

Effects of a doubled orthodontic force magnitude on tooth movement and root resorptions. An inter-individual study in adolescents

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SUMMARY The aim of this clinical and histological study was to compare the effects of two controlled, continuous forces of 50 cN (≈ 50 g) and 100 cN (≈ 100 g) on tooth movement and root resorptions. The patients, consisting of 32 individuals, 14 boys and 18 girls (mean age 13.1 years), were divided into four groups of eight individuals. The experimental periods were 4 and 7 weeks. In this investigation, designed as an inter-individual study, only the maxillary first premolar on the right side was utilized. The test tooth was buccally moved by means of a fixed orthodontic appliance. A continuous, weekly controlled force of 50 cN was applied to 16 premolars and a force of 100 cN to the remaining 16 test teeth. The force declined on average 22 per cent during the first week when 50 cN was applied and 27 per cent when 100 cN was applied. Tooth movements were studied on dental casts using a coordinate measuring machine. After 4 and 7 weeks, the tooth movements ranged between 0.5 and 3.4 mm (4 weeks) and 2.7 and 7.1 mm (7 weeks) for 50 cN and between 1.0 and 2.9 mm (4 weeks) and 2.2 and 8.3 mm (7 weeks) for 100 cN, with no significant difference when the force magnitude was doubled. Root resorptions were registered in histological sections in all experimental teeth, more frequently after application of 50 cN compared with 100 cN after 7 weeks. However, the severity of root resorption (extension and depth of resorbed root contour and size of root area on histological sections) did not differ significantly when the applied force was doubled to 100 cN. Great individual variations were noted regarding both the magnitude of tooth movement and amount of root resorption.

Introduction

Since orthodontic treatment often requires a long treatment period, efficacy is an important factor. However, not only tooth movements but also adjoining adverse tissue reactions have to be considered. It is therefore a general opinion that the amount of force acting upon the tooth and responsible for the tooth movement has to be chosen carefully. An optimal force is characterized by a maximal cellular response (apposition and resorption of supporting tissues) (Burstone, 1985) with maintenance of the vitality of the tissue. Thus, the amount of tooth movement is not the only indicator of optimal force (Burstone, 1985). The everyday clinical question is: "How can teeth be moved as quickly as possible with the least amount of tissue damage?"

In 1932, Schwarz stated that "...biologically the most favorable treatment is that which works *with forces not greater than the pressure in the blood capillaries*. This pressure in humans as well as in most mammalia is 15–20 mm Hg; it is about 20 to 26 g for 1 sq. cm surface". This corresponds to 54 cN on a premolar with a mean root area of 2.34 cm^2 (Jepsen, 1963) $[(20 + 26)/2 \text{ g} = 23 \text{ g for } 2.34 \text{ cm}^2 \text{ i.e. } \approx 54 \text{ g} \approx 54 \text{ cN}]$. Reitan (1957, 1960, 1964, 1985) has always been a spokesman for light forces, especially in the initial stage of tooth movement, to minimize adverse tissue reactions. In the early 1950s Smith and Storey (Smith and Storey, 1952; Storey and Smith, 1952) proposed the 'optimal force' theory, i.e. that there is a range of force or pressure that produces the maximum of tooth

displacement in man. Below this range there is only little tooth movement and when the force is increased above the range the movement is slowed down, at least in the short term. This theory was critically reviewed by Boester and Johnston (1974). They found in 10 individuals during 10 weeks that space closure after bimaxillary premolar extractions was about the same after application of 5, 8 and 11 ounces (≈ 140 , 225 and 310 cN respectively) but significantly less when a force of 2 ounces (≈ 55 cN) was used. A more linear relationship between force magnitude and tooth movement, at least up to 300 cN, was reported in a study by Hixon *et al.* (1969). Thus, several studies have related the amount of force to the achieved tooth movement and sometimes with a relationship between increased force and faster movement (Table 1).

The question of how the orthodontic force magnitude influences both the rate of tooth movement and the adverse tissue reactions, however, has received little attention and few experimental studies have been performed (Reitan, 1964; King and Fischlschweiger, 1982). From a clinical point of view it is thus import-

ant to try to determine the point where the 'price' for the tooth movement, i.e. adverse tissue reactions, above all manifested as root resorptions, exceeds the benefits of a perhaps more efficient tooth movement when using an increased amount of force.

