Effects of magnitude of intrusive force on pulpal blood flow in maxillary molars

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Introduction: In this study, we aimed to evaluate and compare blood-flow changes in the pulp tissues of maxillary molars over a 6-month period after orthodontic intrusion using different magnitudes of force. **Methods:** Twenty patients were randomly divided into 2 groups (n = 10) according to the amount of intrusive force applied. An intrusive force of either 125 g (light) or 250 g (heavy) was applied to the overerupted maxillary first molars using mini-implants; no force was applied to the contralateral molars. Laser Doppler flowmetry was used to measure pulpal blood flow (PBF) at baseline and during intrusion at 24 hours, 3 days, 7 days, 3 weeks, 4 weeks, 3 months, and 6 months. The data were analyzed with the Mann-Whitney U and Wilcoxon signed rank tests, with $P < 0.05$ considered statistically significant. **Results:** PBF decreased significantly at 3 days and continued to remain suppressed until 3 weeks, after which a gradual trend of recovery was observed until 3 months, when the levels returned to near those measured before intrusion. When the data were analyzed with regard to the amount of applied force, significant differences were observed between the 2 groups only at 3 and 7 days. **Conclusions:** These findings demonstrate that despite slight regressive changes in pulpal tissue over the short term, PBF values tend to return to their initial levels within 3 months, indicating that changes observed in PBF are reversible, even during radical intrusions of molars with 125 and 250 g of forces. (Am J Orthod Dentofacial Orthop 2015;148:83-9)

One of the greatest challenges encountered in clinical dentistry is the overeruption of maxillary molars; this usually results from early loss of antagonistic teeth. Treatment is important because overeruption can cause occlusal interferences and functional disturbances as well as severe difficulties during prosthetic reconstructions. Nonsurgical treatment strategies are focused mostly on molar intrusion, which entails great risk for pulp microcirculation. Little research has been conducted on the effects of orthodontic intrusion on dental pulp in human subjects with matched controls. In most cases, research has involved animal models or histologic methods.[1-3] Butcher and Taylor[1] reported that the application of intrusive forces to monkey incisors caused pulp tissue necrosis, and another study on rat incisors found compromised pulpal blood flow (PBF) after intrusion.[2] Histologic studies of human teeth have shown that the main changes after intrusion include vacuolization of pulp tissue, circulatory disturbances, congestion, hemorrhage, and fibrohyalinosis.[3] Only a few clinical studies have evaluated the response of dental pulp to intrusive forces in humans.[4-8] Of these, Sabuncuoglu and Ersahan,[4] Ikawa et al,[5] and Sano et al[6] described significant reductions in PBF caused by the intrusive forces, whereas Barwick and Ramsay[7] found no changes in PBF during intrusion. Of the work done on human subjects, the intrusive forces were applied on incisors, but on molars in only 1 study.[8]

To prevent circulatory disturbances in dental pulp during intrusion, the magnitude of force needs to be considered[9]; however, the optimal magnitude of force for molar intrusion has not yet been established. Although Umemori et al[10] recommend a force of 500 g, Park et al[11] successfully used 200 to 300 g, and Kalra et al[12] used a force of 90 g. It is generally assumed that the greater the orthodontic force, the greater the pulpal changes and their consequences, but sound scientific data to support this assumption are lacking.[9] Early histologic studies made it clear that excessive force applied in orthodontic treatment leads to undesirable results, but there is still no generally accepted limit to the magnitude of the force that may be used to obtain satisfactory molar intrusion

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without harmful effects.[3] Therefore, this study was undertaken to use laser Doppler flowmetry (LDF) to evaluate the response of molar pulp to orthodontic intrusion performed under controlled clinical conditions with either light (125 g) or heavy (250 g) intrusive forces applied to overerupted maxillary first molars by mini-implants. PBF was measured at baseline and at various intervals during intrusion, and changes in PBF were analyzed according to the amount of force and the duration of intrusion.

