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Pain intensity during the first 7 days following the application of light and heavy continuous forces

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SUMMARY The purpose of the present study was to determine whether a force of 20 cN can be biologically active for tooth movement and to examine the pain intensity during the application of light (20 cN) or heavy (200 cN) continuous forces for 7 days.

In the first experiment, a force of 20 cN was applied to eight canines in five volunteers. The mean tooth movement during 10 weeks was 2.4 mm. In the second experiment, two forces of 20 or 200 cN were applied to maxillary premolars in 12 male subjects (aged 24–31 years) to measure pain intensity for 7 days. Spontaneous and biting pain were recorded every 2–4 hours on a 100 mm visual analogue scale (VAS). Wilcoxon signed-rank test was used for statistical analysis.

Comparing the VAS score at force initiation with the other time points, there was no significant difference in spontaneous pain for either group, or in biting pain for the light-force group. However, biting pain in the heavy-force group during the time period from 6 to 156 hours was significantly ($P < 0.05$) greater than that at force initiation. Comparing the VAS scores between the light- and heavy-force group, VAS scores for biting pain in the heavy-force group during the time period from 8 to 100 hours was significantly ($P < 0.05$) greater than that in the light-force group.

A force of 20 cN can move teeth, but pain intensity while biting may be greater approximately 8 hours to 5 days following the application of heavy continuous force compared with light force.

Introduction

Ninety-five per cent of patients were found to report pain during orthodontic treatment (Kvam *et al.*, 1987; Scheurer *et al.*, 1996). Therefore, fear of pain could be a key factor in discouraging patients from seeking orthodontic treatment (Oliver and Knapman, 1985). When a force is applied to a tooth, in general the pain intensity increases with time, between 4 and 24 hours but falls to a fairly normal level at day 7 (Ngan *et al.*, 1989; Jones and Chan, 1992; Scheurer *et al.*, 1996; Fernandes *et al.*, 1998). Females have been reported to complain of more severe pain than males (Unruh, 1996; Berkley, 1997), and the pain sensitivity in females has been shown to vary with the menstrual cycle (Riley *et al.*, 1999). It has also been suggested that older patients appear to perceive more pain than younger patients (Jones, 1984; Jones and Chan, 1992; Scheurer *et al.*, 1996; Fernandes *et al.*, 1998). Therefore, a relationship could be established between pain during the application of orthodontic force and fear, gender, age, and time especially during the first 7 days.

An attempt has been made to control pain using light forces during orthodontic tooth movement (Bergius *et al.*, 2000). This attempt was based on the theory suggested by Reitan (1985). However, a relationship between orthodontic force magnitude and the resultant discomfort has been questioned (Boester and Johnston, 1974; Andreasen and Zwanziger, 1980; Jones and Chan, 1992; Fernandes *et al.*, 1998). In the reported experimental designs, occlusal interference (Boester and Johnston, 1974; Andreasen and Zwanziger, 1980) and great interindividual variance in pain (Jones and Chan, 1992; Fernandes *et al.*, 1998) could have affected the results (Simmons and Brandt, 1992; Bergius *et al.*, 2000). Therefore, a study designed to compare differing force magnitudes would be required, without the effect of occlusal interference, to examine the relationship between force magnitude and pain intensity in an individual.

The relationship between orthodontic force magnitude and root resorption, which is another deleterious effect of orthodontic force, has been also disputed (Stenvik and Mjör, 1970; Owman-Moll *et al.*, 1996a,b; Faltin *et al.*, 1998). However, it was recently demonstrated that the mean volume of the total root resorption crater in a heavy-force (225 cN) group was 3.31-fold greater than in a light-force (25 cN) group (Chan and Darendeliler, 2005).

At present, an optimal orthodontic force is hypothesized to produce a maximum rate of tooth movement without tissue damage or discomfort (Proffit, 1999). Different force ranges for clinical use in orthodontics have been reported: e.g. a force as small as 20 cN was reported to produce effective maxillary canine retraction over 3 months (Daskalogiannakis and McLachlan, 1996; Iwasaki *et al.*, 2000), and a muscle force of approximately 2 cN above the resting force with sufficient time was capable of moving premolars (Weinstein, 1967). In addition, tooth movement was reported to be more effectively performed with a force of 200 cN than with a force of 50 cN, when maxillary premolars were buccally moved over a period of 49 days (Owman-Moll *et al.*, 1996b). Although these clinical studies used a wide range of initial forces (20–200 cN), few reports have shown biologically active tooth movement with the 20 cN force.

