In vitro study of needle deflection: A linear insertion technique versus a bidirectional rotation insertion technique

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Objective: Deflection of dental needles during tissue penetration has been associated with a failure to achieve successful anesthesia. The purpose of this study was to determine whether needle deflection in a tissuelike substance could be minimized through the use of a bidirectional rotation insertion technique. **Method and materials:** Three in vitro deflection test models were constructed, each incorporating a different tissuelike substance of a different density. Each substance was tested with 3 different needle sizes (30-gauge, 27-gauge, and 25-gauge). A customized dental surveyor allowed for standardized needle insertions to a standardized depth of 20 mm. Two different insertion techniques, a linear insertion technique and a newly described bidirectional rotation insertion technique, were tested. Radiographic analysis was performed after each insertion. **Results:** The bidirectional rotation insertion technique described was consistently more effective in minimizing needle shaft deflection for 30-, 27-, and 25-gauge needles. The differences were statistically significant. Each of the different tissuelike substances consistently demonstrated this reduction in needle deflection. **Conclusion:** The factor that most greatly affects the path taken by a needle through a tissuelike substance is the force vectors that act on the needle's beveled surface. The use of a bidirectional rotation insertion technique minimized needle deflection, resulting in a straighter tracking path for 30-, 27-, and 25-gauge dental needles, in 3 different tissuelike substances tested in this study. (Quintessence Int 2000;31:33–39)

Key words: computer-controlled drug delivery system, deflection, force penetration, insertion technique, local anesthesia, needle

CLINICAL RELEVANCE: Needle deflection is a major contributing factor to anesthetic failures. A new insertion technique, the bidirectional rotation insertion, produced greater accuracy in an in vitro model. Increased accuracy may lead to greater success in obtaining local anesthesia.

Successful local anesthesia is critical to the daily practice of dentistry. It is a prerequisite to ensure maximum patient comfort while a wide variety of clinical procedures are performed on the hard and soft tissues of the oral cavity. Therefore, achieving predictable results in local anesthesia is of great importance to all clinicians. Failure to do so can lead to increased stress for both the operator and the patient.[1,2] An injection that is recognized as one of the more difficult in dentistry is the inferior alveolar nerve block.[3] A number of physical factors have been associated with the relative success or failure of the inferior alveolar nerve block. They include anatomic variations between patients, operator technique, and needle deflection.[4,5]

Contemporary dental anesthesia textbooks indicate needle deflection as a source of anesthetic failures.[4,5] It has been reported that the rate of failure for inferior alveolar nerve block can range from 20% to 30%, and most dentists have experienced some difficulty with this injection.[4–8] The inferior alveolar nerve is contained within the pterygomandibular space. For a needle tip to be in close proximity to the intended target, it must penetrate a variety of tissue types, including mucosa, buccinator muscle, submucosal connective tissue, fat, and the temporopterygoid fascia.[9]

The needle initiates its path when it first enters through the buccal mucosa at a point between the pterygomandibular raphe and temporal crest of the mandibular ramus. The mucosa should be held firmly

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in place during insertion to ensure precise needle entry. The standard technique requires needle penetration of the buccinator muscle and fascia. As the needle advances, it will traverse the connective tissue and adipose tissue found within the pterygomandibular space. The final intended target for the needle is the mandibular foramen, found distal and inferior to the mandible lingula.[8] All these tissue layers offer varying degrees of resistance to needle penetration.[9] The entire inferior alveolar neurovascular bundle has a diameter of approximately 2.2 mm, and the pterygomandibular space has a total estimated volume of only 2 mL.[10] Even a small deviation from the intended target may have a negative effect on the success of an inferior alveolar nerve block.[11]

The most widely accepted model for studying needle deflection is an in vitro model that utilizes tissuelike substances. This design provides a reliable testing environment without the need for human tissues. Experimentation of this type eliminates many of the difficult ethical questions raised by animal studies. The clinical relevance of a needle deflecting through an analog model to the human condition has been previously established.[12-15] It has been demonstrated that this type of testing provides valuable insight into needle characteristics in an experimental setting.[16-19]