It was the purpose of this investigation to compare, in a clinical study in adolescents the effect of a commonly-used orthodontic well-controlled, continuous force (50 cN \approx 50 g) and a doubled force (100 cN \approx 100 g) on the rate of tooth movement and on related root resorption.

Subjects and methods

Experimental design and orthodontic appliance

A total of 32 maxillary premolars from 32 individuals (14 boys and 18 girls), aged 10.1–15.8 years (mean 13.1 years) were used. The patients had been referred for orthodontic specialist treatment and showed bilateral maxillary crowding or maxillary protrusion. The orthodontic treatment was planned to include bilateral first premolar extractions. In order to

Table 1 Achieved orthodontic tooth movement related to the magnitude of force.

Authors	Year	Species	Applied force	Force control	Tooth movement
Andreasen and Johnson	1967	Homo	200 g, 400 g	Weekly	Average 2.5 times faster with 400 g compared with 200 g*
Andreasen and Zwanziger	1980	Homo	100–150 g 400–500 g	Weekly	Larger force/larger displacement*
Boester and Johnston	1974	Homo	55 g, 140 g 225 g, 310 g	Weekly	140 g, 225 g and 310 g caused about the same space closure. 55 g caused less space closure
Burstone and Groves	1961	Homo	25–150 g	?	50–75 g caused optimal tooth movement. Increased force did not increase movement
Hixon <i>et al.</i>	1969	Homo	300 g, vs. 64–1515 g	$\times 2/\text{week}$	Higher force/increased rate of displacement*
Hixon <i>et al.</i>	1970	Homo	60–1037 g	$\times 3/\text{week}$	Higher force/increased rate of displacement*
King and Fischlschweiger	1982	Rat	50–200 g		Maximal displacement at 40 g, while larger forces produce less movement
Maltha <i>et al.</i>	1993	Dog	50 g, 100 g 200 g	$\times 2/\text{week}$	No difference between different forces and rate of displacement
Reitan	1960	Dog	100 g, 200 g	?	100 g and 200 g caused the same magnitude of displacement
Smith and Storey	1952	Homo	175–300 g, 400–600 g	Weekly	Optimal rate of displacement with an optimal force magnitude
Storey and Smith	1952	Homo	175–300 g, 400–600 g	Weekly	Optimal rate of displacement with an optimal force magnitude

* Faster displacement with increased force magnitude.

utilize the teeth for the experiment the extractions were postponed for 4 or 7 weeks.

The design of the study was approved by the Ethics Committee of the Medical Faculty of Göteborg University, Sweden.

The orthodontic tooth movement was performed with a fixed appliance (Lundgren *et al.*, 1995a), consisting of a sectional arch (Sentalloy 0.018" heavy) attached to a molar band on the first maxillary molar and ligated to a bonded bracket on the first maxillary premolar on the right side which was used as the test tooth. The molar bands on both sides were united with a transpalatal bar for reinforcement of the anchorage. A lingual arch with an anterior acrylic bite block was soldered to the molar bands to reduce the occlusal forces on the test tooth. It should be observed that this investigation was performed as an inter-individual study, that is only the maxillary first premolar on the right side was utilized as the test tooth and a comparison of the effects was made between the individuals. A force of 50 cN was applied to 16 premolars by the use of a 0.018" Sentalloy Heavy arch wire (Tomy, Tokyo, Japan). The remaining 16 test teeth were moved with twice as large a force, 100 cN by the use of a 0.016" Australian Regular arch wire (AJ Wilcock, Kinglake, Whittlesea, Australia). The force was controlled weekly and reactivated to 50 cN and 100 cN respectively, and was measured to the nearest 1 cN with a strain gauge (Haldex®, Halmstad, Sweden). The experimental periods were 4 and 7 weeks.

Tooth movement registration

Alginate impressions were taken just before the start and at the end of the experimental periods, and dental casts were prepared for analysis of tooth movements. With a sharp pencil, a point on each of the buccal and palatal cusps of the test and control teeth was marked on the cast. The horizontal, buccally directed, tooth movement was measured with a coordinate measuring machine (Validator 100®, TESA SA, Renens, Switzerland) to the nearest 0.01 mm. The apparatus and procedures have been described in detail elsewhere (Lundgren *et al.*, 1995a, b).