The purpose of the present research was therefore to detect whether a force of 20 cN could result in tooth movement, and to examine pain intensity during the first 7 days following the application of light or heavy continuous forces to maxillary premolars.

Subjects and methods

All subjects in both experiments gave written informed consent and the study protocol was approved by the Hospital Ethics Committee (approval number 17–67).

First experiment

Subjects. Five healthy volunteer patients, two males and three females between the ages of 15 and 20 years, who required orthodontic treatment involving extraction of the first premolars and distalization of the canines and demonstrated good oral hygiene, participated in this experiment. Eight first premolars required extraction (six maxillary and two mandibular) and eight canines distalization (six maxillary and two mandibular).

Methods. All patients were treated with upper and lower pre-adjusted edgewise appliances, with a 0.018 × 0.025 inch slot (Master Series-A Friction Free System, American Orthodontics, Sheboygan, Wisconsin, USA). Following premolar extraction incisor, canine and second premolar slots and first molar brackets were initially aligned and levelled using a Co-Cr wire (Elgiloy, Rocky Mountain Orthodontics, Denver, Colorado, USA) up to 0.016 × 0.022 inches. The maxillary first molars were stabilized with a Nance appliance.

Application of a force of 20 cN to the canine was performed with a specially manufactured Ni-Ti closed-coil spring (super light spring, Tomy International, Tokyo, Japan) from the first molar to a sliding hook on a 0.016 × 0.022 inch Co-Cr wire mesial to the canine. To apply a continuous force of 20 cN, the deflection of the spring was adjusted to 1.7 mm. The patients were seen every 2 weeks, and the force magnitude was checked with a tension gauge (546-125, Mitutoyo, Kawasaki, Japan) and adjusted.

In order to measure the movement of the canine, an acrylic jig was made for each arch (Huffman and Way, 1983). The acrylic capped the incisor teeth and rested on both the lingual tissues and the occlusal tip of the second molar, thus allowing the jig to be repeatedly placed in the mouth in the same position. Vertical 0.032 inch wires were embedded in the jigs, just distal to the lateral incisors, to serve as reference points for measurement of distal movement of the canines.

Measurements were obtained at 2 weekly intervals over a 10 week period. Each measurement was taken using a fine-tip digital calliper (MAX-CAL, 0.01 mm resolution, NSK, Tokyo, Japan) by a single investigator (MO). Each measurement was repeated five times, and the average was recorded. Measurement error was calculated according to the formula $E = \left(\sum d^2 / 2n\right)^{1/2}$, with E representing the error, d the difference between n two measurements [maximum and minimum values of the five repeated measurements of each of the 48 measurement occasions (six occasions of eight canines)] and n the number of samples (Dahlberg, 1940). Measurement error was found to be 0.03 mm.

Second experiment

Subjects. In the second experiment, only males were selected to exclude the gender differences. Twelve healthy adult volunteers participated in this part of the study. Inclusion criteria for selection were willingness to participate, normal occlusion, adult, and male. Exclusion criteria were missing teeth other than the third molars, experience of previous active orthodontic treatment, lateral open bite, severe periodontal disease or dental caries, unilateral chewing habit, and second premolars with two or more roots. Their ages ranged from 24 to 31 [mean: 26.7, standard deviation (SD): 2.6] years.

Method of force application. The appliance consisted of a superelastic closed-coil spring which extended from a button bonded on the buccal surface of the second premolar to a hook crimped on a 0.017 × 0.022 inch Co-Cr wire. The first premolar and the first molar were anchored to the canine and the second molar with a 0.7 mm stainless steel wire bonded on the lingual surface to prevent extrusion and occlusal interferences of the first premolar and the first molar during the experimental period. Prior to force application with the closed-coil spring, the Co-Cr wire was inserted into brackets bonded on the first premolar and the first molar (Figure 1). The Co-Cr wire had a step up to provide a point of attachment for the springs to apply force in an apical direction. To apply a continuous constant force of 20 cN, a super light spring was used, and for a force of 200 cN, a commercially available Ni-Ti closed-coil spring (heavy spring, Sentalloy Coil Springs, Tension Coils, heavy, Tomy International). With this latter force system, the type of tooth movement is considered to be tipping as well as intrusion (Figure 1).