Needle diameter (gauge) and the relative flexibility or resilience of the needle shaft are the physical characteristics reported to affect needle deflection.[13] Early studies focused primarily on static shaft flexibility and did not take into account any of the vector forces generated on the needle's bevel during movement.[13-19] These studies concluded that shaft diameter is the most critical factor affecting bending or deflection of the needle.[13-19]

Aldous[17] was the first to investigate needle deflection with a dynamic testing method that more accurately portrayed clinical conditions. He incorporated the use of a dental surveyor that standardized the direction of the injection force. He selected materials of uniform densities to serve as tissuelike simulations. The actual path and degree of needle deflection was recorded on radiographic films after the needle was inserted in the test material. Aldous[17] concluded that the relative degree of needle deflection is inversely proportional to the needle shaft diameter. He also stated that the shape and angle of the bevel affect the degree of deflection.

Robinson and coworkers[18] expanded Aldous's original investigation to measure needle deflection geometrically in 2 spatial planes. Radiographs were taken at perpendicular angles, allowing a more precise analysis of needle deflection. They concluded that all needles produce a path of deflection and that the degree of deflection cannot be correlated to the gauge of a needle. Robinson et al[18] suggested that deflection is related more to the type of alloy used for manufacture of the needle than to the gauge.

Jeske and Boshart[19] tested a unique needle design (Tru-jet Cannulae) using the same testing model described by Aldous.[17] The needle they tested was beveled on 2 opposite sides of the shaft, placing the needle tip at approximately the center of the long axis. They concluded that needle tip design is more critical to reducing and eliminating deflection than is the diameter of the needle.

Controversy in the literature exists regarding the factors responsible for needle deflection. This study was conducted to determine if use of a new bidirectional rotation insertion technique could minimize needle deflection. A second objective of the study was to determine if the gauge of the needle had an effect on the amount of deflection when bidirectional rotation insertion was used. A final objective was to determine which factors had the greatest influence on the magnitude of needle deflection.

METHOD AND MATERIALS

Bidirectional rotation insertion technique

A new needle insertion technique has been presented to overcome the undesirable effect of needle deflection. This technique seeks to produce a more accurate, straight-line needle tracking through substances, regardless of needle gauge. The technique relies on a penlike grasp that makes it possible to rotate a needle in a back-and-forth manner. The needle is rotated between the thumb and index finger 180 degrees in each direction. The type of rotation used is analogous to techniques that have been described for endodontic file instrumentation and acupuncture.[20,21] The purpose of the bidirectional rotation is to neutralize the force vectors that act on the needle bevel and bend the needle shaft. This bidirectional rotation action is maintained during the entire course of needle advancement.

Deflection tests

The testing protocol for the study followed the design set forth by Robinson et al.[18] Three deflection test models were constructed. The test models differed in the tissuelike substances that were used. The following materials served as tissuelike substances in this study: hydrocolloid (test model A), frankfurters (test model B), and soft bite-wafer wax (test model C). For each tissuelike substance, 3 different needle gauges were tested: 30-gauge 1.25-inch, 27-gauge 1.25-inch, and 25-gauge 1.25-inch (Monoject Ultra Sharp Model 400, Sherwood Medical).

In each of the 3 models, the needle was inserted to a depth of 20 mm. This standardized working length was selected because of the availability of the 30-gauge 1.00-inch (25.4-mm) needle. All 3 tests employed a modified dental surveyor (Ney) to produce standardized needle insertions (Fig 1). Traditional screw-on needle hubs were attached to a customized arm of the surveyor. The needle was then advanced into the tissuelike substance using either the test technique (the bidirectional rotation insertion movement) or the control technique (the traditional insertion with a linear nonrotation movement). A sufficient number of tests was performed for each needle within a substance to provide adequate statistical relevance.

Test model A. For the first deflection test model, hydrocolloid (Acculoid Extra Strength, Van R Dental) was placed into a 6-oz plastic container that fit into the custom surveyor jig. The jig was constructed to produce consistent, perpendicular angulation of the x-ray tube head. The custom jig was designed to record needle deflection in 2 planes of space fixed at 90 degrees from one another (Fig 1). This enabled the total amount of deflection to be calculated from an algebraic formula. A total of 60 insertions was performed with 30 needles (10 needles for each needle gauge size).

