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Effects of force magnitude on tooth movement: an experimental study in rabbits

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SUMMARY The aim of the present study was to investigate the effects of two different force levels on the amount of total and daily tooth movement in rabbits and to determine whether any increase in tooth movement is equal to the increase in force. Forces of approximately 20 (group I) and 60 (group II) g (19.6 and 58.8 cN) were applied to the upper central incisors of 25 young adult (14 weeks of age) New Zealand female rabbits. The distance between the incisors was measured daily from the mid-levels of the crowns using a digital calliper for 20 days. Analysis of variance and Bonferroni multiple range test were used for statistical analyses.

The distance between the teeth in group II was significantly greater than that in group I during the first 3 days. Between days 4 and 14, no significant difference was observed. During the last 6 days, except for day 19, tooth movement in group II again increased, resulting in the distance between the teeth being greater in group II. The mean total opening was 3.98 ± 0.59 mm in group I and 4.82 ± 0.82 mm in group II, and the mean difference was approximately 0.8 mm.

The results of this study show that there was a close relationship between tooth movement and force magnitude. However, higher forces did not produce force-equal tooth movements.

Introduction

Changes in the stress/strain distribution in the periodontium after the application of orthodontic forces trigger remodelling processes. Orthodontic forces create compression of the periodontal ligament (PDL) fibres and reduce the PDL space in the pressure area. At the tension site, PDL fibres are stretched depending on the magnitude of strain, and orthodontic force results in widening of the periodontal membrane (Thilander *et al.*, 2000). As a result of remodelling of the PDL and the alveolar bone, tooth movement takes place (Henneman *et al.*, 2008).

The magnitude of orthodontic force has received significant attention without considering its importance in relation to other characteristics of the force system and surface area of the PDL over which it is dissipated. Conflicting results have been reported in the literature regarding the relationship between the magnitude of force and the amount of tooth movement. Some authors suggest that application of heavy forces produces more tooth movement than light forces (Mitchell *et al.*, 1973; Storey, 1973; Andreasen and Zwanziger, 1980), while Fortin (1971) claimed that the application of light forces resulted in more tooth movement than heavy forces. There is also another group of authors who consider that there is no association between force magnitude and the amount of tooth movement (Pilon *et al.*, 1996; Owman-Moll *et al.*, 1996a; Kyomen and Tanne, 1997; Melsen, 1999).

Different animals such as rats, rabbits, cats, and dogs have been used in experimental studies related to tooth movement (Kuitert *et al.*, 1988; van de Velde *et al.*, 1988; van Leeuwen *et al.*, 1999; Ren *et al.*, 2003b; von Böhl *et al.*, 2004; Seifi *et al.*, 2007; Deguchi *et al.*, 2008).

In a recent literature review on force magnitude, Ren *et al.* (2003a) suggested that new studies are necessary in order to determine the relationship between force magnitude and subsequent tooth movement. In addition, no experimental study comparing daily tooth movement produced by different forces was found in the literature. Thus, the purpose of this study was to investigate the effects of two different force levels on the amount of total and daily tooth movement in rabbits and to determine the relationship between the magnitude of orthodontic force and subsequent tooth movement.

Materials and methods

The study protocol was approved by the Ethical Committee Board of the School of Dentistry, Atatürk University (Protocol Number is 2006/13).

Twenty-five young, healthy female New Zealand rabbits (mean age 14 weeks) were used. The rabbits were randomly divided into two experimental groups with 12 rabbits in group I and 13 rabbits in group II. The rabbits were individually housed in smooth-walled Macrolan cages and fed *ad libitum* with commercial pellets and water from thick-walled glass dishes. The mean weight of the animals was 2.19 ± 0.53 kg in group I and 2.32 ± 0.37 kg in group II at the beginning of the experiment.

The animals in each group were anaesthetized at the first session by an intramuscular injection of ketamine (37.5 mg/kg) and xylazine (5 mg/kg). A small notch was made with a bur on the labial surface of the upper first incisors at 1.5–2 mm above the gingival margin and then the notches were drilled in a vestibulo-palatal direction by means of a bur. Cooling was achieved with a syringe filled with physiologic saline.