MATERIAL AND METHODS

This study was approved by the institutional review board and ethics committee of the Ministry of Health's Kecioren Training and Research Hospital (B.10.4.ISM.4.06.68.49/495) in Ankara, Turkey, and complied with the principles of the Declaration of Helsinki. Informed consent was obtained from all participants. In total, 20 healthy patients (age range, 20-40 years; mean age, 27.6 years) with overerupted maxillary first molars were selected from among the patients applying to the hospital for treatment. Initial periapical radiographs were taken, and patients with missing maxillary first molars, trauma, caries, restorations, periapical radiolucency, root resorptions, or previous orthodontic treatment were excluded from the study. The participants were randomly divided into 2 groups ($n = 10$) according to the level of force applied. In group 1 (light), an intrusive force of 125 g was applied to the overerupted maxillary first molar, and in group 2 (heavy), an intrusive force of 250 g was applied. No force was applied to the contralateral molars, which served as controls. Force was applied with a mini-implant inserted according to the following procedures.

Orthodontic crown bands with buccal tubes were cemented onto the maxillary molars, and a continuous 0.016×0.022-in stainless steel wire was placed in the maxillary arch in preparation for mini-implant insertion. One mini-implant (AbsoAnchor; Dentos, Taegu, Korea; 1.3 mm diameter, 6 mm length) was inserted into the buccal alveolus between the maxillary first and second molars, and another was placed in the paramedian palatal area 2 mm from the midpalatal suture and close to the imaginary midline between the second premolar and the first molar. Standard periapical radiographs were taken to check the positions of the mini-implants in relation to neighboring roots. One week after placement, the mini-implants were loaded, and intrusive forces of 125 or 250 g were applied. Maxillary molar intrusion was performed using elastic power chains attaching the alveolar mini-implant to the main archwire and the palatal mini-implant to a lingual button on the maxillary molar. Force levels were checked at monthly appointments. Molar intrusion was accomplished in 6 months, when the mini-implants were removed. No other treatment was performed until after the intrusion was complete.

PBF was measured using an LDF (Periflux PF 4001; Perimed, Järfälla, Sweden). The LDF output signal voltage is linearly related to red blood cell flow (number of cells $\times$ average velocity), which is recorded in perfusion units (PUs) to provide a relative measurement of blood flow. The LDF used in this study has a 1-mW helium-neon laser with a wavelength of 632.8 nm. A straight probe (PF 416; Perimed) with a diameter of 2 mm was used to conduct a light beam of 125 μm (fiber-to-fiber distance, 500 μm) to the measurement site in the dental pulp and to retrieve the backscattered light to the flowmeter. Before each measurement, the probe was calibrated for zero voltage and a motility standard of 250 PU using a plastic block (Perimed).

LDF measurements were recorded just before intrusion (T0) and at hour 24 (T1), day 3 (T2), day 7 (T3), week 3 (T4), week 4 (T5), month 3 (T6), and month 6 (T7) after intrusion. Accuracy and reproducibility of the measurements were achieved by giving each patient a custom-fabricated splint of self-curing acrylic resin that was used to secure the probe in the appropriate position approximately 2 mm from the gingival margin (Fig 1). Before PBF measurement, arch and molar bands were temporarily removed from the teeth, a black rubber dam and a splint were positioned in the patient's mouth, and the patient was allowed to relax in the dental chair in a supine position for approximately 10 minutes. PBF was measured in the test and control molars at the same session; however, because only 1 probe was available, the measurements were performed consecutively, with the probe remaining on 1 tooth for approximately 1 minute before being transferred to the contralateral tooth. All measurements were performed by the same operator (S.E.) under standardized environmental conditions at a constant room temperature. Attempts were made to minimize bias caused by movement of the subject and the probe, and pulse rate and blood pressure were recorded throughout the measurement sessions. No participant reported pain or discomfort during the procedure. After a constant reading was obtained, the splint and the rubber dam were removed, and the arch and molar bands were repositioned on the teeth. For each measurement session, the mean PU for each tooth was calculated based on the phase of stable values, excluding peaks attributable to movement artefacts. LDF data were transferred to a computer connected to the RS-232 port of the flowmeter using the system's own software (PeriSoft for Windows; Perimed) and stored for analysis later.

