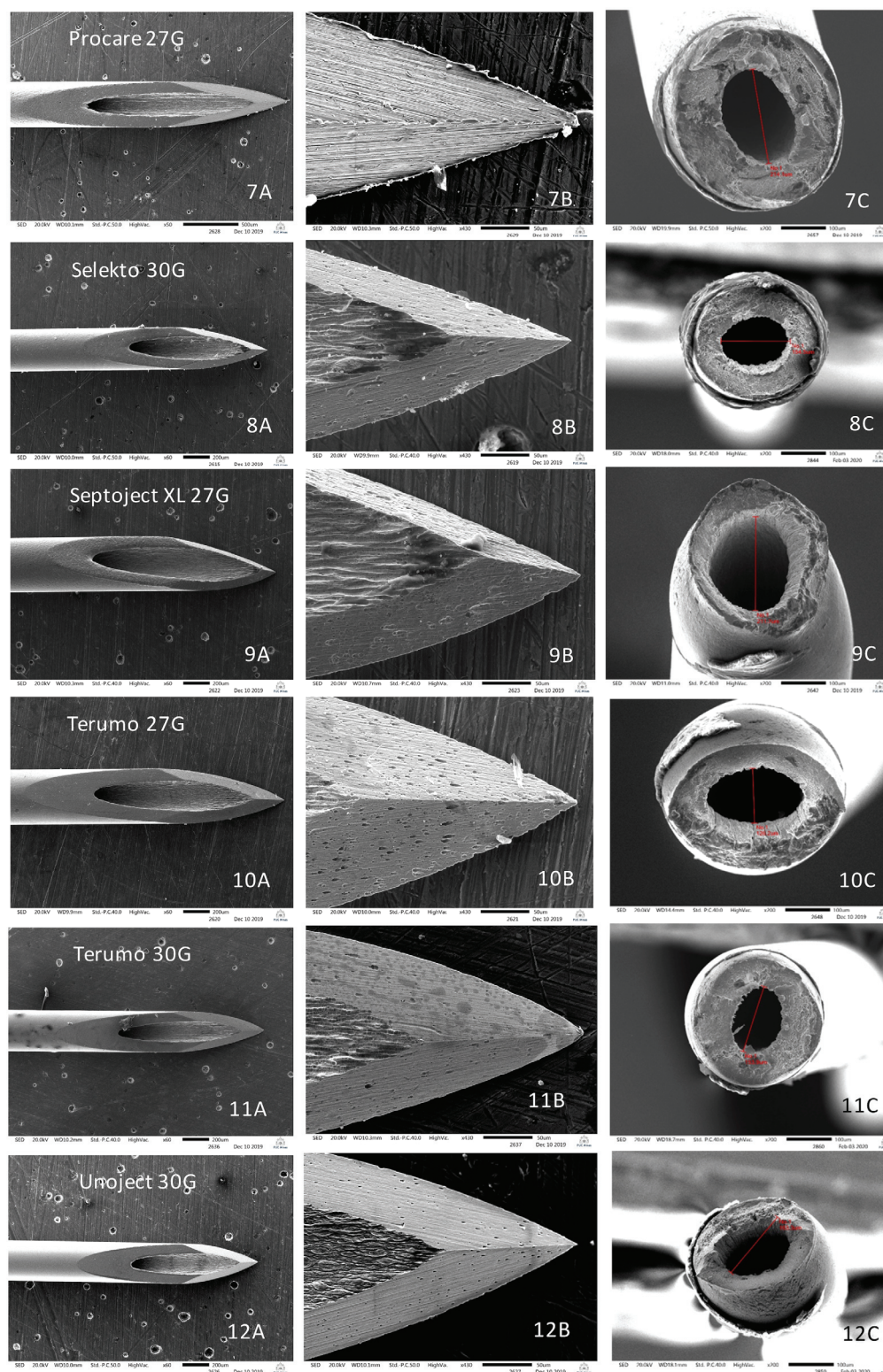


Fig. 3. Micromorphologies of the needles. (A) Needle bevel with 60-fold magnification. (B) Tip of the needle with 430-fold magnification. (C) Needle fracture site with 200-fold magnification.

load and angle for the number of bends sustained until fracturing. Analysis was performed using the R [20]

language with a 5% significance level.