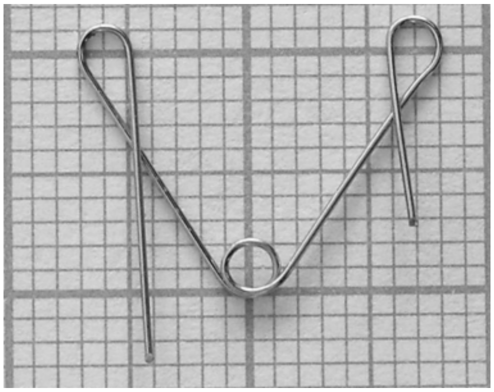

Figure 1 A helical torsion spring prepared on millimetric graph paper.

Figure 2 A helical torsion spring inserted on the incisor teeth of a rabbit.

Force element

The appliance used in this study was an expansion spring. This spring was previously used by Storey (1973) and Stark and Sinclair (1987) and modified by Karadede (1992). The spring arms were 13 mm long with an angle of 70 degrees (Figure 1). In order to produce two different forces, 0.012 and 0.014 inch round stainless steel archwires were used. The forces generated by the springs were measured with a gauge (040–713; Dentaurum, Ispringen, Germany) before application. When the free ends of the springs were closed to 4 mm, which corresponded to the width between the holes prepared in the rabbit incisors, the springs of the thin archwire initially exerted a force of 20 ± 3 g and the other springs a force of 60 ± 5 g. Springs exerting a force of 20 g were used in group I and those with a 60 g force in group II.

The free ends of the springs were inserted into the holes in the incisor teeth. The residual ends were bent distally and cut in order to stabilize the springs in the mouth (Figure 2).

Measurements

The distance between the incisors was measured every morning at the same time from the visible mid-level of the crowns using a digital calliper with accuracy of 0.01 mm, for 20 days. Three successive measurements were made at each session, and their mean values were used for statistical analysis. The springs were removed at the end of the 20th day. Occlusal radiographs of two rabbits in each group were taken to observe whether sutural opening had occurred.

Statistical analysis

In order to compare the amount of tooth movement both within and between groups, analysis of variance for repeated measurements was used. In addition, the changes in daily tooth movement were analysed by Bonferroni multiple range test.

All statistical analyses were performed using the statistical package for social sciences (Windows 98, version 10.0, SPSS Inc., Chicago, Illinois, USA).

Results

A tipping movement was observed in both groups. Daily measurements of the distance between the incisors and their comparisons between the groups are shown in Table 1. The distance between the teeth in group II was significantly greater than that in group I during the first 3 days of force application. Between days 4 and 14, no statistically significant difference was observed between the groups, although there was an increase in the distance in both groups. During the last 6 days, the distance between the teeth increased more in group II.

At the end of the experimental period, the mean distance between the incisors was 3.98 ± 0.59 mm in group I and 4.82 ± 0.82 mm in group II. The data in Table 1 show that tooth movement in both groups occurred in three phases (initial, arrest, and acceleration). Daily changes in tooth movement in both groups can clearly be seen in Figure 3.

According to the results of variance analysis, statistically significant increases in tooth movement occurred during the experimental period ($F = 264.12$; $P = 0.000$), and there was also a significant difference regarding the amount of tooth movement between the groups ($F = 4.08$; $P = 0.000$).

The Bonferroni multiple range test of the daily increases in tooth movement are shown in Table 2. Statistically significant increments were observed on days 1 and 14 in group II. However, the teeth in this group moved at a slower rate on the other days. For group I, the increments in daily tooth movements were at a statistically significant level for the first 4 days and on day 15. During the other days, the teeth moved slowly as in the other group. However, the same amount of movement that occurred on day 1 in group II took place over the first 3 days in group I.

No sutural opening was observed in the animals of either group for whom occlusal radiographs were obtained (Figure 4).

Table 1 Mean and standard deviation (SD) of the distance between the incisor teeth measured daily and P values comparing daily measurements in both groups.