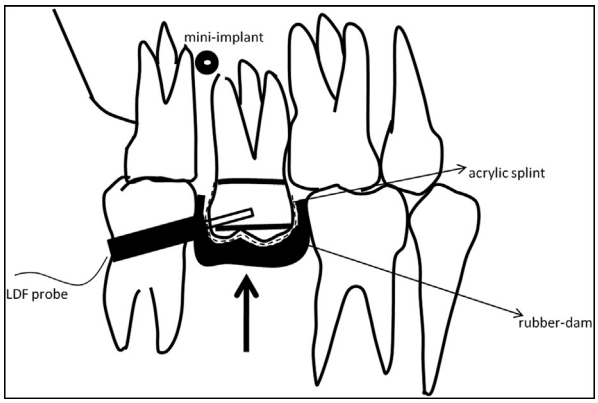

Fig 1. Schematic drawing of the mini-implant and LDF probe.

Statistical analysis

The statistical analysis was performed using a software program (version 13.0; MedCalc Software, Ostend, Belgium). Changes in PBF within and between groups were assessed by Wilcoxon signed rank and Mann-Whitney U tests, respectively, with statistical significance set at $P < 0.05$.

RESULTS

Overeruption was corrected by intruding the maxillary molars 1 to 2 mm over a 6-month period using a mini-implant system. The treatment had an overall success rate of 97.5%. Of the 40 mini-implants inserted, mobility was observed in the fifth month in 1 implant, which was removed but not replaced because treatment was nearing conclusion. No subject complained of pain or tooth discoloration during the study period, and periapical radiographs of the patients in the study group showed no signs of root resorption.

When analyzed in relation to the duration of intrusion, no differences between the T0 PBF values of the study and the control groups were observed ($P = 0.791$ and $P = 0.940$, respectively, for the light and heavy forces), and no significant changes in PBF were observed in the control group at any point during the study (Table). Initially, PBF did not change significantly in the first 24 hours (8.7% ± 0.6% and 8.7% ± 0.5%, respectively, for the light and heavy force groups). However, PBF decreased significantly at T2 (6.1% ± 0.4% and 5.4% ± 0.7%, respectively, for the light and heavy force groups; $P < 0.001$). It subsequently remained suppressed, with no statistically significant change in PBF between T2 and T3 ($P = 0.799$ and $P = 0.919$, respectively, for the light and heavy force groups) or between T3 and T4 ($P = 0.878$ and $P = 0.959$, respectively, for the light and heavy force groups). The initial decrease in PBF was followed by a gradual trend of recovery of intrusion beginning at T4 in which the PBF values at T6 attained levels similar to those measured before intrusion. No significant changes in PBF were observed from T6 to T7 ($P = 0.959$ and $P = 0.646$, respectively, for the light and heavy force groups), and no differences in PBF were found between T7 and T0 ($P = 0.959$ and $P = 0.959$, respectively, for the light and heavy force groups).

When analyzed in relation to the amount of intrusive force, mean baseline PBF values of the light and heavy force groups were similar (8.7% ± 0.6 % and 8.7% ± 0.8%; $P = 0.910$, respectively, for the light and heavy force groups), and no significant changes in PBF were observed in the control group at any point during the study. Moreover, no significant differences were found between the light and heavy force groups at T1 ($P = 0.970$). However, Mann-Whitney U test results showed more pronounced decreases of PBF at T2 and T3 in the patients in the heavy force group than in the light force group ($P = 0.011$ and $P = 0.014$, respectively, at T2 and T3). No significant differences between the 2 study groups were observed at any other times. Figure 2 shows the relationship between PBF (PU), applied force magnitude (g), and the time points.