At the initiation of force application to the upper second premolars, the deflection of the spring was adjusted to 1.7 mm, so that the force magnitude applied was 20 cN with the super light spring and 200 cN with the heavy spring. The mechanism was controlled daily and the corresponding forces were checked with a tension gauge (546-125, Mitutoyo).

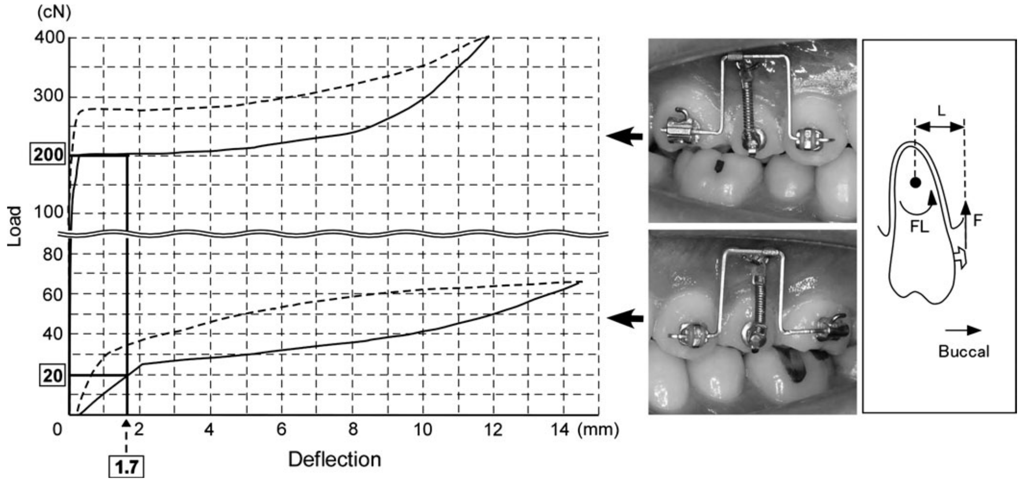

Figure 1 Load–deflection curve of a closed-coil spring, sectional arch for applying orthodontic force and schematic diagram of the load to the tooth. Middle upper: the heavy spring. Middle lower: the super light spring. Right: the load to the tooth. The type of tooth movement is considered to be tipping as well as intrusion by the moment (F × L).

In six subjects, a continuous constant force of 20 cN was applied on one side with the super light spring for all 7 days (light-force group), and 1 week later, a continuous force of 200 cN was applied on the other side with the heavy spring for a further 7 days (heavy-force group). In the remaining six subjects, a force of 200 cN was applied first followed by a 20 cN force for the same period. For each subject, the 20 and 200 cN forces were assigned randomly to the right and left sides. The subjects were blind to the order of force application. The time of initiation of force application was 08:00 in all subjects. Each subject was instructed not to take any analgesics or drugs during the experimental period. Food consumption was prohibited until noon, just after the initiation of force application. To examine occlusal interference of the first and second premolars and the first molar, the upper and lower tooth contact areas of these teeth were checked daily at 08:00 using occluding papers to detect any increase in size compared with the same areas recorded prior to the experiment.

Measurement of pain intensity. A 100 mm visual analogue scale (VAS) was used to record spontaneous and biting pain, daily, over the first 7 day period after the initiation of force application. VAS is widely used and has been described by other investigators as being sensitive and reliable and having certain advantages over verbal scales (Scott and Huskisson, 1976; Seymour, 1982). On the first day, assessments of pain were made every 2 hours for the first 12 hours following the initiation of force application. For the following 6 days, assessments were made every 4 hours from 08:00–20:00 (i.e. four times per day). Each subject received a recording sheet with two VAS, one for spontaneous pain and one biting pain (pain while biting in occlusion) at each time. Each scale was 100 mm in length and weighted at both ends by small pictograms representing 'happy' and 'sad' faces (Ngan *et al.*, 1989). The subjects were given oral and written instructions on how to complete the VAS by marking the spot on the line which they believed to best represent the pain they were perceiving at that time. The VAS score is the distance from the left end of the line to the point of the subject's mark, measured to the nearest millimeter.

In order to measure the pain threshold for the first premolar and first molar, the tension on the bracket was gradually increased with a tension gauge (PS-20N, Imada, Toyohashi, Japan) in a palatal direction, and the force at which the subject began to feel pain was determined as the pain threshold (Yamasaki *et al.*, 1985). The maximum load force was 20 N. The pain threshold was measured every 2 hours on the first day and at 08:00 daily thereafter.