Each needle served as its own control between the 2 techniques. The needle was first inserted into the tissuelike substance with a linear nonrotation movement. The same needle was then inserted into the test material with the bidirectional rotation insertion technique. After the needle was used for the second insertion technique, it was discarded and the test was repeated with a new needle.

After each needle insertion, 2 radiographic films were exposed at 15 mA, 65 kV(p), 10 impulses, and then developed. A metallic x-ray grid was used to record the maximum amount of deflection produced. Each film was measured with a Boley gauge on a superimposed grid from the point of insertion to the tip of the needle. The total amount of deflection produced was calculated using a geometric principle described by Robinson and coworkers.[18]

Test model B. A second deflection test was performed on processed meat, frankfurters (Hebrew National). The protocol used in the first test model was followed. A total of 42 insertions was performed with 21 needles (7 needles for each needle gauge size, 30-, 27-, and 25-gauge).

Test model C. A third deflection test was performed on soft bite-wafer wax (Hygenic). A custom platform was constructed to align the wax parallel to the long axis of the needle held by the dental surveyor arm. The use of soft bite-wafer wax allowed visual inspection to measure and determine the amount of needle deflection.

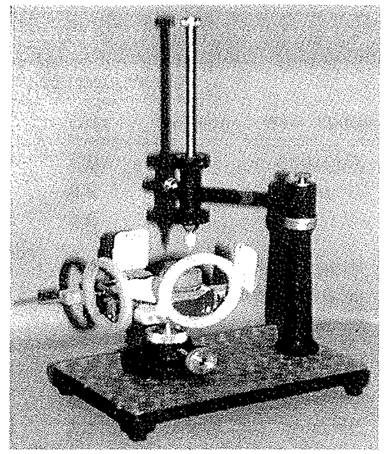

Fig 1 Customized dental surveyor with fabricated radiographic jig and tissuelike substance container.

The needle bevel was oriented perpendicular to the surface of the wax; this was confirmed by the operator, who was wearing ×2.5 magnification loops (Designs for Vision). The needle was first inserted in the wax with a nonrotation linear movement, to a depth of 20 mm. The wax was marked at a point where the needle tip ended in the wax to identify the deflection. The needle was removed from the wax and positioned in front so that the needle shaft was aligned to the access hole created from the initial insertion. A Boley gauge was used to measure the distance of deflection that was observed.

The same needle was employed for the second test, the bidirectional rotation insertion technique. Each needle therefore served as its own control. A total of 100 insertions was performed with 50 needles of a 30-gauge size. An additional 40 insertions, with 10 27-gauge and 10 25-gauge needles, was conducted to compare the 2 techniques. The needles used for this study were randomly selected from a standard box of 100 needles, supplied by a local dental distributor.

RESULTS

The study design involved repeated sets of 3 experiments comparing needle deflection for the 2 techniques of needle insertion for a particular needle gauge in different injection media. Statistical data analysis involved paired t tests for each experiment. The bidirectional rotation insertion technique was consistently more effective than linear insertion in minimizing and eliminating needle shaft deflection for 30-, 27-, and 25-gauge needles (Fig 2). Each of the tissuelike substances tested consistently demonstrated

TABLE 1 Needle deflection in 3 test substances

		Linear insertion (mm)			Rotation insertion (mm)*		
Material	Needle size	Mean	SD	Range	Mean	SD	Range
Hydrocolloid	30-gauge	4.7	0.3	4.0–5.0	1.1	1.4	0.0–1.7
	27-gauge	4.6	0.3	4.1–5.2	0.8	0.2	0.5–1.1
	25-gauge	3.8	0.1	3.2–4.0	0.5	0.2	0.0–0.7
Frankfurter	30-gauge	2.2	1.1	1.6–2.7	0.2	0.3	0.0–0.7
	27-gauge	1.4	0.3	1.0–1.5	0.6	0.2	0.0–0.7
	25-gauge	0.9	0.3	0.7–1.0	0.2	0.4	0.0–0.5
Wax	30-gauge	2.7	0.3	2.3–3.8	0.1	0.2	0.0–0.2
	27-gauge	3.4	0.5	3.2–3.7	0.1	0.5	0.0–0.3
	25-gauge	2.6	0.4	2.3–3.1	0.1	0.3	0.0–0.2

* The bidirectional rotation technique was consistently more effective than linear insertion in minimizing and eliminating needle shaft deflection for 30-, 27-. and 25-gauge needles and with each tissuelike substance tested. Statistically significant ($P < 0.05$).

