Intrusion of multiradicular teeth and related root resorption with mini-screw implant anchorage: A radiographic evaluation

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Introduction: Mini-screw implants (MSIs) hold great potential for enhancing intrusive mechanics applied to multiradicular teeth. This experimental study used various force magnitudes to evaluate (1) the stability of immediately loaded MSIs, (2) the amounts of tooth intrusion produced, and (3) the amounts of root resorption produced. **Methods:** By using a split-mouth repeated-measures design, intrusive forces were applied for 98 days to the mandibular second (LPM2), third (LPM3), and fourth (LPM4) premolars of 8 mature beagle dogs (ages, 20-24 months). With 12 MSIs (IMTEC, Ardmore, Okla) placed in the lingual and buccal cortical plates of each dog, Sentalloy coil springs (GAC International, Bohemia, NY) applied constant intrusive forces of 50, 100, or 200 g per tooth. The intrusive forces were randomly assigned between pairs of teeth; LPM2 was loaded with 50 or 100 g, LPM3 with 100 or 200 g, and LPM4 with 50 or 200 g. Multilevel statistical procedures were used to model tooth movements and root resorption, based on 64 standardized radiographs per tooth taken at 14-day intervals. **Results:** Only 1 of the 96 immediately loaded MSIs failed. Significant ($P < .05$) amounts of intrusion, from 1.2 to 3.3 mm, were obtained after 98 days of force application. The statistical models showed no significant differences in the amounts of tooth movement between pairs of teeth loaded with different force magnitudes. Root resorption at the furcation and apices was 0.1 mm or less. **Conclusions:** Constant intrusive forces from 50 to 200 g produce clinically significant amounts of intrusion with little or no root resorption, suggesting that immediately loaded MSIs hold great promise as fixed anchorage devices for intruding multiradicular teeth. (Am J Orthod Dentofacial Orthop 2007;132:647-55)

Over the years, orthodontists have developed various approaches for intruding the posterior teeth and controlling the vertical dimension, including posterior bite blocks, headgears, magnetic forces, active vertical corrector, vertical chincups, and maxillofacial surgery, among others.[1-14] Although these approaches are viable treatment options, most have limitations, such as force control and patient compliance, which directly affect treatment results.

Because the forces are concentrated at the apices, it has been suggested that intrusion holds a greater risk for apical root resorption than other types of tooth movements, especially in patients with a genetic predisposition.[15,16] Intrusion of single and multiradicular teeth has been associated with root resorption at the apices and in the interradicular area.[17-21] Although it has been suggested that external apical root resorption of anterior teeth depends on the amount of movement,[22] most studies reported no relationship between the amount of resorption and intrusion.[17,23-27] However, there is a tendency for more root resorption after the application of heavier rather than lighter intrusive forces.[17,21,28]

Most earlier studies comparing intrusive forces used mechanics with at least 1 tooth as the anchor unit.[17,21,28-31] However, such forces applied to the intruding teeth might be compromised because of loss of force when the anchor unit moves in the opposite direction. Fixed anchorage devices avoid the negative side effects of reciprocal force mechanics and minimize patient compliance. By using a fixed anchorage device, the magnitude of the force can be better controlled, and it might be possible to substantially diminish root resorption by decreasing forces. Osseointegrated dental implants, titanium

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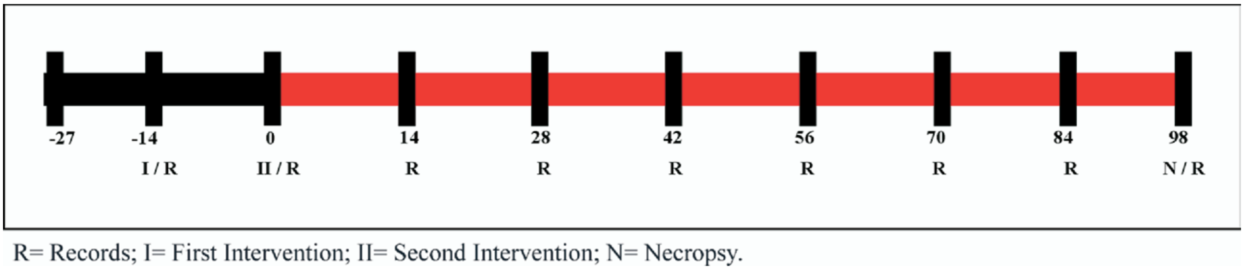

Fig 1. Timeline and sequence of investigation (days).

mini-plates, and mini-screw implants (MSIs) have shown great potential as fixed anchorage for controlling orthodontic forces and intrusion.[18,32-56] Unfortunately, osseointegrated dental implants, palatal implants, and titanium miniplates require more extensive, often surgical, intervention for placement and removal; this is a limitation for many patients.