Statistical analysis

For the first experiment, the null hypothesis (H_0) was tested using binomial distribution to check the validity of the number of subjects: the canine does not move with a force of 20 cN. An alternative hypothesis (H_1) was defined for comparison.

Considering the probability of H_0 and H_1, P values were defined as follows:

$$H_0\text{: } P = 0.6 \text{ versus } H_1\text{: } P > 0.6.$$

In general, if the random variable X follows the binomial distribution with parameters n and P, it can be indicated '$X \sim \text{Bin}(n, P)$' under H_0. The probability of achieving exactly X successes were given by the probability mass function

$$\Pr(X; x) = {}_nC_X\, p^x\, (1\text{-}p)^{n-x},$$

where P is the probability that the teeth move, X the number of moved teeth, n the number of all teeth, and $\Pr(X; x)$ the probability mass function that the teeth move under H_0.

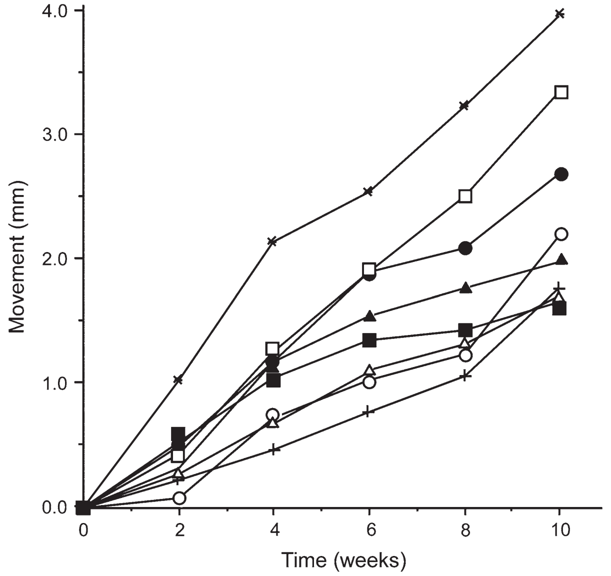

Figure 2 Time–movement curves for the canine over 10 weeks in eight subjects.

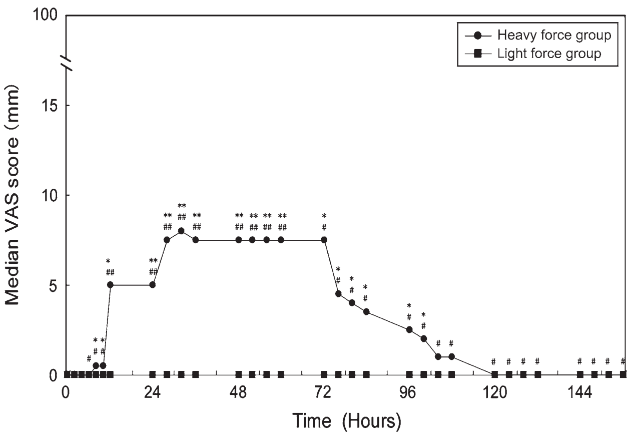

Figure 3 Time course of median visual analogue scale (VAS) scores for biting pain of the maxillary second premolar in the light- (20 cN) and heavy- (200 cN) force groups. Wilcoxon signed-rank test: comparison between force initiation and the other time points, #$P < 0.05$, ##$P < 0.01$, and comparison between the light- and heavy-force group, *$P < 0.05$, **$P < 0.01$.

For the second experiment, a Wilcoxon signed rank test was used to determine whether there was any significant difference in VAS score over time or between the light- and heavy-force groups according to the normality of data distribution. Probability levels of $P < 0.05$ were considered statistically significant. This test was calculated using the Statistical Package for Social Science (SPSS for Windows, SPSS Inc., Chicago, Illinois, USA). In addition, a sample size calculation (Faul *et al.*, 2007) was carried out using data derived from the preliminary experiment of three subjects. The maximum difference of the mean VAS score between the light- and heavy-force groups was 21.6 (SD 20.6). From these data with a standardized difference of 1.05, a sample size of 12 teeth in each force group would give a power of 0.80 with a significance level of 0.05.

Results

First experiment

The mean tooth movement of the eight canines was 2.4 mm over a 10 week period (Figure 2).