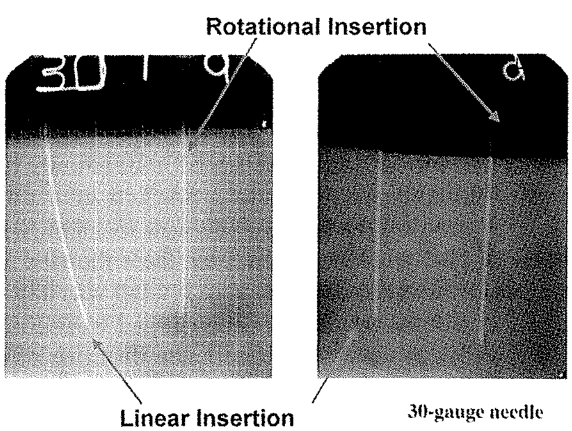

Fig 2 Insertion of a 30-gauge needle with 2 different techniques: linear insertion and bidirectional rotation insertion. Radiographs represent needle insertion in 2 planes of space fixed 90 degrees from each other.

this reduction in needle deflection with the bidirectional rotation insertion technique.

The differences in deflection between linear and rotation insertion techniques were found to be statistically significant ($P < 0.05$) in each of the experiments conducted. A 95% confidence level, with no overlap of the upper and lower limits, was observed.

Mean values for needle deflection with linear insertion and bidirectional rotation insertion are presented in Table 1.

DISCUSSION

It has long been suggested that all needles deflect, irrespective of the diameter of the needle being used. Aldous[17] was the first to devise a dynamic testing method to record deflection, and he concluded that needle deflection is inversely related to needle diameter. Robinson and coworkers[18] investigated deflection, modifying Aldous's model to improve the measuring and recording accuracy. They concluded that all the tested needles deflected, irrespective of gauge. Robinson et al[18] stated that the degree to which needles deflect is not related to diameter shaft but may be related to the specific metals used in manufacture.

A previous study has shown that beveled tip design of a needle will influence the path the needle takes as it penetrates through substances of varying densities.[13] It is apparent that a force system is produced on the needle's beveled surface. This force vector system is the same for any cylindrical object with a beveled end, and it will follow Newton's third physical law of equal and opposite forces.[22] Therefore, an application of a resultant vector force on the beveled surface of an eccentrically pointed cylindrical shaft will produce physical bending (deflection) along the path of insertion (Fig 3). The amount of deflection exhibited by the beveled cylindrical object is determined by the sum of the forces acting on an object in a specific medium.

A bi-beveled needle has the advantage of possessing a needle tip that is centrally located along the needle shaft. Testing of this needle design yielded the expected results of reduced needle shaft deflection.[17,19] The bi-beveled needle eliminates the perpendicular forces that are responsible for needle shaft deflection. However, the most common needle commercially available is an eccentrically pointed beveled needle.[23] Another needle, the Accujet (Astra Pharmaceuticals), enables bevel orientation to be monitored. A visual marker on the needle hub allows the operator to position the bevel in a specific direction. It is thought that