MSIs are presently the smallest fixed anchorage devices available for orthodontic use. Of all fixed anchorage devices, they are the least invasive, the most conservative in terms of placement and removal, the most flexible with respect to implantation site selection, and the least expensive. MSIs are especially well suited for noncompliant patients and are esthetically more acceptable than extraoral appliances. However, the literature pertaining to their use as anchorage for intrusive mechanics is limited, consisting of a few case reports,[36-44] 1 retrospective study,[45] and 1 experimental comparison.[18] There is great variability among these reports regarding force magnitudes, intrusion movements, timing of MSI loading, and effects of the forces on root structure. To date, no study has evaluated intrusive movements and root resorption of multiradicular teeth after the application of various force magnitudes with fixed anchorage.

This split-mouth repeated-measures design used MSIs as anchorage to apply 3 forces (50, 100, or 200 g) to the mandibular second, third, and fourth premolars (LPM2, LPM3, and LPM4, respectively) in beagle dogs. Our aims were to evaluate (1) MSI stability after immediate loading, (2) differences in the amounts of tooth intrusion, and (3) differences in the amounts of root resorption.

MATERIAL AND METHODS

The study included 8 skeletally mature beagles, 7 males and 1 female, weighing 10 to 15 kg, aged 20 to 24 months. The animals were housed at the Animal Resource Unit at Baylor College of Dentistry, Dallas, Texas, according to the guidelines of the Institutional Animal Care and Use Committee. After arrival at the facility (day –27), the animals were quarantined for 13 days and fed a balanced soft diet to prevent appliance damage.

The procedures and timeline of the study were the same for each dog (Fig 1). Before each intervention and record-taking session, the animals were anesthetized with ketamine (2.2 mg per kilogram, intramuscularly) and xylazine (0.22 mg per kilogram, intramuscularly). While anesthetized, the animals' vital signs were monitored and recorded by trained personnel.

The first intervention was performed on day –14. While sedated, the animals initially received a dental cleaning; then they were intubated and maintained with 1% isofluorane and oxygen (1 liter per minute), followed by the infiltration of local anesthetic (0.5% bupivacaine with 1:200,000 epinephrine), for crown preparation. The crowns of the LPM2, LPM3, and LPM4 were prepared, and full-arch impressions were taken with heavy and light body polyvinylsiloxane material (Coltène AFFINIS; Coltène/Whaledent, Altstätten Switzerland).

After the impressions, tantalum bone markers (BMs) were placed in each quadrant, later to be used as references for radiographic superimposition. These BMs were fabricated from 99.95% tantalum wire (0.8 mm diameter, 1.5 mm long). BMs were placed by using a spring-loaded appliance (Fritschi, Monterrey, Mexico) in the interradicular bone of the premolars.

Periapical radiographs (27 × 54 mm, Kodak Ultra-Speed film; Eastman Kodak, Rochester, NY) were taken of all prepared teeth in each quadrant. The radiographic technique was standardized by using a previously fabricated acrylic radiographic guide tray (FastrayTM, Bosworth, Skokie, Ill) for each quadrant (2 per animal). Each radiographic guide tray had a fixed film holder, a removable indicator arm, and an aiming ring (Dentsply; York, Pa). Each tray was fitted to the mandibular canine and first molar, which served as stable structures. Radiographs were taken at the first intervention and every 14 days thereafter until sacrifice.

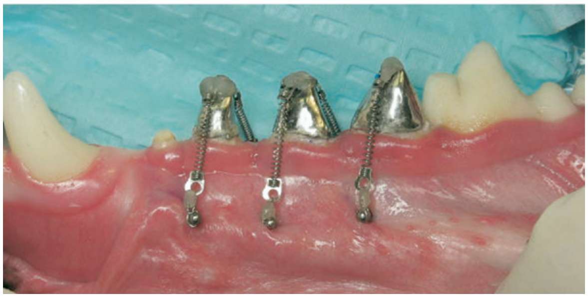

Fig 2. Mandibular left quadrant after second intervention and appliance activation.