The result showed that $\Pr(X;x) = {}_8C_8 \times 0.6^8 \times 0.4^{8-8} = 1 \times 0.6^8 \times 1 = 0.016$ ($P < 0.05$). Therefore, the null hypothesis could be rejected. The probability was that the tooth movements were greater than 60 per cent.

Second experiment

During the experimental period, the force magnitude was constant for both springs. No premature contact or resultant occlusal interference was observed at the first and second premolars or first molar. The pain thresholds for loading force of the first premolar and first molar was 20 N and did not decrease at any time point.

When comparing the VAS score at force initiation with the other time points (Figure 3), there was no significant difference in spontaneous pain for either group or in biting pain for the light-force group. However, VAS scores for biting pain in the heavy-force group from 6 to 156 hours were significantly ($P < 0.05$) greater than at the initiation of force application.

When comparing the VAS scores between the light- and heavy-force groups, there was no significant difference in spontaneous or biting pain from the initiation of force application to 6 hours or from 104 to 156 hours. However, VAS scores for biting pain in the heavy-force group were significantly ($P < 0.05$) greater than those for light-force group from 8 to 100 hours (Table 1).

Discussion

The results of this study showed a significant difference in the intensity of tooth pain during the first 8 hours up to 5 days, following application of a heavy orthodontic force compared with a light force.

On application of the defined orthodontic force, the load with the heavy spring became almost uniform, even when the deflection was increased (Figure 1). However, the load with the super light spring increased when the deflection was increased to around 20 cN. Therefore, the force magnitude was checked daily with a tension gauge and was confirmed to be constant.

Although a few reports have shown a force of 20 cN to be efficient for canine retraction, orthodontic forces of 100–200 cN have generally been used (Jarabak and Fizzell, 1972). Therefore, significant doubts could be raised as to whether 20 cN is a biologically active force that would result in tooth movement. In the current study, irreversible change, i.e. tooth movement,

Table 1 Visual analogue scale scores over 7 days for biting pain of the maxillary second premolar in the light- and heavy-force group.

Day	Time (hours)	Light-force group						Heavy-force group						*P*2
		Mean	Median	SD	Minimum	Maximum	*P*1	Mean	Median	SD	Minimum	Maximum	*P*1	
1	0	0.0	0.0	0.0	0.0	0.0	—	0.0	0.0	0.0	0.0	0.0	—	ns
	2	0.3	0.0	0.6	0.0	2.0	ns	1.3	0.0	3.1	0.0	10.0	ns	ns
	4	0.5	0.0	1.4	0.0	5.0	ns	1.8	0.0	3.2	0.0	10.0	ns	ns
	6	1.6	0.0	3.3	0.0	10.0	ns	2.3	0.0	3.5	0.0	10.0	*	ns
	8	2.1	0.0	4.2	0.0	12.0	ns	8.5	0.5	16.7	0.0	58.0	*	*
	10	1.8	0.0	3.6	0.0	10.0	ns	11.0	0.5	19.4	0.0	61.0	*	*
	12	2.4	0.0	5.4	0.0	17.0	ns	13.3	5.0	20.1	0.0	63.0	**	*
2	24	2.7	0.0	5.7	0.0	18.0	ns	13.3	5.0	13.3	0.0	35.0	**	**
	28	2.6	0.0	5.4	0.0	17.0	ns	16.8	7.5	18.7	0.0	54.0	**	**
	32	4.3	0.0	10.9	0.0	38.0	ns	16.3	8.0	17.4	0.0	49.0	**	**
	36	3.9	0.0	6.6	0.0	20.0	ns	14.3	7.5	14.6	0.0	42.0	**	**
3	48	3.3	0.0	5.3	0.0	14.0	ns	12.8	7.5	14.5	0.0	41.0	**	**
	52	2.9	0.0	4.6	0.0	12.0	ns	11.5	7.5	12.8	0.0	35.0	**	**
	56	2.5	0.0	4.2	0.0	11.0	ns	9.8	7.5	10.1	0.0	28.0	**	**
	60	2.2	0.0	4.0	0.0	11.0	ns	9.4	7.5	9.4	0.0	25.0	**	**
4	72	1.6	0.0	3.2	0.0	10.0	ns	8.0	7.5	7.6	0.0	20.0	*	*
	76	1.7	0.0	3.3	0.0	10.0	ns	6.8	4.5	7.0	0.0	20.0	*	*
	80	1.7	0.0	3.3	0.0	10.0	ns	6.4	4.0	6.8	0.0	20.0	*	*
	84	1.5	0.0	3.1	0.0	10.0	ns	6.1	3.5	6.9	0.0	20.0	*	*
5	96	1.5	0.0	3.1	0.0	10.0	ns	5.5	2.5	6.9	0.0	20.0	*	*
	100	1.5	0.0	3.1	0.0	10.0	ns	4.5	2.0	6.1	0.0	20.0	*	*
	104	1.5	0.0	3.1	0.0	10.0	ns	4.0	1.0	6.2	0.0	20.0	*	ns
	108	1.6	0.0	3.2	0.0	10.0	ns	4.1	1.0	6.1	0.0	20.0	*	ns
6	120	1.4	0.0	3.1	0.0	10.0	ns	3.2	0.0	6.1	0.0	20.0	*	ns
	124	1.4	0.0	3.1	0.0	10.0	ns	3.5	0.0	6.4	0.0	20.0	*	ns
	128	1.4	0.0	3.1	0.0	10.0	ns	3.5	0.0	6.4	0.0	20.0	*	ns
	132	1.4	0.0	3.1	0.0	10.0	ns	3.5	0.0	6.4	0.0	20.0	*	ns
7	144	1.4	0.0	3.1	0.0	10.0	ns	2.5	0.0	4.2	0.0	10.0	*	ns
	148	1.4	0.0	3.1	0.0	10.0	ns	2.5	0.0	4.2	0.0	10.0	*	ns
	152	1.4	0.0	3.1	0.0	10.0	ns	2.4	0.0	4.1	0.0	10.0	*	ns
	156	1.4	0.0	3.1	0.0	10.0	ns	2.5	0.0	4.2	0.0	10.0	*	ns