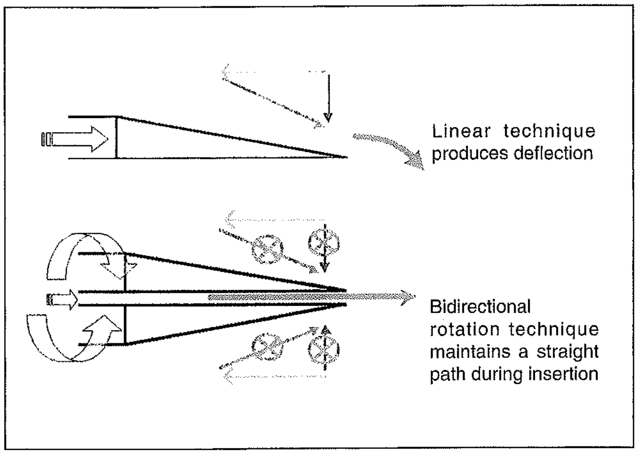

Fig 3 Simplistic illustration of the vector force system applied to the beveled end of a needle. Vector analysis illustrating the path taken during needle insertion with the linear insertion and the bidirectional rotation insertion techniques. Yellow arrow = movement of needle; red arrow = final path of needle movement; brown arrow = resultant force vector; blue arrow = vertical force vector; green arrow = horizontal force vector; purple cross = canceled force vector.

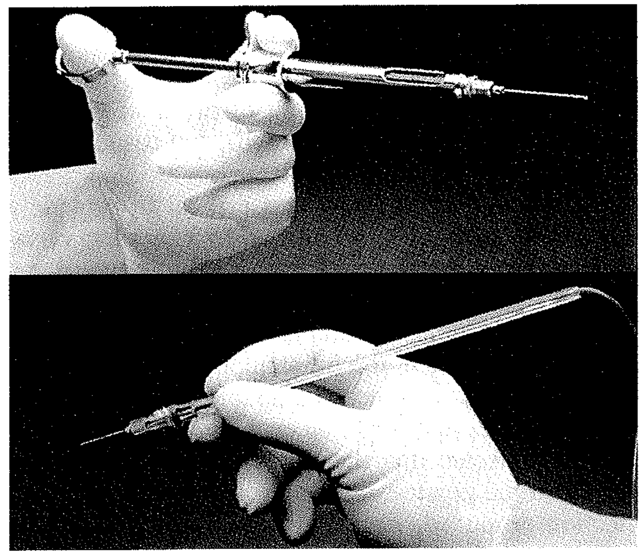

Fig 4 The bidirectional rotation technique is maximized by the use of a penlike grasp *(below)* rather than a palm-thumb grasp *(above)*.

this will assist the dentist in better control of the final needle position. The needles described above require the operator to use a linear insertion technique.

Use of the bidirectional rotation insertion technique, even with an eccentrically pointed beveled needle, allows the operator to cancel out the perpendicular force vectors on the bevel that cause bending along the needle shaft (see Fig 3). This technique generates forces that cause the needle to travel in a linear path. The straight path produced by the bidirectional rotation insertion technique will occur irrespective of needle gauge, bevel design, or the metal alloys used in manufacture.

Berns and Sadove[11] conducted a radiographic in vivo study. Sixty-six inferior alveolar nerve block injections were performed on adult patients. A 22-gauge needle was used to administer a mixture of local anesthetic and radiopaque dye. Cephalometric lateral head films were taken after the needle was inserted to the proper depth and securely positioned in place. The radiographic images revealed bending of a rigid 22-gauge needle at its final position. The authors stated that the needle tip should be no more than 0.5 cm from the mandibular foramen. They concluded that the closer the needle tip is placed to the mandibular foramen, the more likely the success of the inferior alveolar nerve block. The study supported the observation that there is a direct correlation between a positive clinical outcome (ie, anesthesia) and the positioning of the needle tip. The study documented radiographic evidence of in vivo needle deflection. It is therefore not unreasonable to infer that needle deflection affects the final needle tip position, thus affecting clinical success.

In addition to reducing needle deflection, the bidirectional rotation insertion technique seems to substantially reduce the force required to penetrate a substance. Preliminary data suggest that a reduction of force penetration in the range of 40% to 50% can be anticipated when this technique is used (unpublished data). This may prove to be particularly beneficial for those injections that penetrate dense connective tissue, for example, the palatal tissue of the oral cavity. Additional investigation is warranted to determine the clinical implications of these findings.