Table 3. Percentage of chemical element each needle according to EDS analysis

Needle trademark	Chemical element								
	Fe	C	Cr	Ni	O	Si	Mn	Al	Ca
Dencojet 27G	51	15.8	14.6	6.6	5.3	5.1	1.3	0.2	-
Injex 27G	55.8	12.2	15.2	6.3	3.6	4.3	1	1.5	0.2
Jets 30G	58.1	16.4	8.9	7.1	2.9	2.9	1.5	1.7	0.4
Jets 27G	46.1	16.7	13.3	5.5	5.7	11.2	1.2	0.3	-
Misawa 30G	65	4.7	18.1	8.3	-	1.6	1.6	0.7	-
Misawa 27G	66.6	2.8	18.5	8.6	-	1.1	1.7	0.7	-
Procure 27G	61.3	8.3	17	7	2	2.4	1.1	1	-
Selekto 30G	63.8	5.1	17.8	8	1.6	1.5	1.6	0.6	-
Septoject XL 27G	63.5	5.5	18	8.5	-	1.5	1.7	1.2	-
Terumo 27G	64.7	4.6	18.6	8.1	-	1.4	1.7	1	-
Terumo 30G	57	11	16	7	2.7	3.8	1.5	1	-
Unoject 30G	67.2	1.9	18.5	8.2	-	0.9	1.8	1.4	-

RESULTS

Regarding the measurement of the anterior and posterior lengths of extra-short, short, and long anesthetic needles, there were statistically significant differences between the measurements of needles from different brands in the same group ($P < 0.05$) (Table 2). Among the extra-short needles, the Jets Korea brand was significantly longer than Misawa Japan brand ($P < 0.05$). Among the short needles, those from Unoject 30G Japan had significantly greater anterior lengths than the other needles and those from Selekto Germany had greater anterior lengths than those from Terumo 30G Japan and greater posterior lengths than the other needles ($P < 0.0001$). In the group of long needles, it was observed that the Misawa 27G Japan needles had greater anterior lengths than the other needles and the Septoject XL France needles had significantly greater posterior lengths than the other needles ($P < 0.0001$).

There were no significant differences in the diameters of needles between the two extra-short brands ($P > 0.05$) (Table 2). Regarding the short needles, Selekto Germany needles had a smaller average diameter than the other needles in the same group ($P < 0.05$). The long needles from Injex Brasil generally had smaller mean diameters than the other needles in the same group ($P < 0.05$), although there was no difference compared to the Terumo

27G brand.

In our micromorphological physical analysis, the needles with the 30G diameters had the shortest bevel lengths, except for the Terumo 30G (Fig. 3-11A) and Unoject 30G (Fig. 3-12A) needles, which had elongated bevels. Foreign bodies were detected in the bevel regions of the Dencojet 27G (Fig. 3-1B) and Injex 27G (Fig. 3-2B) needles, and at the tips of the Jets 30G (Fig. 3-3B), Misawa 30G (Fig. 3-5B), Procure 27G (Fig. 3-7B), and Terumo 27G (Fig. 3-10B) needles.

The Dencojet 27G (Fig. 3-1A), Injex (Fig. 3-2A), Jets 27G (Fig. 3-4A), Misawa 27G (Fig. 3-6A), Procure 27G (Fig. 3-7A), Septoject XL 27G (Fig. 3-9A), Terumo 27G (Fig. 3-10A), and Terumo 30G (Fig. 3-11A) brands had longer bevels than the other needles evaluated in this study. The bevels of the Unoject 30G (Figs. 3-12A and 3-12B) needles exhibited the greatest smoothness among all evaluated needles. Those with the highest roughness were the Jets 30G and 27G needles (Fig. 3-3B and 3-4B) and the Procure 27G needles (Fig. 3-7B). We also observed that the 30G needles were thinner than the 27G needles.