Time, time elapsed since the initiation of force application; P1, comparison between force initiation and the other time points by Wilcoxon signed-rank test; P2, comparison between light- and heavy-force group by Wilcoxon signed-rank test.
*$P < 0.05$, **$P < 0.01$; ns: not significant.

was not ethically allowed as the subjects were healthy adult volunteers. The results of the first experiment however, clearly showed that a 20 cN force was biologically active.

It has been reported that occlusal interference might enhance tooth pain in edgewise treatment (Simmons and Brandt, 1992). In the current study, the first premolar and first molar on each side were anchored to the canine and the second molar with a wire to prevent these teeth from extrusion, thus preventing occlusal interference. As a result, occlusal interference was not observed when examined using occluding paper during the experimental period. The reported pain thresholds of the first premolar and first molar did not decrease at any time point and none of the subjects reported pain on loading of these teeth. Therefore, it is considered that biting pain was solely due to pain from the upper second premolars in each subject, and pain intensity was lower than that reported in patients undergoing edgewise treatment (Ngan *et al.*, 1989; Jones and Chan, 1992; Scheurer *et al.*, 1996; Fernandes *et al.*, 1998; Firestone *et al.*, 1999).

No relationship between weekly reported pain experience and force magnitude, in which orthodontic forces of 55 and 100 to 150, 140, 225, 310, and 400 to 500 cN were applied, on posterior teeth over a 10 week period was found (Boester and Johnston, 1974; Andreasen and Zwanziger, 1980). Also, there was no difference in pain perception when comparing superelastic Ni-Ti wires, exerting lighter forces, with multistranded steel (Jones and Chan, 1992) or conventional Ni-Ti (Fernandes *et al.*, 1998) wires. Occlusal interference (Boester and Johnston, 1974; Andreasen and Zwanziger, 1980) and great interindividual variance in pain (Jones and Chan, 1992; Fernandes *et al.*, 1998) could have affected the experimental results (Simmons and Brandt, 1992; Bergius *et al.*, 2000). In the current study, the relationship between orthodontic force magnitude and pain intensity could be examined by the approach used, excluding the effect of occlusal interference/interindividual variance on pain intensity.

Conclusion

The results of this study show that

1. A clinically applied continuous force of 20 cN can effectively move teeth.

2. There was no significant difference in tooth pain intensity for the 20 cN light-force group between the time of force initiation and other time points.
3. Pain intensity while biting for the 200 cN heavy-force group from 6 to 156 hours was significantly greater than that at the time of force initiation.
4. Pain intensity while biting may be greater approximately 8 hours to 5 days following the application of a heavy continuous force compared with a light force.

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