The traditional handheld syringe requires a palm-thumb grasp (Fig 4) and does not lend itself easily to the rotation insertion technique. This may explain why the technique has not been described in the past. A recently introduced anesthetic delivery system (The Wand, Milestone Scientific) was designed to use a lightweight, disposable, penlike handpiece requiring the operator to use a thumb and index finger grasp (Fig 4). The benefits of a bidirectional rotation insertion technique can be maximized with this penlike grasp.

The density of the substance in which a needle is inserted appears to influence the amount of deflection produced by the bevel. In this study, the tissuelike substance with greatest density, (ie, hydrocolloid) consistently produced greater deflection than did less dense substances. Entry in a fluid-filled compartment would minimize deflection as a result of the fluid viscosity. The oral cavity is primarily composed of tissues with a broad spectrum of densities.

In the testing model, it was critical to provide a consistent and uniform material to eliminate variations between specimens. Three different types of materials were tested, reflecting a range of densities. There are no published studies quantifying the densities of oral tissues in the infratemporal fossa. The materials selected offered a reasonable spectrum analogous to tissues that might be encountered in vivo.[13,17,18] Results indicated that the type of insertion technique used had the greatest influence on the amount of deflection produced, irrespective of the density of the substance tested.

Needle length appeared to be another factor that influences the amount of deflection. The standard testing distance of 20 mm was selected in this study based on the commercial availability of a 30-gauge, 1.00-inch needle. Insertion distances of 25 mm and more are typical for the inferior alveolar nerve block. It would be expected that these greater distances would result in greater rates of deflection.[22] Longer needles that travel greater distances would demonstrate larger amounts of bending than were observed in this study. This would only accentuate this study's findings.

The increased length of the thicker needle can explain the finding that needle deflection of 27-gauge needles was greater than that of 30-gauge needles in the denser tissuelike substance (wax). The standard 27-gauge needle is 0.25 inch (6 mm) longer than the 30-gauge needle, producing increased "springiness." This could account for the greater bending of the needle that was observed. Irrespective of differences among the different needle sizes, all needles demonstrated a significant reduction in deflection with the bidirectional rotation insertion technique.

In this study, linear insertion was always tested before rotation insertion. Maintenance of this order of needle insertions was believed to minimize bias produced through dulling or deforming of the needle. A random order between different techniques could have been selected. Each of these possible study designs has its own merits.

The use of the bidirectional rotation insertion technique may become clinically relevant for injections such as the inferior alveolar nerve block. Clinically, the authors have observed a reduction in failed inferior alveolar nerve block injections, as well as a quicker onset of anesthesia with its use. These findings are anecdotal. Future research should be conducted to determine the actual clinical benefits of this technique. This study has demonstrated that a needle that traverses 20 mm of a tissuelike substance can deflect as much as 5 mm. The bidirectional rotation insertion technique provides greater accuracy of placement for those injections that require deep needle penetration.

For injections in the palate or other supraperiosteal infiltration injections, high-level accuracy may not be necessary to achieve successful anesthesia. However, it is noteworthy that all needle penetrations required reduced force when the bidirectional rotation technique was used. This suggests that the needle penetration force may be reduced by the rotation insertion technique. This hypothesis requires further investigation to determine the validity of these statements.

CONCLUSION

The success of local anesthesia in dentistry is multifactorial. One of the most challenging of all local anesthesia injections is the inferior alveolar nerve block. Not all anesthetic failures are related to needle deflection. However, needle deflection has been identified as one of the elements that can reduce the accuracy and predictability of the inferior alveolar nerve block. This study was conducted to investigate the cause-and-effect relationship between the needle and deflection:

1. The factor that most greatly affects the path taken by an eccentrically beveled needle through a tissuelike substance is the force vectors that act on the beveled surface.
2. The use of a bidirectional rotation insertion technique minimized needle deflection, resulting in a straighter tracking path for 30-, 27-, and 25-gauge dental needles.
3. The use of a bidirectional rotation insertion technique minimized needle deflection in the 3 different tissuelike substances tested in this study.

Further investigations are necessary to determine if the in vitro results will translate to clinical benefits for the inferior alveolar nerve block and other deep-penetrating injections that require accuracy.

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