DISCUSSION

LDF has been applied to measure PBF in both humans[4-8] and experimental animals.[13] Recently, LDF has become a popular technique applied for pulp vitality testing in traumatized teeth because of its greater sensitivity and specificity compared with other dental pulp tests.[9] However, LDF assessment of PBF is highly susceptible to environmental and technical factors, such as flowmeter characteristics, gingival isolation device, ambient temperature, position of the probe, and patient position and rest status as well as other patient-related factors such as stress, medication, and age-related changes.[14,15] Moreover, although lasers with longer wavelengths give higher flux readings (probably because of their greater penetration through tooth tissue), the inclusion of nonpulpal blood flow in the signal may reduce the vital-to-nonvital signal ratio.[15] For this reason in this study, we used a 632.8-nm laser source rather than a 780- or an 810-nm laser. Furthermore, a custom-made acrylic resin splint was used to stabilize the probe, maintain it in contact with the tooth, and create a reproducible position for follow-up measurements, and a black rubber dam was used in conjunction with the splint to minimize the contribution of neighboring pulp and gingiva to the flux signal. The same technique has been successfully used previously.[8]

Table. PBF measurements of all groups during the observation periods

	T0	*T1*	*T2*	*T3*	*T4*	*T5*	*T6*	*T7*
Light force group (n = 10)								
Mean ± SD	8.7 ± 0.6	8.7 ± 0.6	6.1 ± 0.4	6.1 ± 0.6	6.1 ± 0.8	7.0 ± 0.9	8.7 ± 0.8	8.7 ± 0.8
Median (minimum-maximum)	8.8 (8.0-9.8)	8.8 (8.0-9.8)	6.1 (5.6-6.8)	6.2 (4.9-6.8)	6.0 (4.9-7.4)	6.8 (5.7-8.6)	8.8 (7.4-9.8)	8.7 (7.0-9.9)
Control group (n = 10)								
Mean ± SD	8.7 ± 0.8	8.7 ± 0.9	8.7 ± 0.8	8.7 ± 0.6	8.7 ± 0.7	8.7 ± 0.7	8.7 ± 0.6	8.7 ± 0.8
Median (minimum-maximum)	8.5 (7.7-10.4)	9 (6.9-10.1)	8.6 (7.9-10.1)	9.0 (7.3-9.2)	8.6 (7.9-10.1)	8.8 (7.7-10.1)	8.6 (7.9-9.5)	8.8 (6.9-9.9)
*P**	0.791	0.762	<0.001	<0.001	<0.001	<0.001	0.912	0.796
Heavy force group (n = 10)								
Mean ± SD	8.7 ± 0.8	8.7 ± 0.5	5.4 ± 0.7	5.4 ± 0.5	5.4 ± 0.4	6.3 ± 1.0	8.7 ± 0.9	8.7 ± 0.9
Median (minimum-maximum)	8.5 (7.7-10.1)	8.7 (8.0-9.7)	5.5 (4.0-6.8)	5.5 (4.5-6.1)	5.5 (4.8-6.2)	6.4 (4.9-7.9)	8.6 (7.2-10.0)	8.4 (7.5-10.3)
Control group (n = 10)								
Mean ± SD	8.7 ± 0.8	8.7 ± 0.8	8.7 ± 0.6	8.7 ± 0.6	8.7 ± 0.8	8.7 ± 1.0	8.7 ± 0.7	8.7 ± 0.9
Median (minimum-maximum)	8.9 (7.7-10.1)	8.9 (7.2-10.0)	8.7 (6.9-10.1)	8.8 (7.7-9.7)	9.0 (7.7-10.1)	8.6 (7.2-10.6)	8.9 (7.4-9.7)	8.7 (7.3-10.1)
*P**	0.940	0.820	<0.001	<0.001	<0.001	<0.001	0.940	0.880

*Mann-Whitney U test.