Table I. Mandibular premolar force magnitude assignments, with 8 specimens per force per tooth (total n = 48)

	*Force (g)**	
Tooth	*Light*	*Heavy*
LPM2	50	100
LPM3	100	200
LPM4	50	200

*Forces are total per tooth.

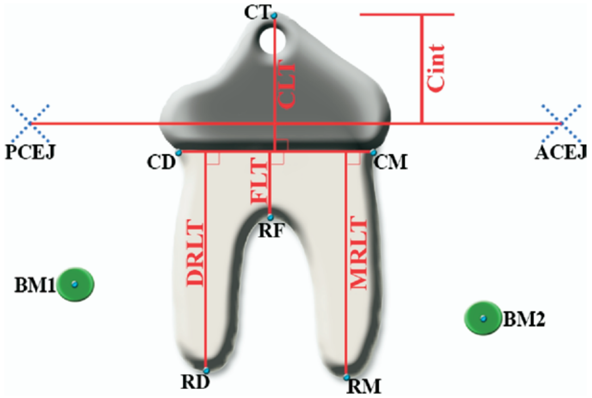

Fig 3. Radiographic landmarks and measurements: *BM1* and *BM2*, center of BMs 1 and 2; *ACEJ*, the most distal point of the cementoenamel junction of the mandibular canine; *PCEJ*, the most mesial point of the cementoenamel junction of the mandibualr first molar; *CT*, tip of the cast crown following its longitudinal axis; *CM*, the mesial border of the cast crown; *CD*, the distal border of the cast crown; *RM*, mesial root apex; *RF*, deepest point of the root furcation; *RD*, distal root apex; *Cint*, crown intrusion; *CLT*, crown length; *MRLT*, mesial root length; *FLT*, furcation length; *DRLT*, distal root length.

At the end of the first intervention, postoperative analgesics (torbugesic 0.2 mg per kilogram, intramuscularly, and banamine 1 mg per kilogram, intramuscularly) and antibiotics (penicillin and benzathine 300,000 iu per 10 lbs, intramuscularly) were administered.

Individual cast metal crowns were then made for the LPM2, LPM3, and LPM4 (Fig 2). They were fabricated from vitallium alloy (Vitallium, Dentsply; York, Pa); careful margin adaptation of the metal crown was performed to prevent interference with tooth intrusion.

At the second intervention, on day 0 (Fig 1), all crowns were cemented with adhesive resin cement (Panavia 21 EX, Kuraray Medical, Kurashiki, Japan), and an MSI placement site was selected for each tooth. The MSIs in this experiment were 1.8 mm in diameter and 6 mm long (IMTEC, Ardmore, Okla). A total of 12 MSIs were placed per animal, with 3 buccal and 3 lingual MSIs per side. The MSIs were placed after drilling a pilot hole with a slow-speed drill (1.1 mm diameter) with copious irrigation. Each tooth had 1 MSI placed on the buccal and 1 on the lingual aspects. The intrusive force was achieved by placing the buccal MSI in the mesial interradicular bone and the lingual MSI in the distal interradicular bone of the tooth being intruded (Fig 2).

The force was delivered immediately after MSI placement by 2 Sentalloy (GAC International, Bohemia, NY) closed-coil springs (1 per MSI) attached with a 0.01-in stainless steel ligature (Fig 2). For this split-mouth design, there were 2 randomly assigned force magnitudes (heavy or light) for each tooth (Table I). The force of each coil spring was checked and calibrated with a gram-force gauge (Correx; Haag-Streit, Koeniz, Switzerland) during the initial activation and at the records procedures (every 14 days) to ensure that the same force was maintained throughout the experiment. After the intervention, postoperative analgesics and antibiotics were administered, and the animals were fitted with Elizabethan hoods for no more than 5 days to prevent them from damaging the appliances.

At each intervention and record procedure, the teeth and the appliances were cleaned by using mouth rinse and a soft toothbrush. Photographs, radiographs, force calibration, width measurements, and implant stability records were taken at the second intervention and every 14 days thereafter until the dogs were sacrificed on day 98.