	Group I (20 g force, n = 12)		Group II (60 g force, n = 13)		Significance (between groups)
	Mean	SD	Mean	SD	
Day 0	0.00	0.00	0.00	0.00	
Day 1	1.58	0.31	2.06	0.37	**
Day 2	1.90	0.38	2.22	0.31	*
Day 3	2.03	0.38	2.40	0.32	*
Day 4	2.20	0.37	2.46	0.30	NS
Day 5	2.27	0.36	2.51	0.30	NS
Day 6	2.32	0.38	2.54	0.31	NS
Day 7	2.42	0.38	2.59	0.32	NS
Day 8	2.55	0.41	2.71	0.31	NS
Day 9	2.69	0.47	2.82	0.31	NS
Day 10	2.81	0.49	2.96	0.32	NS
Day 11	2.94	0.51	3.11	0.40	NS
Day 12	3.10	0.50	3.32	0.45	NS
Day 13	3.27	0.59	3.53	0.50	NS
Day 14	3.37	0.62	3.86	0.60	NS
Day 15	3.46	0.61	4.00	0.70	*
Day 16	3.53	0.60	4.13	0.68	*
Day 17	3.67	0.59	4.33	0.69	*
Day 18	3.74	0.60	4.60	0.83	**
Day 19	3.86	0.63	4.68	0.80	**
Day 20	3.98	0.59	4.82	0.82	**

NS, not significant. *$P < 0.05$, **$P < 0.01$.

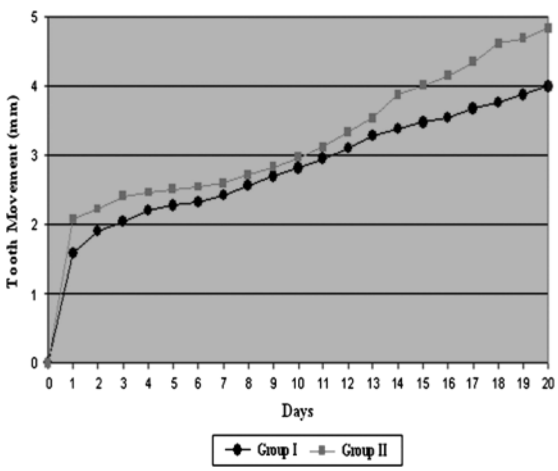

Figure 3 Time–displacement curves according to the daily increases in tooth movements in group I (20 g force) and group II (60 g force).

The mean weight of the animals was 2.72 ± 0.60 kg in group I and 2.97 ± 0.38 kg in group II at the end of the experiment.

Discussion

Different experimental animals such as rats (Rygh *et al.*, 1986; Gibson *et al.*, 1992; Kyomen and Tanne, 1997; Kohno *et al.*, 2002; Ren *et al.*, 2003b), monkeys (Melsen, 1999), rabbits (Kuitert *et al.*, 1988; van de Velde *et al.*, 1988; Seifi *et al.*, 2007), dogs (Fortin, 1971; Pilon *et al.*, 1996; van Leeuwen *et al.*, 1999; von Böhl *et al.*, 2004; Deguchi *et al.*, 2008), and cats (Mitchell *et al.*, 1973) have been used to study tooth movement. Rats and rabbits are commonly used in such studies because of their availability. In the present investigation, only female rabbits were used to avoid gender differences in metabolic activity and behaviour of the animals towards the procedures.

Table 2 Mean and standard deviation (SD) of daily increases in the distance between incisors and the results of Bonferroni multiple range test in both groups.

