Pulp vitality and histologic changes in human dental pulp after the application of moderate and severe intrusive orthodontic forces

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Introduction: Orthodontic forces produce a series of changes in dental pulp. However, no one has attempted to investigate the incidence of pulp necrosis after orthodontic therapy in the clinic. In this study, we aimed to investigate pulp vitality and histologic changes after the application of moderate and severe intrusive forces.

Methods: Twenty-seven adolescent patients were assigned to 1 of 3 groups: the control group of 3 subjects; the moderate-force group, with 12 subjects who received a 50-g force to the first premolars bilaterally; and the severe-force group, with 12 subjects who received a 300-g force. The forces were applied for 1, 4, 8, or 12 weeks. An electric pulp tester was used to test for vitality, and teeth that did not respond to the electric pulp tester were subsequently tested thermally with a stick of heated gutta-percha.

Results: The teeth with a negative response to the electric pulp tester still responded to the thermal test. We found odontoblast disruption, vacuolization, and moderate vascular congestion in both force groups, but no necrosis was observed. Pulp stones were formed only in the severe-force group.

Conclusions: Dental pulp still has vitality after intrusive treatment with different forces. These data provide new insights into the effects of intrusive orthodontic forces.

Orthodontic forces are known to produce a series of changes in dental pulp after tooth movement. As a consequence of environmental constraints in a rigid and noncompliant shell, changes in pulpal blood flow or vascular tissue pressure have serious implications for the health of dental pulp. The main pulp changes after the application of intrusive forces include vacuolization of the pulp tissue, circulatory disturbances, congestion, hemorrhage, and fibrohyalinosis.1,2

It has been suggested that injury from orthodontic forces might be permanent, and the pulp could eventually lose its vitality.3 However, other studies showed that orthodontic forces had no significant long-lasting effects.4,5 A recent study showed that heavier forces applied during rapid palatal expansion were more likely to affect the pulpal vasculature, but the pulp of the posterior permanent teeth was still vital.6 Darendeliler et al7 found that 50 g of constant and continuous force could produce the ideal amount of tooth movement, but exceeding this force might cause periodontal ischemia, leading to root resorption. However, no study has attempted to investigate the incidence of pulp necrosis after orthodontic therapy in the clinic. Therefore, in this study, we aimed to investigate the histologic alterations of the dental pulp resulting from the application of moderate and severe orthodontic forces and to determine whether dental pulp loses its vitality after the application of a severe orthodontic force.

MATERIAL AND METHODS

This study was conducted on 54 maxillary first premolars collected from 27 prospective orthodontic patients (15 male, 12 female) with a mean age of 17.9 years (range, 14-24 years) who required first premolar extractions. The 27 subjects were randomly divided into 3 groups: the control group without orthodontic forces (3 subjects), the moderate-force group (12...
subjects), and the severe-force group (12 subjects). The moderate-force group had 50 g of buccally directed orthodontic intrusive force on both sides, and the severe-force group had 300 g of force. The experimental first premolars were extracted 1, 4, 8, or 12 weeks after the initial force application (6 teeth from each group were extracted at each time).

All study participants met the following criteria: (1) no major systemic disease, (2) no medication use, (3) healthy periodontium (minimal gingival inflammation, probing depths ≤3 mm, and no bone loss as determined by radiographs), (4) no endodontically treated teeth, (5) no trauma history, (6) complete root development determined radiographically (and confirmed visually after extractions), and (7) no moderate or severe crowding. The study was approved by the institutional review board of Jilin University in Changchun, China, and all participants gave informed consent.