To measure buccolingual tipping, the average of 3 repeated width measurements was used. These width measurements were made with a digital caliper (Maryland Metrics, Baltimore, Md) between each pair of teeth at 2 levels, the gingival margin and the crown tip.

Table II. Polynomial model describing LPM2 crown intrusion movements (mm) in beagles subjected to light and heavy forces for 98 days

	Constant (day 49)		*Linear*		*Quadratic*	
Explanatory variable	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
LPM2 50 g						
Cint	1.0093	0.4415	0.02588	0.006746	NS	NS
CM	1.1992	0.1919	0.02502	0.004761	NS	NS
CD	1.1629	0.1874	0.02242	0.003906	NS	NS
LPM2 100 g						
Cint	1.4097	0.3174	0.02976	0.000849	NS	NS
CM	1.1493	0.3135	0.02833	0.007489	NS	NS
CD	0.9182	0.2152	0.02181	0.057623	NS	NS

CM, Crown mesial; *CD,* crown distal; *Cint,* crown intrusion; *NS,* not significant ($P < .05$).

Then the periapical radiographs were scanned at a resolution of 300 dpi and digitized by using Viewbox Software (version 3.1.1.8; Athens, Greece). First, the landmarks indicated in Figure 3 were digitized. After this, the radiographs were superimposed by using the BMs as registration points and orienting the radiographs along the occlusal plane (ACEJ-PCEJ). After superimposition, 7 measurements were computed for each tooth, including the following.

1. Crown intrusion (Cint): the perpendicular distance from the occlusal plane (ACEJ-PCEJ) to the crown tip (CT).
2. Crown mesial (CM): the perpendicular distance from the occlusal plane (ACEJ-PCEJ) to the crown mesial margin (CM).
3. Crown distal (CD): the perpendicular distance from the occlusal plane (ACEJ-PCEJ) to the crown distal margin (CD).
4. Mesial root length (MRLT): the perpendicular distance from the margin of the crown (CM-CD) to the mesial root apex (RM).
5. Furcation length (FLT): the perpendicular distance from the margin of the crown (CM-CD) to the root furcation (RF).
6. Distal root length (DRLT): the perpendicular distance from the margin of the crown (CM-CD) to the distal root apex (RD).
7. Crown length (CLT): the perpendicular distance from the margin of the crown (CM-CD) to the crown tip (CT).

Statistical analysis

To statistically determine the patterns of change during the experimental period and to compare the forces used, multilevel statistical models were developed by using the MLwiN software (version 2.01, Centre for Multilevel Modelling, Institute of Education, London, United Kingdom). The iterative generalized least squares method was used to estimate the model parameters.[57] These models make maximum use of the repeated measures, allow for missing data, and make it possible to directly test the experimental effects.

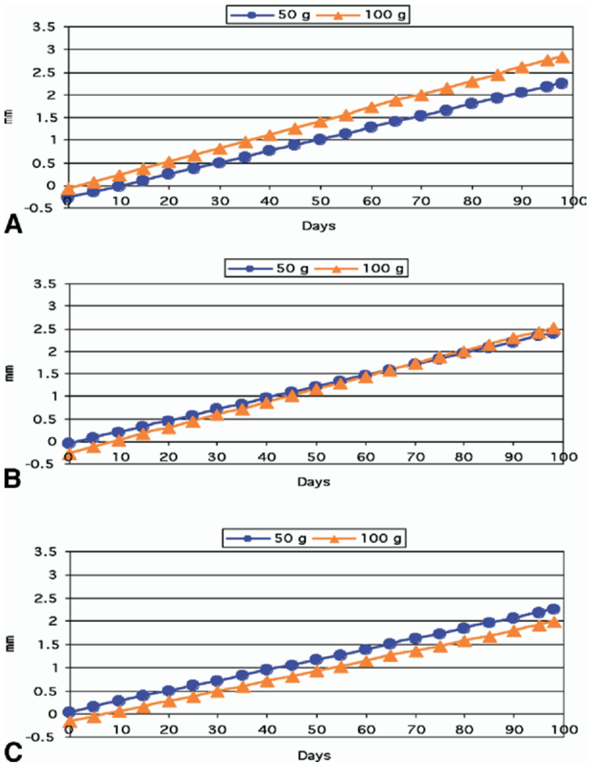

Fig 4. Crown movements of LPM2 subjected to light (50 g) and heavy (100 g) forces for 98 days: **A,** Cint; **B,** CM; **C,** CD.