At the needle fracture sites, it was observed that the lumens were not obliterated in any of the analyzed needles, but deformations were observed along with reductions of the lumens. In several needles, the outer shell detached from the inner layer following fracturing (Figs. 3-1D, 2-3D, 3-9D, 3-10D, 3-12D) with the most

Table 4. Median (minimum; maximum) loads (in Newtons) for folding anesthetic needles (27G and 30G) from different manufacturers according to angles over two bends

Flexion	Needle trademark	Needle flexion angle		
		30°	60°	90°
First	Jets 30G	3.51 (2.69; 3.69) Bf	4.39 (4.01; 4.94) Aef	4.27 (3.65; 5.06) Af
	Misawa 30G	8.02 (5.20; 8.30) Ac	7.27 (6.71; 7.47) Ac	7.17 (5.96; 9.93) Ad
	Selekto 30 G	6.57 (4.23; 6.75) Ad	5.38 (3.24; 6.04) Ae	4.33 (3.45; 4.59) Bf
	Terumo 30G	5.44 (3.40; 6.51) Bd	6.43 (5.40; 6.59) Bd	7.64 (6.33; 8.48) Ad
	Unoject 30G	4.05 (3.20; 4.25) Ae	4.03 (3.69; 4.73) Af	4.05 (3.65; 5.66) Af
	Dencojet 27G	8.82 (6.75; 9.97) Bbc	10.46 (7.39; 13.48) ABb	11.38 (9.25; 13.48) Ab
	Injex 27G	9.45 (7.64; 10.50) Ab	8.00 (5.60; 11.50) ABbc	7.72 (6.53; 8.10) Bd
	Jets 27G	6.08 (5.22; 6.81) Ad	6.04 (5.60; 7.43) Ad	5.56 (4.98; 6.39) Ae
	Misawa 27G	8.16 (7.80; 8.60) Ac	9.09 (7.37; 9.87) Ab	6.25 (5.90; 8.22) Bd
	Procare 27G	13.72 (10.81; 14.51) Ba	14.75 (12.79; 19.66) Aa	14.49 (13.32; 15.80) ABa
	Septoject XL 27G	11.16 (9.01; 13.66) Aa	9.61 (6.33; 13.22) Ab	6.99 (5.72; 14.51) Ad
Terumo 27G	9.23 (4.86; 11.42) Abc	8.58 (7.51; 11.12) Ab	8.10 (7.62; 8.93) Ac	
Second	Jets 30G	3.63 (3.00; 3.95) Bd	4.63 (3.97; 5.06) Afg	*4.73 (3.95; 5.20) Af
	Misawa 30G	*7.64 (5.18; 8.20) Ac	*6.99 (6.73; 7.33) Ad	*7.05 (5.84; 9.05) Ad
	Selekto 30 G	6.14 (4.61; 7.86) Ac	5.52 (3.26; 5.76) ABf	4.45 (3.65; 4.84) Bf
	Terumo 30G	6.02 (5.06; 7.86) Bc	6.53 (5.46; 6.57) Be	7.72 (6.49; 7.96) Ad
	Unoject 30G	*3.45 (3.04; 3.77) Cd	4.35 (4.15; 4.53) Bg	*5.14 (5.00; 6.00) Ae
	Dencojet 27G	8.86 (7.21; 10.11) Bb	13.34 (8.84; 15.92) Aab	*12.67 (11.40; 14.51) Ab
	Injex 27G	10.40 (8.24; 10.96) Bb	*11.65 (7.37; 14.45) ABbc	*11.87 (9.73; 13.16) Abc
	Jets 27G	6.99 (5.78; 7.74) Bc	*8.30 (5.98; 12.99) Ac	*6.97 (6.29; 9.33) ABd
	Misawa 27G	*10.07 (7.64; 10.60) Ab	*9.83 (8.62; 13.40) Abc	*10.60 (6.21; 11.71) Ac
	Procare 27G	13.66 (12.49; 14.20) Ba	*14.12 (12.91; 18.64) Aa	*14.16 (13.14; 15.31) ABa
	Septoject XL 27G	*11.77 (9.65; 15.76) Aa	11.44 (7.33; 13.10) Abc	*11.95 (7.60; 15.47) Abc
Terumo 27G	8.72 (8.14; 10.98) Bb	*10.34 (9.13; 12.93) Abc	*8.72 (8.32; 9.45) Bc	

(*) Significant difference compared to the first flexion for the same manufacturer and angle ($P \leq 0.05$). Different letters (uppercase horizontally and lowercase vertically when comparing brands for each angle) indicate statistically significant differences ($P \leq 0.05$). P (angle) = 0.0010; P (brand) < 0.0001; P (angle \times brand) = 0.0018; P (flexion) < 0.0001; P (angle \times flexion) < 0.0016; P (brand \times flexion) < 0.0001; P (angle \times brand \times flexion) = 0.0092.

evident separation occurring for the Dencojet 27G (Fig. 3-1D), Jets 30G (Fig. 3-3D), and Unoject 30G (Fig. 3-12D) needles.