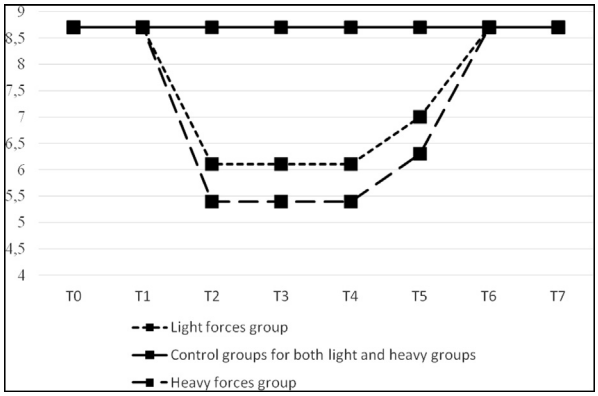

Fig 2. Relationship between PBF (PU), applied force magnitude (g), and time points.

To further ensure the validity of measurements, special care was taken to maintain ambient temperatures and patient-related factors such as position, rest, and stress levels.

LDF assessment is widely understood to be easier in anterior teeth than in posterior teeth because probe placement is more difficult in the posterior region; moreover, some researchers have suggested that the greater dentin thickness also makes it difficult to obtain LDF readings in the molars.[16] In a study examining the effects of power increases on signals recorded from teeth, Sasano et al[16] found that first premolars gave no signal at laser outputs of 2, 5, 7, or 10 mW; they suggested that the thick dentin prevented the photons from deeply penetrating and passing through the tooth toward the receiving fiber. In contrast to this assertion, Vongsavan and Matthews[17] found that LDF could pass through enamel and dentin of 2 to 3.5 mm in thickness to measure blood flow in dental tissues, and Ikawa et al[18] showed that laser light was capable of penetrating roots at a depth of 6 mm. In our study, at no time during any observation period was there an absence of PBF, indicating that enamel thickness is not a significant issue in measurement. The findings of Sasano et al could be attributed to their use of an LDF probe comprising 2 glass optical fibers—one for transmitting light onto the labial surface, and the other for receiving it at the palatal surface of the same tooth.

PBF values were found to be significantly affected by orthodontic intrusion. No differences were observed among the baseline PBF values of the control and study groups, and no significant changes in PBF were observed in the control group at any point during the study. The stable temporal pattern of blood flow observed in the control group is an indication of the consistency of the LDF testing method. No differences were observed in PBF values at T0 and T1 after the application of intrusive force in either study group. The initial stability in PBF in both groups can be attributed to an acute inflammatory reaction, which is characterized by blood vessel dilatation and increased blood circulation.[19] The most significant change in PBF was observed at 3 days after the onset of intrusion. This could be the result of a significant compression of the blood-supplying vessels because of the transient apical displacement caused by intrusion.[6] PBF values remained suppressed until T4 and began to show signs of recovery at T5; this could

represent the transition between the acute and chronic phases of the intrusion process. PBF values showed a steady increase between T4 and T6, when the levels returned close to those measured before intrusion. These findings suggest that clinical assessment of PBF in molars should begin no later than 3 days after intrusion and continue intermittently for 3 months.