Each model consisted of a fixed part and a random part. The fixed part determined the polynomial that best fit the repeated measurements of crown intrusion and

Table III. Polynomial model describing LPM3 crown intrusion movements (mm) in beagles subjected to light and heavy forces for 98 days

	Constant (day 49)		*Linear*		*Quadratic*	
Explanatory variable	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
LPM3 100 g						
Cint	0.8345	0.2897	0.02408	0.007208	0.000198	0.000067
CM	0.8613	0.2374	0.02251	0.007676	NS	NS
CD	0.8195	0.2612	0.02407	0.007894	0.000173	0.000068
LPM3 200 g						
Cint	0.8389	0.4179	0.03019	0.007675	0.000249	0.000011
CM	0.8916	0.2749	0.02790	0.005805	0.000223	0.000082
CD	1.1248	0.2387	0.03386	0.006575	0.000229	0.000088

CM, Crown mesial; *CD,* crown distal; *Cint,* crown intrusion; *NS,* not significant ($P < .05$).

root resorption. The parameters of the polynomial were derived by first fitting higher-order polynomial terms (ie, quartic), testing them statistically, and rejecting them sequentially until a lower-order term (quadratic, linear, or constant) attained significance. The constant term described the crown heights and root lengths at day 49, the linear terms described rates of change (velocity) per day, and the quadratic terms described the acceleration each day. Standard errors were used to determine significance ($P < .05$). After having determined the appropriate polynomial, an additional set of models was developed to statistically test the effects of various force magnitudes on intrusion and root resorption. The models evaluated differences in rates of change (linear and quadratic) as well as differences at the end of the experiment. The models partitioned random variation at 2 levels: between animals at the higher level and between measurement occasions, nested within animals, at the lower level.

RESULTS

The stability of the MSIs was tested every 14 days. They were determined to be stable if there was no mobility when submitted to lateral forces. All but 1 MSI remained stable throughout the experiment (success rate, 99%). One MSI, at the buccal side of LPM4, subjected to a 100-g force, failed. This failure was due to bone resorption around the MSI, which was evident radiographically at midtreatment. The failure occurred after 50 days of loading; a new MSI was placed at an adjacent site, and force application was continued.

The LPM2s were intruded 2 to 2.8 mm over the 98 experimental days (Table II). The pattern of intrusion was linear for all measurements. Although crown intrusion was slightly greater for the heavy (100 g) than the light (50 g) forces, the rates of change and the amounts of intrusion at the end of the experimental period were not significantly different (Fig 4).

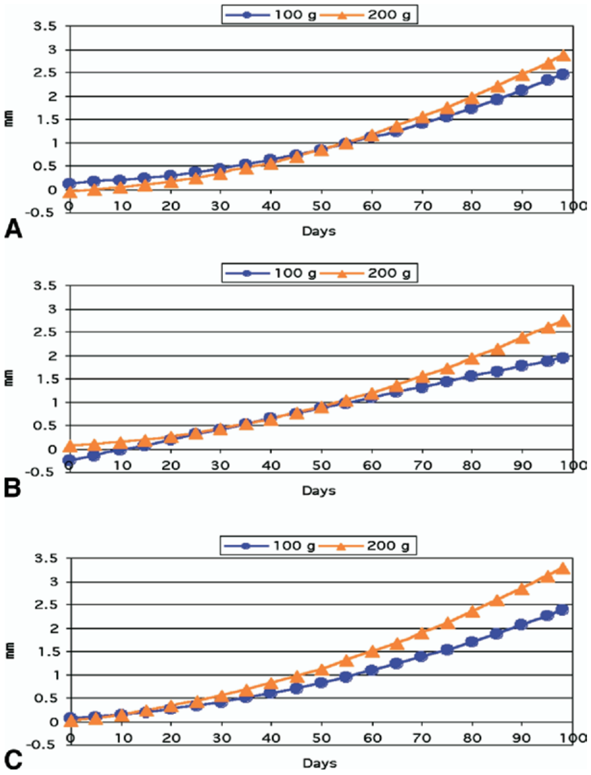

Fig 5. Crown movements of LPM3 subjected to light (100 g) and heavy (200 g) forces for 98 days: **A,** Cint; **B,** CM; **C,** CD.