Days	Group I (20 g force, n = 12)			Group II (60 g force, n = 13)		
	Mean difference	SD	Significance	Mean difference	SD	Significance
1	1.58	0.31	***	2.06	0.36	***
2	0.33	0.21	*	0.17	0.22	NS
3	0.13	0.04	***	0.18	0.16	NS
4	0.17	0.11	*	0.06	0.06	NS
5	0.07	0.05	NS	0.05	0.04	NS
6	0.05	0.05	NS	0.03	0.02	NS
7	0.10	0.08	NS	0.05	0.04	NS
8	0.13	0.10	NS	0.13	0.11	NS
9	0.14	0.13	NS	0.11	0.09	NS
10	0.12	0.15	NS	0.13	0.14	NS
11	0.13	0.14	NS	0.16	0.18	NS
12	0.16	0.16	NS	0.21	0.19	NS
13	0.17	0.22	NS	0.22	0.33	NS
14	0.10	0.07	NS	0.33	0.23	*
15	0.08	0.05	*	0.14	0.27	NS
16	0.08	0.10	NS	0.13	0.12	NS
17	0.14	0.10	NS	0.20	0.21	NS
18	0.07	0.09	NS	0.27	0.25	NS
19	0.12	0.16	NS	0.08	0.22	NS
20	0.12	0.13	NS	0.14	0.19	NS

NS, not significant. *$P < 0.05$, ***$P < 0.001$.

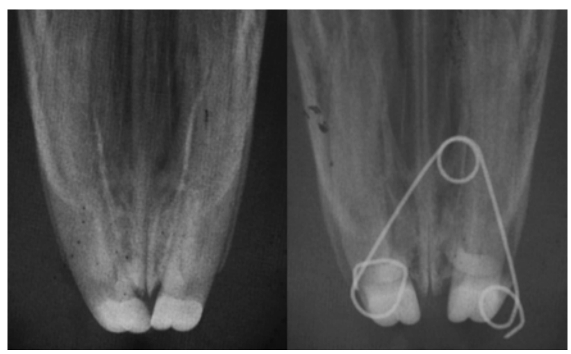

Figure 4 Pre- and post-experiment occlusal radiograph of one rabbit showing mid-palatal suture.

A number of force systems have been used in previous research, such as elastics (Yoshida *et al.*, 1999; Fukui *et al.*, 2003), archwires and bands (Boisson and Gianelly, 1981), springs with different designs (Kuitert *et al.*, 1988; van de Velde *et al.*, 1988; Kyomen and Tanne, 1997), and coil springs (Bridges *et al.*, 1998; van Leeuwen *et al.*, 1999;

Yoshida *et al.*, 1999; Hatai *et al.*, 2001; Nakamura *et al.*, 2003; von Böhl *et al.*, 2004) in order to move the teeth of experimental animals. Under some conditions, some of these force elements may be detrimental to the periodontal tissues of experimental animals (Boisson and Gianelly, 1981). Some experimental designs necessitate difficult laboratory and/or surgical procedures (Boisson and Gianelly, 1981; Pilon *et al.*, 1996; van Leeuwen *et al.*, 1999; Hiyashi *et al.*, 2004; von Böhl *et al.*, 2004).

Preparation of the springs used in the present research required minimal laboratory preparation and they were easily applied to the incisors of the rabbits. In addition, no unfavourable effects, such as food retention, periodontal tissue damage, or dislocation of the springs, were observed.

A period of 20 days for the experiment was chosen as previous studies have generally lasted for 21 days (Roche *et al.*, 1997; Sun *et al.*, 2006).

The magnitude of orthodontic force has received a great deal of attention in orthodontics. One of the main questions arising is whether heavy forces result in greater tooth movement. Quinn and Yoshikawa (1985) hypothesized that a certain threshold level of force was required to induce tooth movement, that increased force levels caused the rate of movement to increase to a maximum, and that a further increase in force led to a decrease in the rate of tooth movement.

Houston and Tulley (1986) stated that a 30 g force applied to the crown of a single-rooted human tooth was appropriate for tipping movement. Kuitert *et al.* (1988) and van de Velde *et al.* (1988) applied force of 50 g to the incisor teeth of rabbits and noted pathological changes in the periodontal tissues.

Experimental studies on tooth movement are often difficult to compare because of the use of different appliances and the magnitude, type, and duration of force. Storey (1973) used tipping forces of 28–170 g in rabbit maxillary incisors. In the present study, tipping movements were observed due to the root length of the rabbit the incisors, the application point of the force, and the spring design used. When the maxillary anatomy of rabbits was taken into consideration (Barone *et al.*, 1973), it was clear that forces such as those used in the present experiment could not result in sutural opening.