These findings indicate that changes in molar pulp vascularity vary somewhat according to the amount of intrusive force applied (125 vs 250 g). Whereas PBF values at T1, T6, and T7 of intrusion were similar to the T0 values regardless of the amount of force applied, the application of heavy force as compared with light force resulted in significantly more pronounced decreases in PBF at T2 ($P = 0.011$) and T3 ($P = 0.014$). This could be due to the iatrogenic trauma caused by the heavy forces at the early stage of intrusion. Many earlier studies support the findings that heavier intrusive forces tend to produce greater microcirculatory disturbances.[3-6,20-22] Both Sano et al[6] and Brodin et al[22] reported greater reductions in PBF with increases in intrusive forces, and Ikawa et al[5] showed that PBF decreased significantly with an increase in intrusive force up to 5 N. Moreover, in a histologic study in which intrusive forces between 35 and 250 g were applied for 4 to 35 days to teeth scheduled for orthodontic extraction, Stenvik and Mjor[3] found significant alterations in pulp, including evidence of intravascular and extravascular degradation of red blood cells with forces above 120 g, which, given the occlusion of blood vessels, was attributed to stasis of PBF. In contrast to these earlier studies and our study, Nixon et al[23] found a significant increase in the number of capillaries in rats in line with the magnitude of intrusive force applied. The discrepancy in findings between that study and ours may be due to variations in methodologies (LDF study of human teeth vs histologic observation of rat teeth) and length of observation period (6 months vs 14 days). Although we found that the application of heavy intrusive forces resulted in a greater initial decrease in molar PBF than did light forces, PBF values in the study groups at 3 months and again at the end of the experiment (6 months) were similar to those of both baseline and control values. Thus, despite the tendency of higher force to produce more severe decreases in PBF at the initial stage of intrusion, these vascular changes were shown to be reversible, having subsided in only 3 months.

An explanation for the severe reduction in the PBF of the molars noted during the first 3 weeks of intrusion is possibly related to molar anatomy. PBF rates are affected by blood vessel constriction and circulatory disturbance, which are, in part, determined by the anatomy of the root apex.[8] Studies have shown that in comparison with incisors and premolars, molars have smaller apical foramina,[24-26] and the decrease in apical diameter might account for an increase in circulatory disturbance.[8] Stenvik and Mjor[3] reported more severe histologic disturbances in teeth with smaller apical foramina. Conversely, larger vessels entering the pulp play a major role in minimizing a decrease in blood flow during the application of an orthodontic force; this could explain the finding of Labart et al[27] that pulpal respiration increased in the continuously erupting incisors of rats. In addition, root anatomy affects stress distribution, and the greater root surface area of molars compared with other teeth would mean a wider distribution of a given stress at the root surface.[8] A lesser amount of stress could be expected to produce a lesser impact on blood flow.[8] Therefore, the reversible vascular changes seen in the molar pulp at T6 and T7 in this study could be due to the wider stress distribution effects on the molar root.[8]

Most previous studies examining the effects of orthodontic intrusion on dental pulp have been either experimental animal or histologic studies, and the results have been conflicting.[1-3,6,7,21,23,28] In general, the published data from animal studies have demonstrated that pulp tends to exhibit reduced vascular activity in response to orthodontic intrusion. Anstendig and Kronman[28] found a decrease in the number of blood vessels after the application of orthodontic force in dogs. Using in-vivo microscopy, Guevara and McCluggage[2] also observed an initial decrease in blood flow in rats. Konno et al[13] evaluated changes in pulpal morphology and blood flow in response to intrusion in a dog model and found that pressure generated by intrusive forces reduced the number of capillary blood vessels below the apical foramen, producing slight degenerative changes in pulp tissues. These findings are in line with those of our study. In contrast, in a histomorphometric study on rats, Nixon et al[23] reported an increase in the number of functional pulpal vessels after the application of orthodontic force, and Kvinnsland et al[21] showed a substantial increase in blood flow in the dental pulp of mesially tipped rat molars. The different responses reported may be due to variations in tooth anatomy among animal species, the magnitude of force exerted by orthodontic appliances, and the complex physiology of human dental pulp differing from that of animal pulp. Thus, it would be wrong to correlate our results with previous findings on other animal species or histologic findings on human teeth.