The LPM3s were intruded 1.9 to 3.3 mm. Five of the 6 measures showed curvilinear patterns of intrusion (Table III), with rates increasing over time; the remaining measure showed a linear pattern. Over 50% of crown intrusion occurred during the last 30 days of the experiment. Although the heavy (200 g) force showed greater intrusion than the light (100 g) force, the differences in rates and the final amounts of intrusion were not statistically significant (Fig 5).

Table IV. Polynomial model describing LPM4 crown intrusion movements (mm) in beagles subjected to light and heavy forces for 98 days

	Constant (day 49)		*Linear*		*Quadratic*	
Explanatory variable	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
LPM4 100 g						
Cint	0.6545	0.2125	0.01851	0.007137	0.000147	0.000069
CM	0.5844	0.2511	0.01591	0.006668	NS	NS
CD	0.5056	0.2279	0.01969	0.006581	0.000185	0.000076
LPM4 200 g						
Cint	0.3083	0.4121	0.01764	0.007807	0.000210	0.000078
CM	0.5549	0.1788	0.01437	0.005830	NS	NS
CD	0.6593	0.1956	0.01645	0.006232	NS	NS

CM, Crown mesial; *CD,* crown distal; *Cint,* crown intrusion; *NS,* not significant ($P <.05$).

The LPM4s also showed significant amounts of intrusion, but less than the other 2 teeth. Three of the 6 measures showed curvilinear patterns of intrusion similar to the LPM3 (Table IV). The amounts of intrusion were 1.2 to 1.9 mm, produced over 98 days of constant loading. Group differences (50 vs 200 g) in the rates and the amounts of intrusion at the end of the experimental period were not statistically significant (Fig 6).

There was little or no root resorption associated with the intrusive movements. None of the periapical radiographs demonstrated blunting of the root apices. The metric analysis showed statistically significant ($P <.05$) root resorption for 5 of the 18 measurements. However, there was no consistent pattern of root resorption; resorption involved all 3 teeth and occurred with both light and heavy forces. Importantly, the total amounts of resorption were consistently less than 0.1 mm (Fig 7).

DISCUSSION

The results of this experiment showed excellent stability of the MSIs after immediate loading with forces of 25 to 100 g (each MSI received 50% of the force applied to each tooth). Ninety-nine percent of the MSIs remained stable throughout the 98 days of the experimental period. One MSI failed after 50 days of loading with a constant force of 100 g. The failure was related to bone resorption, which was evident radiographically around the MSI. Root resorption extended to the distal root of the adjacent tooth. Because it was an isolated case, the bone resorption at the peri-implant surface was probably associated with inflammation, infection, or overheating of the bone during placement. Our results compared well with MSIs that were loaded after 3 to 6 weeks of healing.[18,51,56] Our overall failure rate was substantially lower than previously reported for immediately loaded MSIs (13%-20%).[52,53,56] The main reasons for failure reported by these studies were placement difficulties (leads to failure in primary stability) and inflammation of soft tissues around the MSIs. Our success rate is probably due to the primary stability achieved, minimal peri-implant inflammation, the soft diet, and the controlled experimental situation.

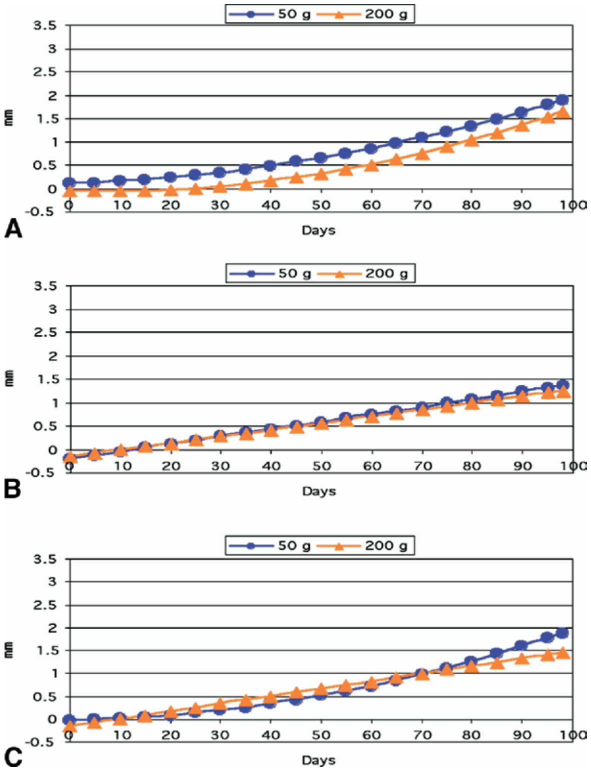

Fig 6. Crown movements of LPM4 subjected to light (50 g) and heavy (200 g) forces for 98 days: **A,** Cint; **B,** CM; **C,** CD.