EDS analysis (Table 3) revealed that only the Injex 27G (Fig. 3-2C) and Jets 30G (Fig. 3-3C) needles contained calcium in their chemical compositions (0.2% and 0.4%, respectively). Differences in carbon concentrations were observed in some needles such as the Jets 27G needles (Fig. 3-4C), which contained 16.7% carbon, and the Unoject needles (Fig. 3-12C), which only contained 1.9% carbon. A high percentage of silicon was detected in the Jets 27G needles (Fig. 3-4C) at 11.2%, but only 0.9% silicon was detected in the Unoject 30G needles (Fig. 3-12C). Manganese was observed regularly in all needles, ranging from 1% to 1.8%, as well as nickel ranging from 5.5% to 8.6%. Only the Misawa 30G and

27G, Septoject XL 27G, and Terumo 27G needles did not contain oxygen according to the EDS analysis. Iron was the component with the highest concentration in all needles, varying from 46.1% in Jets 27G needles to 67.2% in Unoject 30G needles.

The results of the flexural loads for needles at different bending angles during the first two bends are listed in Table 4. The Misawa 30G and Septoject XL 27G needles do not exhibit statistically significant differences in loads between the three angles evaluated ($P > 0.05$) for both bends. In the first bend, the Unoject 30G, Jets 27G, and Terumo 27G needles also do not exhibit statistically significant differences in loads between the three angles evaluated ($P > 0.05$). The same result appears for the Misawa 27G needle in the second bend ($P > 0.05$). The other needles exhibit significant differences in loads

Table 5. Median (minimum; maximum) numbers of bends before the fracturing of anesthetic needles (27G and 30G) from different manufacturers under different bending angles

Needle trademark	Number of fracturing		
	30°	60°	90°
Jets 30G	-	7.00 (7.00; 9.00) Aab	8.00 (7.00; 9.00) Aa
Misawa 30G	-	5.00 (5.00; 5.00) Aef	5.00 (4.00; 5.00) Acd
Selekto 30 G	-	6.00 (6.00; 9.00) Aabc	5.00 (4.00; 9.00) Abc
Terumo 30G	-	6.00 (6.00; 8.00) Abcd	5.00 (4.00; 5.00) Bde
Unoject 30G	-	8.00 (7.00; 9.00) Aa	6.00 (4.00; 6.00) Bbc
Dencojet 27G	-	6.00 (5.00; 10.00) Aabc	4.00 (4.00; 5.00) Bde
Injex 27G	-	6.00 (5.00; 9.00) Abcd	5.00 (5.00; 5.00) Bde
Jets 27G	-	7.00 (6.00; 9.00) Aab	6.00 (5.00; 9.00) Aab
Misawa 27G	-	6.00 (5.00; 6.00) Acde	5.00 (5.00; 7.00) Abc
Procure 27G	-	5.00 (5.00; 6.00) Ade	4.00 (4.00; 4.00) Be
Septoject XL 27G	-	4.00 (3.00; 5.00) Af	4.00 (3.00; 5.00) Ae
Terumo 27G	-	6.00 (5.00; 7.00) Abcd	5.00 (5.00; 5.00) Bde

At a 30° angle, no needles were broken. Groups with medians followed by different letters (uppercase horizontally and lowercase vertically) differ significantly from each other ($P \leq 0.05$). P (brand) < 0.000; P (angle) = 0.000; P (brand × angle) = 0.0079.