A lingual button was bonded onto the buccal surfaces of the maxillary first premolars. Intrusive orthodontic forces were applied by a clear closed elastomeric chain (ORMAER; Dentsply Raintree Essix Glenroe, Sarasota, Fla) (Fig 1, A). The force magnitude was measured with a strain gauge (Dentaurum, Ispringen, Germany) at the beginning of the intrusion to ensure that proper forces were applied. The elastomeric chain was changed each time the patients revisited, once a week. A transpalatal arch was used to reinforce the anchorage (Fig 1, B). For the moderate-force (50 g) group, a transpalatal arch was used to reinforce the anchorage 4 weeks before the application of the force, and a Nance arch was additionally used to reinforce the anchorage 8 weeks after the application of the force. For the severe-force (300 g) group, both transpalatal and Nance arches were used to reinforce the anchorage immediately after the application of the force.

An electric pulp tester (Analytic Technology, Redmond, Wash) was used in this study. Toothpaste was the conducting medium. The testing site was confined to the buccal cusp tips of the molars and the premolars. Teeth that did not respond to the electric pulp tester were tested thermally with a stick of heated gutta-percha (hot testing). All teeth were isolated with cotton rolls and dried thoroughly before testing. The testing procedure was explained to the patients. The readings of the electric pulp tester were recorded, and the results of the thermal testing were recorded as a positive or a negative (yes or no) response.

Electric pulp tests were performed immediately before placement of the lingual button to provide a baseline for the study and at 1, 4, 8, and 12 weeks after the intrusion treatment.

At week 1, 4, 8, or 12 after the treatment, teeth were extracted by an oral surgeon with minimum trauma. After extraction, the crown of each tooth was cut with a bur to facilitate the fixation, and the tooth was fixed in 10% formalin for 1 week. Then the specimens were decalcified and embedded in paraffin. Serial sections (5 μm thick) were cut longitudinally from each tooth and stained with hematoxylin and eosin dye. The sections were evaluated using a computer image analyzing system (HPIAS-1000, version 6.0; Media Cybernetics, Silver Spring, Md).

Statistical analysis
The data were processed with SPSS software (version 11.5; SPSS, Chicago, Ill). The electric pulp tester data were analyzed using the Student t test and 1-way analysis of variance. P <0.05 indicated a statistical difference.

RESULTS
The total measurement period was from 1 week to 12 weeks after the application of the orthodontic force. Teeth that did not respond to the electric pulp tester underwent subsequent thermal testing. All teeth still responded positively to the thermal test. As shown in the Table, the teeth in the severe-force group responded negatively to the electric pulp tester from 4 to 12 weeks, whereas the teeth in the moderate-force group had no response from 8 to 12 weeks. When the teeth responded...
to the electric pulp tester, there were significant differences between the moderate-force and severe-force groups at weeks 1, 2, and 3 ($P < 0.05$). Readings of the moderate-force group at weeks 2 and 4 were significantly increased compared with those at baseline ($P < 0.05$). In addition, there were significant differences between the readings of the moderate-force group at weeks 5, 6, and 7 and those at baseline ($P < 0.001$). After 4 weeks, pulp vitality measurements became significantly different from those during the previous weeks ($P = 0.009$). Readings of the electric pulp tester increased over time in the severe-force group, but showed no statistical difference ($t = 3.799; P = 0.06$).

In the control group, we observed a columnar odontoblast cell layer with normal morphology. A cell-free zone was obvious, and no inflammatory cell infiltration or vascular congestion was observed (Fig 2, A).

At week 1, the odontoblast nuclei in the odontoblast zone in both force groups appeared abnormal, and vacuolization in the odontoblast layer and moderate vascular congestion were observed. The structure of the cell-free zone was disrupted in the severe-force group. No significant change was observed in the root pulp.

At week 4, in the coronal pulp of the experimental groups, vacuolization and moderate vascular congestion were observed. The arrangement of the odontoblast cell layers, the cell-free zones, the vessels, and the amounts of pulpal cells were similar to those in the control group. In addition, the extent of vacuole formation was worse in the severe-force group than in the moderate-force group. The resorption of craters in the root with some cementum deposition was obvious in the severe-force group (Fig 2, B). At week 8, in the coronal pulp of both experimental groups, vacuolization was particularly obvious. Vascular congestion and dilatation were more obvious than at week 4. In the severe-force group, several pulp stones appeared near the fibers, and vacuolization, inflammatory extravasation, and adipose degeneration were clearly observed (Fig 2, C). However, no pulp stones were found, but root resorption appeared in the moderate-force group (Fig 2, D).