Clinically significant amounts of intrusion (1.2-3.3 mm) were obtained with MSIs as anchorage for 98 days (Fig 8). Differences were due primarily to tooth size. The LPM4 was intruded less than the other 2 teeth,

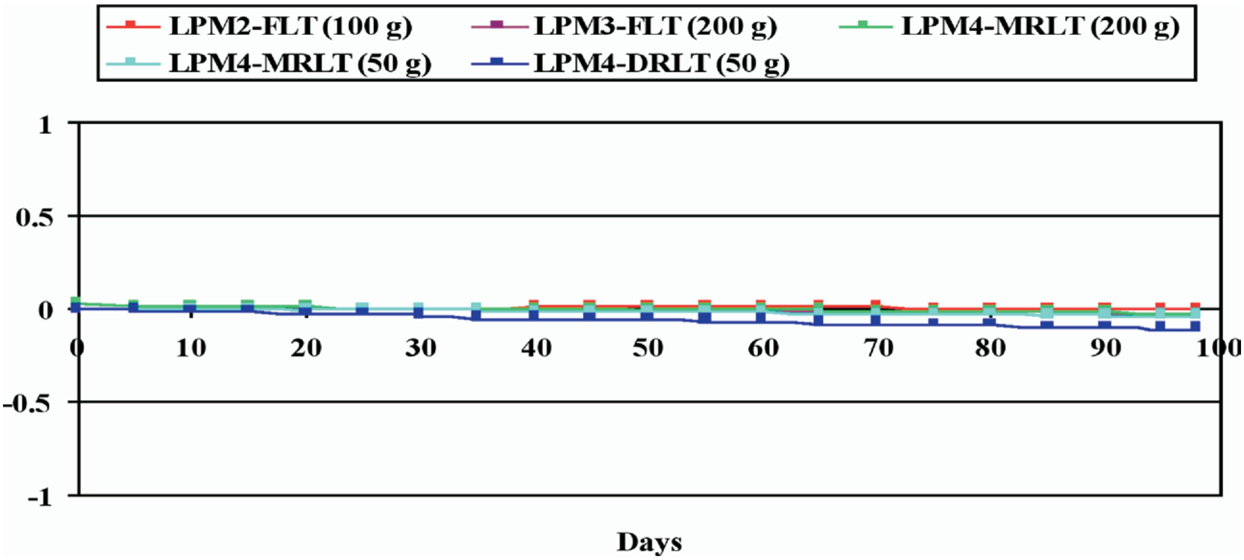

Fig 7. Root resorption of LPM2, LPM3, and LPM4 subjected to heavy and light forces for 98 days.

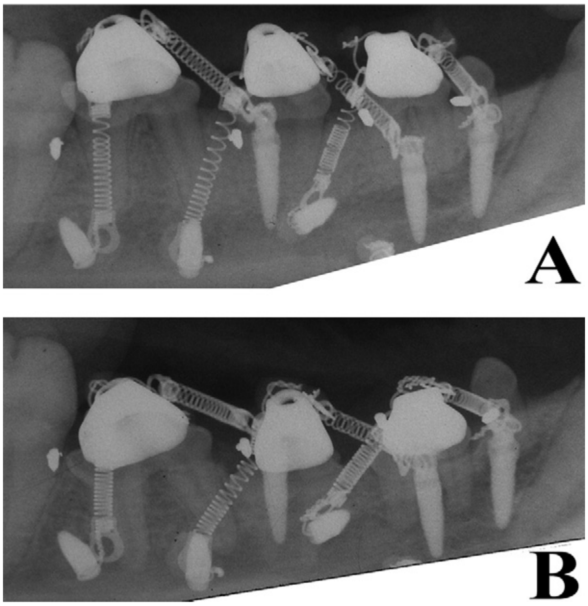

Fig 8. Periapical radiographs of LPM2, LPM3, and LPM4: **A,** Initial loading at day 0; **B,** after 98 days of constant loading.