between different bending angles ($P < 0.05$). For the first bend, the Jets 30G, Terumo 30G, and Dencojet 27G needles exhibit a greater load at 90° than at 30° ($P < 0.05$). For the first bend, the Selekto 30G, Injex 27G, and Misawa 27G needles exhibit a greater load at 30° than at 90° ($P < 0.05$). For the second bend, the Jets 30G, Terumo 30G, Unoject 30G, Dencojet 27G, and Injex 27G needles exhibit a greater load at 90° than at 30° ($P < 0.05$). For the second bend, the Selekto 30G needles exhibit a greater load at 30° than at 90° ($P < 0.05$). It can also be observed that at a 30° angle, the Misawa 30G and Unoject 30G needles exhibit significant decreases in loading for the second bend ($P < 0.05$). The Misawa 27G and Septoject XL 27G needles exhibit a significant increase in loading for the second bend ($P < 0.05$). At the 60° angle, the Misawa 30G and Procure 27G needles exhibit a significant decrease in loading for the second bend ($P < 0.05$). The Injex 27G, Jets 27G, Misawa 27G, and Terumo 27G needles exhibit a significant increase in loading for the second bend ($P < 0.05$). There are significant differences between brands under all conditions. At an angle of 30°, the Procure 27G and Septoject XL 27G needles exhibit greater loading than the other needles ($P < 0.05$). At angles of 60° and 90°, the Procure 27G needles exhibit greater loading than the other needles ($P < 0.05$).

The results for the number of bends until fracturing (Table 5) indicate that there is no needle fracturing at an angle of 30° until the tenth bend. For the Terumo 30G, Unoject 30G, Dencojet 27G, Injex 27G, Procure 27G, and Terumo 27G needles, the number of bends until fracturing is significantly lower at 90° than at 60° ($P < 0.05$). There is a significant difference in loading between the marks for these two bending angles ($P < 0.05$). For the 60° angle, the Unoject 30G needles have a median value of eight bends (ranging from seven to nine bends), which is significantly greater than that of the Misawa 30G, Terumo 30G, Injex 27G, Misawa Japan 27G, Procure 27G, Septoject XL 27G, and Terumo 27G needles ($P < 0.05$). At 90°, the Jets 30G needles have a median value of eight bends (ranging from seven to nine bends), which is significantly greater than that of the Misawa 30G, Selekto 30G, Terumo 30G, Unoject 30G, Dencojet 27G, Injex 27G, Misawa 27G, Procure 27G, Septoject XL 27G, and Terumo 27G needles ($P < 0.05$).

DISCUSSION

Extra-short needles may not reach the desired location for efficient infiltrative anesthesia, which may motivate a dentist to use the entire length of the needle in an

attempt to reach the target nerve, which is dangerous in the event of needle fracturing [18,19,21,22]. Short gingival needles may have lengths of 20 to 25 mm [4]. In this study, lengths varied with average values within that range (between 20.36 mm for Terumo 30G and 24.31 mm for Unobject 30G), indicating that the ANSI/ADA [5] standards were followed.

Needles with lengths between 26 and 29 mm do not fit into any of the classification groups proposed by Malamed [4]. We found that some needles such as the Injex 27G (28.62 mm), Jets 27G (29.45 mm), and Septoject XL 27G (29.30 mm) needles were within this length range. Despite being classified by the manufacturers as long needles, they have lengths that are below the established criteria for long needles (at least 30 mm), which can compromise the procedure of anesthesia of trunk nerves such as the lower alveolar nerve through the direct technique or Gow-Gates technique, where long needles (over 30 mm) are required [4]. Therefore, it is possible that there will be limited success in blocking pain. Additionally, there is an increased risk of needle fracturing following total penetration into the soft tissues, making it impossible for a dentist to remove the fractured needle using forceps [2,15]. Because these needles are almost 2 mm shorter than the recommended length for this purpose, various risks are incurred, especially if a longer length is required, such as in situations when the patient is above the average height standard with a very bulky face or wide jaws [23].