The relationship between force magnitude and the rate of orthodontic tooth movement is controversial. Most clinical strategies regarding tooth movement are based on the assumption that higher forces delivered to the periodontal tissues will yield the most rapid rate of tooth movement. In other words, the rate of movement is sensitive to changes in force magnitude. This assumption was supported by the findings of Mitchell *et al.* (1973), Storey (1973), and Andreasen and Zwanziger (1980).

The mean opening in the present study at the end of the experiment was 4.82 ± 0.82 mm in the 60 g force group and 3.98 ± 0.59 mm in the 20 g force group, which was statistically significant. These results coincide with the studies which found that increased force levels resulted in greater tooth movement (Mitchell *et al.*, 1973; Storey, 1973; Andreasen and Zwanziger, 1980). van de Velde *et al.* (1988) reported that the upper incisors of rabbits moved 2.3 mm with a 50 g force during the first 3 days. A 2.4 mm movement was also observed in the 60 g force group in the present study over the same period.

Fortin (1971) found more tooth movement in dogs when light forces were applied. It should, however, be noted that Fortin (1971) considered 150–200 g as a light force and 450 g as a heavy force.

In the current study, tooth movements occurred in three phases (initial, arrest, and acceleration) in both groups. This is in agreement with some studies in the literature (Storey, 1973; Yoshikawa 1981; Gibson *et al.*, 1992; Bridges *et al.*, 1998). Other authors have divided tooth movement into two (Kohno *et al.*, 2002; Ren *et al.*, 2003b) or four (Pilon *et al.*, 1996; van Leeuwen *et al.*, 1999; von Böhl *et al.*, 2004) phases. This difference may be caused by a longer (Pilon *et al.*, 1996; van Leeuwen *et al.*, 1999; Ren *et al.*, 2003b; von Böhl *et al.*, 2004) or shorter (Kohno *et al.*, 2002) observation period. In addition, different force magnitudes and appliances may have contributed to this difference.

The initial phase of tooth movement is considered as initial displacement of a tooth in its socket. Prolonged application of a force beyond the bio-elastic limits of the PDL will result in a displacement and induce adaptive proliferation and re-modelling processes. In the present study, the initial displacements were 1.58 and 2.06 mm in groups I and II, respectively. The duration of the initial phase was 4 days in group I and 1 day in group II (Figure 3).

Arrest, or the second phase, is a stage in which minor tooth movement occur. These minor or 'stopped' movements are associated with hyalinization in the PDL. If heavy forces are used, hyalinization areas occur more rapidly and extensively (Storey, 1973; Yoshikawa 1981; Rygh *et al.*, 1986). These hyalinized tissues are removed by tissue repair, requiring a longer duration (Storey, 1973). As can be seen from Figure 3, slow tooth movement occurred in both groups, but the period was slightly longer in the 60 g force group. This phenomenon might be explained by the fact that less tissue damage occurred and the repair process started earlier in the 20 g force group.

The acceleration, or third phase, is characterized by increased tooth movement. This phase may be interpreted as a period in which the biological processes in the remodelling of the PDL and alveolar bone reach their maximum capacity (Storey, 1973). In this phase, which covered the last 6 days of the experiment, tooth movement accelerated in both groups, although it was slightly faster in group II.

Two force levels were used in the present study to determine the possible relationship between force magnitude and the amount of tooth movement. The threefold increased force did not result in equal increments in tooth movement. According to the findings, a 60 g force resulted in a 25 per cent increase in total tooth movement. In a clinical study, Owman-Moll *et al.* (1996b) reported that a fourfold increase in force magnitude resulted in 50 per cent more tooth movement. In another study, however, Owman-Moll *et al.* (1996a) applied forces of 50 and 100 cN, which resulted in tooth movements of 4.3 and 4.5 mm, respectively.

Conclusion

The findings of the present study show that the amount of tooth movement is related to force magnitude, but the increments in total tooth movement are not equal to the increases in force magnitude.

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