perhaps because it has larger roots; this implies a larger enface root surface.[58] The only study that used a similar force application to our study achieved 4.5 mm of intrusion (3.3-5.7 mm) over 12 to 18 weeks, with a constant force of 150 g.[18] Differences in the amounts of intrusion might be explained by differences in sample sizes and active treatment times. Our results compared well with those of Daimaruya et al,[35] who showed average intrusions of 2.1 mm over 4 months and 3.4 mm over 7 months, with 100 and 150 g of constant force, respectively. One retrospective study[45] and many case reports[36,37,40-43] with MSIs or titanium screws for anchorage to intrude posterior teeth (molars and premolars) reported intrusions from from 1 to 6 mm over 5 to 13 months of treatment.

Our study showed similar amounts of intrusion after 98 days of constant forces, from 50 to 200 g. The lighter forces produced slightly less intrusion in the LPM2 and the LPM3, but the opposite was observed for the LPM4. This agrees with a recent study of deep-bite patients by van Steenbergen et al,[30] who reported no statistically significant differences between the 40-g and the 80-g force groups after intrusion of the maxillary anterior teeth of approximately 2 mm. They concluded that higher forces did not increase the rate of intrusion. In contrast, Dellinger[17] reported that intrusion of premolars in 4 *Macaca speciosa* monkeys was related to the forces applied. However, the variability and the small sample size of that experiment (2 premolars per force group), and the lack of statistical comparisons, make it difficult to conclude that the different amounts of intrusion were related to the different forces applied. Steigman and Michaeli[31] suggested that the force applied should depend on capillary blood pressure if one wants to obtain the optimal intrusion rate.

The models of the repeated measurements indicate that crown intrusion was time dependant and might have a curvilinear pattern, with a latency period initially and acceleration of rates after 20 to 30 days. A latency phase, followed by increased rates of tooth movement, was previously reported for intrusion and lateral tooth movements.[35,59] Steigman and Michaeli[31] reported similar results, concluding that intrusion movements had a similar pattern to that of lateral tooth movements.

Radiographically, there was little or no evidence of root resorption associated with the intrusive movements observed. Only 5 of the 18 variables showed signs of minor resorption, which was less than 0.1 mm in all cases. Moreover, there was no clear pattern with respect to the forces, the teeth, or the area of resorption (apical or interradicular). After 7 months of intrusion in beagles, Daimaruya et al[35] reported similar amounts of root resorption radiographically (0.1 ± 0.1 mm). Their histological examination showed that resorption reached the dentin in teeth intruded for 7 months and the cementum in teeth intruded for 4 months. Similarly, Ohmae et al[18] reported no root resorption radiographically, but microscopically they reported mild root resorption limited to the cementum at the furcations and the apices of the beagles' premolars. Even though the small sample size makes direct extrapolation of his results difficult, Dellinger's histological findings[17] showed that force magnitude was related to root resorption, with resorption decreasing as the intrusive forces became lighter. He found severe root resorption with 300 g, moderate resorption with 100 g, and slight to moderate resorption with 10 and 50 g of force applied to the first premolars of monkeys. This agrees with other histologic studies that reported greater resorption lacunae with heavier forces rather than lighter forces to intrude teeth without fixed anchorage.[21,28] Importantly, several studies indicated that repair or remodeling of the cementum occurred at the resorbed areas when the forces were discontinued.[18,29,35] The evidence suggests that root resorption probably does occur at the apices and interradicular regions of the intruded teeth, but it is undetectable radiographically and tends to repair after force application is stopped, suggesting that it might not be clinically meaningful over the time period studied.

CONCLUSIONS

1. Immediately and constantly loaded MSIs are highly stable anchorage devices for delivering forces of 25 to 100 g.
2. Clinically significant amounts of intrusion (1.2-3.3 mm) of multiradicular teeth can be obtained by applying forces of 50 to 200 g for 98 days with MSIs as anchorage.
3. Constant forces differing by as much as 150 g have no significant effect on the amounts of intrusion observed.
4. Radiographically, root resorption was not clinically significant after application of various intrusive forces of 50 to 200 g.

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