In contrast, the so-called long needles exhibited greater variability in length (from 28.78 to 42.44 mm), which can cause professionals to lose their reference of how deep a needle should penetrate in trunk techniques such as the Gow-Gates or direct technique for the inferior or superior alveolar nerves. This issue can even occur in the Vazirani Akinosi technique [1,10]. In all of the aforementioned techniques, 5 mm of the needle should be left outside the soft tissues so that if a fracture occurs, the needle can be removed with forceps [4,24]. However, leaving 5 mm outside the soft tissues requires that the professional knows the exact length of the needle that

has penetrated the tissues. If there is a fracture in the needle, there will be complications in terms of pain at the injection site, limited mouth opening, otalgia, temporomandibular joint dysfunction pain, edema, dysphagia, discomfort, sensitivity in the retromolar region, acute pain, and even hearing loss [19,25]. Deep blood vessels can also be penetrated by very long needles, causing ecchymosis, paresthesia, or edema. Additionally, there have been reports of needle fragments in the immediate anatomical regions of the internal [25,26] and external [27] carotid artery, as well as close to the left facial artery [28], following the migration of dental needles. It is noteworthy that surgeons rarely pay attention to the length of the needle described on the package. Therefore, they may be surprised to uncover the needle and discover that it is longer than the needles they typically use.

The posterior needle length is standardized in the ISO (9.0 to 14 mm) [6] and ANSI/ADA (9.5 to 11 mm) [5] standards. If the posterior length is too short, then a needle may move out of the tube when performing the aspiration maneuver or even fail to pierce the diaphragm, making anesthesia unfeasible. In contrast, when the posterior length is exceedingly long, a portion of the anesthetic solution will remain in the tube and it will not be possible to use all of its contents. The Septoject XL 27G needle has a posterior length greater than the those of other needles and outside the standard range, measuring 13.29 mm on average, which can lead to anesthetic waste. The Procure 27G (12.08mm), as well as the Jets 27G and Injex 27G needles (11.39 mm), are also outside the standard posterior length range.

Most of the bevels of the studied needles were intact with no defects in the metal or bevels that could compromise anesthetic procedures. In general, the bevels were trifaceted to reduce needle insertion pressure and pain during puncturing [29]. The Jets 30G needles had the most irregularities at the tips of their bevels (Fig. 2-3B). Although it is not possible to pinpoint the reason for this irregularity, there is a possibility of increased pain during needle penetration.

Foreign bodies were found on some needles (Jets 30G, Injex 27G, Terumo 27G, and Procure 27G), which could be residual materials from the plastic covers. The tips of the needle beaks were similar, but it should be noted that the 27G needles thicken when approaching the body compared to the 30G needles, which are relatively thin. Although some studies have shown that 29G wide [30] and 30G fine needles do not differ significantly in insertion pain when administering anesthesia, it has also been observed that dental professionals tend to select thinner needles [29]. Additionally, some porosity was observed on the bevels of the Terumo 30G (Fig. 3-11B) and 27G (Fig. 3-10B) needles, as well as on the Dencojet 27G (Fig. 3-1A) needles, which negatively influenced the number of bends until fracturing, particularly for the Dencojet 27G needles, which were some of the first needles to fracture at 90°. In contrast, the Unoject 30G (Figs. 3-12A and 3-12B) needles exhibited remarkable smoothness on their metallic surfaces without any bubbles or irregularities, allowing them to sustain a median value of eight folds until fracturing at 60°. However, they exhibited significantly decreased resistance to fracturing at an angle of 90° with a median value of six folds (Table 5). The Jets 30G needles (Fig. 3-2B) also contained foreign bodies in their metal. They were the most resistant needles to bending without fracturing at an angle of 90° (median of eight folds) (Table 5). One can see that the presence of porosity or irregularities in metals can lead to needle fracturing [31].

In our EDS analysis, the Unoject 30G needles, which had the best surface smoothness, had the lowest levels of C (1.9%) and Si (0.9%) and the highest levels of Fe (67, 2%). The Jets 30G needles had the lowest Cr level (8.9%) among all brands in addition to being one of the few brands that contained Ca (0.4%). For a material to be considered as a stainless steel, the alloy must contain Fe-Cr, Fe-Cr-C, or Fe-Cr-Ni and at least 10.5 wt% of chromium [29] to resist atmospheric corrosion and surface oxidation [29]. The Jets 30G needles were the only needles that did not contain the minimum of 10.5 wt% of chromium, meaning they cannot be considered

a stainless steel needles. It was also observed that Fe is the main element in all needles and is a fundamental component of the metallic alloys because it provides the characteristics of mechanical resistance and malleability [29].