At week 12, odontoblastic degeneration, vacuole formation, and adipose degeneration were widespread in the coronal pulp of the severe-force group (Fig 2, E). Furthermore, vascular dilatation such as arborization, extravasation of red blood cells into pulp tissue, vascular congestion in the cell-rich zone, and inflammatory extravasation were observed (Fig 2, F). In the root pulp, no visible necrotic changes were found. Calciﬁc lines were found around the dentin (Fig 2, G), indicating reparative action in pulp tissues. A few pulp stones were observed near the ﬁbers in both the coronal and root pulps. In the coronal pulp of the moderate-force group, vascular congestion and inflammatory extravasation were similar to those in the severe-force group. In the root pulp, no pulp stones were seen. There were many resorption craters in the dentin, and inﬂammatory cells were observed around the vessels in the moderate-force group (Fig 2, H).

**DISCUSSION**

A force of 15 to 25 g per tooth has been recommended for the intrusion of nontraumatized maxillary incisors. A force of 15 to 25 g per tooth has been recommended for the intrusion of nontraumatized maxillary incisors. The root surface area of the first premolar is greater
than that of the incisor. Therefore, the magnitude for intrusion of the first premolar should be greater than that of an incisor.

In a previous study, 25 g was chosen as a relatively moderate force, and a 9-fold greater force of 225 g was chosen as a relatively severe force. In this study, to consider the force degradation of elastics and to apply forces in their optimum ranges, we chose a 50-g force for intrusive movements and a 6-fold greater force of 300 g as a relatively severe force. We found that root resorption appeared after an intrusive force was applied for 8 weeks in the moderate-force group. However, no
pulp stones or adipose degeneration was found in this group until 12 weeks. These results suggest that moderate intrusive forces do not severely distort blood vessels.

The pulp vitality test is crucial in monitoring the state of dental pulp. Thermal testing is considered more reliable than the electric pulp tester for assessing pulp health. For this reason, teeth that did not respond to the electric pulp tester underwent subsequent thermal testing. In this study, teeth in the severe-force group responded negatively to the electric pulp tester from week 4 on, whereas teeth in the moderate-force group had no response from week 8 on, but all teeth still responded positively to the thermal test. Therefore, the pulpal state in the severe-force group was better than that in the moderate-force group, and no loss of pulp vitality was found in this study.

We found that even 300 g of force continuously intruded the premolar for 12 weeks, and the pulp still appeared to have no damage, indicating that it has an extraordinary ability to withstand insults. Further histologic analysis demonstrated a mild inflammatory response in the dental pulp. At week 4, in the root pulp, the resorption of cementum was clearly observed in the severe-force group. At week 8, root resorption appeared in the moderate-force group. These results indicate that a severe force might induce root resorption. At week 8, adipose degeneration was found in the root pulp. A possible explanation could be that the apical zone is the location that the intrusive force most likely affects. Therefore, the capacity of the apical vessels might be significantly reduced. Pulp stones were found in both the coronal and root pulp in the severe-force group; this might be because distorted vessels make pulp cells anoxemic for a long time. The results demonstrate that supplying vessels in the severe-force group cause a reduced ability of the pulp to react to the impairment of pulpal blood and maintain a sufficient blood supply compared with the moderate-force group.

Several limitations of this study should be pointed out. First, we did not examine intrusive tooth movement or the extrusive movement of the molars; these are important to evaluate the effects of intrusive orthodontic forces. Second, our analysis of the histology of the dental pulp was only descriptive. Further quantitative analysis on the indexes after the application of different forces is needed to provide new insights into the effects of intrusive orthodontic forces.

CONCLUSIONS

After intrusive treatment with different forces, the dental pulp still has vitality and no necrosis is observed.

REFERENCES