Histological procedures

At the end of the experiment, the teeth were extracted with forceps, fixed in 4 per cent form-

alin and subjected to routine histological preparation before embedding in paraffin. With the microtome set to 4 µm, the teeth were serially sectioned parallel to the long axis in a bucco-palatal direction from the mesial surface, when most of the root length was seen, to the middle of the root (3 levels, 0.3 mm apart). The sections, 18 sections in each level, i.e. 54 sections, were stained with haematoxylin and eosin (Kurol *et al.*, 1995b). A light microscope with a micrometer fitted into the eye-piece was used to measure surface extension and depth of root resorptions.

As described in a recent investigation (Kurol *et al.*, 1995b) root resorptions were registered on one randomly chosen histological section at each of the 3 levels, i.e. 3 sections, on each tooth. The surface extension was measured parallel to the root surface. The depth of each resorption lacuna was measured at the deepest point by using the distance from the bottom of the cavity perpendicular to the tangent passing through the borders of the resorption lacuna on the root surface. The measurements were performed to the nearest arbitrary unit ($\approx 13.3 \mu\text{m}$).

The following definitions were used:

Small surface extension of root resorption: < 10 arbitrary units ≈ 0.13 mm.

Medium surface extension of root resorption: $10-100$ arbitrary units $\approx 0.13-1.33$ mm.

Large surface extension of root resorption: > 100 arbitrary units ≈ 1.33 mm.

Small depth of root resorption: < 20 arbitrary units ≈ 0.27 mm.

Large depth of root resorption: > 20 arbitrary units ≈ 0.27 mm.

In eight maxillary premolars the root contour (mm) and the root area (mm^2) in one bucco-palatally directed histological section were measured in a stereomicroscope (Olympus SZH10, Japan) with a PC-based image analysis system (MicroMACRO AB®, Göteborg, Sweden). The mean values of root contour and root area were calculated in order to describe the following:

Resorbed root contour (%). The sum of the extension of the resorptions along the root surface in the three longitudinal and bucco-palatally directed histological sections of each tooth was registered and a mean was calculated and related to a registered mean root contour (Fig. 1A) (Kurol *et al.*, 1995b).

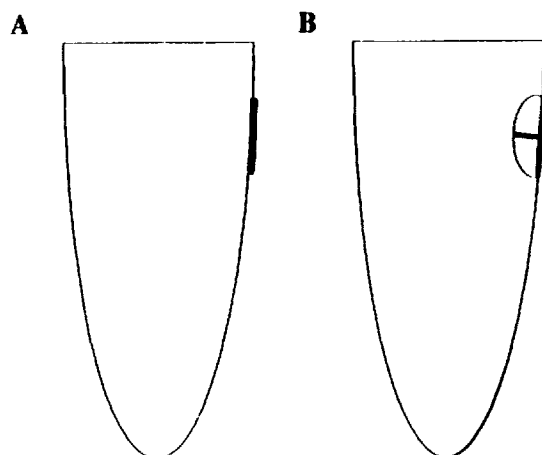


Figure 1 Schematic illustration of registration of root resorption. (A) Resorbed root contour (length in arbitrary units). (B) Resorbed root area (length \times depth in arbitrary units).

Resorbed root area (%). The sum of the resorbed root area (extension \times depth of the resorption lacuna) in the three longitudinal and bucco–palatally directed histological sections of each tooth was registered and a mean was calculated and related to a registered mean root area (Fig. 1B) (Kurol *et al.*, 1995b).

Radiographic registrations

Periapical radiographs using a long cone parallel technique were taken within a week prior to the start of tooth movement and immediately before extraction of the teeth.

All measurements on dental casts and histological and radiographic registrations were performed by one of the authors (PO-M).

Statistical analyses

Analysis of variance was performed by means of the StatView 4.0 statistical computer program

(Abacus Concepts, Inc., Berkeley, CA, USA, 1992).

Results

The orthodontic force magnitude was found to decline on average from 50 to $39 \text{ cN} \pm 5.58$ (22 per cent) and on average from 100 to $73 \text{ cN} \pm 2.75$ (27 per cent) during the first week of the experiment. A similar pattern of force reduction after reactivation was registered after all experimental weeks. There was no significant difference in tooth movements after application of 50 cN when compared with a doubled force magnitude of 100 cN, either after 4 or 7 weeks of loading. After application of a continuous force of 50 cN and 100 cN, the horizontal tooth movements were after 4 weeks on average $1.7 \pm 0.9 \text{ mm}$ and $1.5 \pm 0.7 \text{ mm}$ respectively, and after 7 weeks on average $4.3 \pm 1.5 \text{ mm}$ and $4.5 \pm 1.8 \text{ mm}$ (Table 2). The magnitude of tooth movements increased significantly after 7 weeks compared with 4 weeks when a force of 50 cN ($P=0.0019$) or 100 cN ($P=0.0029$) was used.