LDF has been successfully used for estimating pulpal vitality in adults and children, examining the reactions to pharmacologic agents or electrical and thermal stimulations, and monitoring pulpal responses to traumatic

injuries and orthodontic procedures.[29] Successful application of LDF in human teeth was first described by Gazelius et al.[30] They compared the LDF signals of vital, intact incisors with those of adjacent nonvital teeth and found that the vital teeth exhibited a heartbeat synchronous oscillation that was absent in the nonvital teeth. Olgart et al[31] first documented LDF as a clinically useful diagnostic instrument. They reported on the ability of LDF to correctly identify blood flow to the pulps of 16 traumatized teeth that did not respond initially to electronic pulp testing. Fernieini et al,[32] using LDF, compared the hemodynamic effects of local anesthetic administration. The greatest change was associated with anxiety and occurred just before the injection. This study has confirmed the sensitivity of LDF as an investigational device for assessing hemodynamic changes associated with anxiety and the administration of local anesthesia. Numerous investigations have been performed to elucidate the effects of orthodontic forces on the blood flow response of dental pulp.[4-8,13,33] McDonald and Pitt Ford[33] showed an initial decrease in blood flow to the dental pulp after orthodontic force application. Ikawa et al[5] described how a brief intrusive force significantly reduced PBF, and Sano et al[6] showed that PBF was significantly reduced during continuous application of an intrusive force, but recovery occurred after wire removal. Brodin et al[22] also showed that orthodontic intrusion evoked a temporary reduction in PBF, whereas extrusion had no effect. In contrast to these findings, Barwick and Ramsay[7] indicated that PBF does not change during the brief application of intrusive force. Although they found that the reduction in PBF as a result of the application of intrusive forces ranging from 75 to 4498 g for 4 minutes was not statistically significant, they suggested that this could be attributed in part to the small sample size (n = 8) or LDF signal error. Studies that have been discussed here mainly showed a trend toward the predominance of initial vascular changes, which agree with our results.[4-8,22,33] But those studies were undertaken on anterior teeth, including central and lateral incisors and canines.[4-7,22,33] A few studies on LDF have included molars.[8,34,35] Norer et al[35] investigated both interindividual and intraindividual PBF characteristics for different types of maxillary teeth over 3 sessions at 7-day intervals, but only 1 reading per tooth was taken per session. Intraindividual comparisons of tooth morphotype-related PBF values showed significant differences only for the first molar, whereas significant interindividual differences were found for the lateral incisor, canine, premolars, and first molar.[35] This exception for the first molars was attributed to technique-related difficulties with probe alignment with respect to both tooth location and pulp chamber anatomy.[35] Furthermore, contralateral teeth were indicated to be appropriate controls in the assessment of intraindividual tooth morphotype-related reference values.[35] A recent article by Sabuncuoglu and Ersahan[8] reported short-term regressive changes in pulpal tissues during molar intrusion and also stated that these changes were reversible. These findings are in line with those of our study. However, it would be wrong to correlate our results with the findings of Sabuncuoglu and Ersahan because of variations in methodologies. They applied relatively light forces (100 g) and did not use contralateral teeth as the controls. Furthermore, they could not determine the exact point at which PBF began to recover for lack of closer time intervals.[8] Consequently, our study is the first to evaluate and compare PBF changes of the first molars using different magnitudes of force.

CONCLUSIONS

The following conclusions can be drawn from this study.

1. A significant reduction in maxillary first molar PBF appears to occur during the early stages (day 1-week 3) of intrusion with either light (125 g) or heavy (250 g) force; however, in both cases, PBF values tend to return to their initial levels by 3 months after the initiation of intrusion.
2. The observed decreases in PBF at 3 and 7 days are more pronounced with the application of a heavy intrusive force (250 g) than with a light intrusive force (125 g) ($P < 0.05$); however, the differences in the amount of intrusive force do not result in significant differences in pulpal vascularity at other time points ($P > 0.50$).
3. Forces as great as 250 g can provide molar intrusion with no serious vascular consequences.

Despite the finding that changes in PBF are reversible during radical intrusion of molars with 125 and 250 g of force, whether the application of intrusive forces greater than 250 g affects pulp viability is still unclear. Additional studies are needed to further clarify the biologic effects of intrusion of the molars.

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