The Terumo needles had different chemical compositions according to the needle gauges, with the 27G needles containing 64.7% Fe and the 30G needles containing 57% Fe. These changes were accompanied by an inversion in the proportion of carbon (4.6% for 27G and 11% for 30G), but they did not seem to affect the number of bends prior to needle fracturing (six bends for the 60° angle and five bends for the 90° angle). The Jets needles of different calibers also exhibited different chemical compositions, mainly in terms of Fe (58.1% for 30G versus 46.1% for 27G) and Si (2.9% for 30G versus 27G for 11.2%), but these needles exhibited the greatest median number of bends before fracturing at 90°. Not only does the percentage chemical composition seem to influence the fracture resistance of needles, but so does the needle diameter, presence or absence of porosity, and thermal treatment used in the manufacturing of metallic alloys, meaning the resulting properties can be attributed to needle manufacturers.

The Unoject 30G needles exhibited the best fracture resistance in terms of the maximum number of bends (Table 5) and also exhibited the lowest load forces when bending during the first and second bends at all tested angles (30°, 60°, and 90°) (Table 4). These results suggest a lower risk of fracturing during the administering of local anesthetics because it is possible for these needles to withstand an average of eight bends at 60° before fracturing occurs. In contrast, the Septoject XL 27G needles were the first to fracture with an average of four bends at both 60° and 90°. The manufacturer claims that these needles have internal diameters larger than those of the other needles (XL represents an internal diameter larger than the standard), meaning anesthetic can be injected into the soft tissues with less pressure, causing less pain to the patient. However, McPherson et al. [30] determined that there were no significant differences in

pain during injections according to patient reports when they compared Septoject XL 27G needles to needles from other manufacturers with typical internal diameters. It can be concluded that larger internal diameters may have led to a reduction in the resistance of the needles, causing them to fracture earlier than the other needles at 60° and 90° (Table 5). Figure 2-9A indicates that the Septoject XL needles have larger internal diameters than the other needles.

When bending gingival needles ten times up to 30°, no brands exhibited fracturing (Table 5), suggesting that if a dentist must induce a small bend in a needle (up to 30°), this can be performed with no risk of fracture. It was also demonstrated that when increasing the bending angle, the probability of needle fracturing increases significantly, especially for seven of the needle brands (Terumo 30G, Unoject 30G, Dencojet 27G, Injex 27G, Jets 27G, Procure 27G, and Terumo 27G) (Table 5). Although some researchers have indicated that finer needles are more fragile [4,7-13], this study demonstrated that thin needles (Unoject 30G and Jets 30G) with an average external diameter of 0.31 mm exhibited greater fracture strengths than the wider 27G needles (Table 5).

Bending needles one time does not typically cause fracturing. To subject needles to extreme conditions, 10 bends were performed on each needle in this study, which is difficult to perform clinically. Another peculiarity in the dental literature [3,4,15,17,19] is the apparent fear of the ease of fracturing of fine needles. It is common to recommend wider needles in trunk anesthetic techniques, such as those targeting the lower alveolar nerve. In this study, it was demonstrated that fine needles are more flexible and take longer to fracture.

After fracturing, the outer layers of some needles shifted or detached from the internal materials. This occurred with the Dencojet 27G (Fig. 3-1C), Jets 30G (Fig. 3-3C), and Unoject 30G (Fig. 3-12C) needles, which exhibited significant displacement, which can be attributed to the low-malleability characteristics of the metals and the numbers of bends induced in the needles. The Unoject 30G needles exhibited the greatest

smoothness and their bevels were free of foreign bodies and porosity. They also had the lowest loads required for bending and were the most resistant to fracturing after being bent eight times at 60° and six times at 90°, making them an attractive option for dental professionals. In contrast, the Septoject XL 27G, Procure 27G, Dencojet 27G, and Misawa 30G needles, which had the lowest numbers of bends before fracturing at 60° and 90°, Injex 27G and Jets 30G needles, which exhibited foreign bodies on their bevels, and Terumo 27G needles, which exhibited oxidation on their needle bodies, should be reviewed in terms of quality and manufacturing processes.

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