Root resorptions were registered in all test teeth and were more frequent in the 50 cN group when compared with the 100 cN group both after 4 weeks (mean value 11.9 and 9.9 in number) and after 7 weeks (mean value 13.1 and 10.1 in number) (Fig. 2). The difference after 7 weeks of force application was significant ($P=0.0484$).

When a force of 50 cN was applied, 29 per cent of the resorptions were located in the cervical third and 62 per cent in the apical third of the root. After application of 100 cN, root resorptions were seen almost as often in the apical third as in the cervical third of the root (49 and 46 per cent respectively). Less than 10 per cent of the resorptions were found in the middle part of the root in both groups (Fig. 3) and were mainly located on the palatal root in the bifurcation of the tooth.

Table 2 Mean values (mm) of buccal tooth movement of 32 maxillary premolars after application of a continuous force of 50 cN or 100 cN for 4 and 7 weeks.

Tooth movement (mm)	4 weeks		7 weeks	
	50 cN	100 cN	50 cN	100 cN
Mean	1.7	1.5	4.3	4.5
SD	0.92	0.68	1.50	1.82
Maximum	3.4	2.95	7.10	8.28
Minimum	0.5	0.98	2.74	2.20

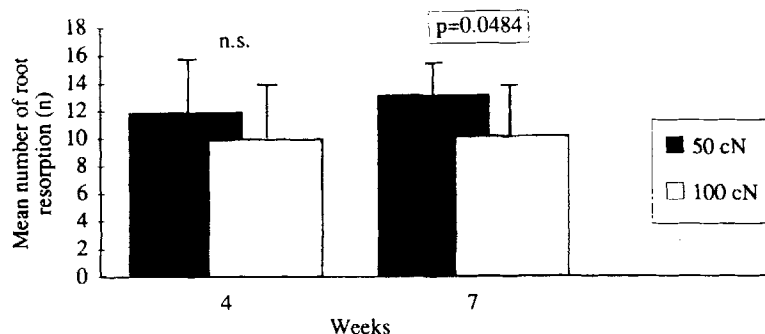


Figure 2 Frequency (mean value \pm SD) of root resorption after application of a continuous force of 50 cN or 100 cN for 4 and 7 weeks; n.s. = no significant difference.

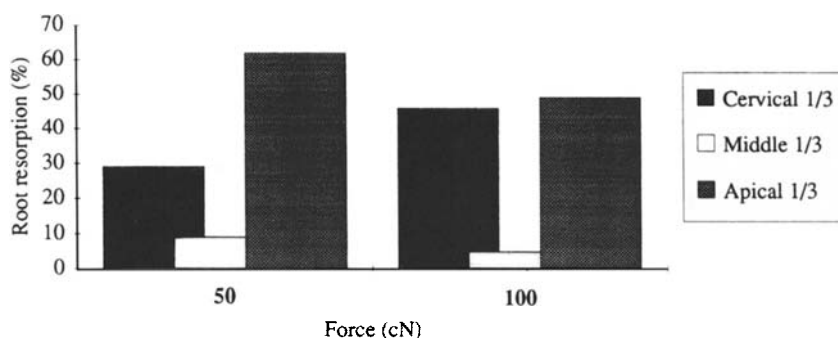


Figure 3 Location of root resorptions in the cervical, middle and apical third of the root after application of a continuous force of 50 cN and 100 cN.

The severity of root resorptions expressed as large surface extension (Fig. 4) and large depth (Fig. 5) or percentage of resorbed root area and resorbed root contour on the histological sections (Fig. 6) after 4 and 7 weeks did not show any significant difference when the applied force was 50 cN compared with 100 cN.

The frequency and severity of root resorption varied markedly within the same test group, with no significant differences between boys and girls (Fig. 7A, subjects 4 and 7; Fig. 7B, subjects 7 and 8). Figure 7A shows that subject 4 exhibited a large number of root resorptions, a large resorbed root contour and a moderately resorbed root area whereas subject 7, in the same group, showed few resorptions, a small resorbed root contour and a small resorbed root area. In Figure 7B, subject 7 shows few resorptions, with only a small resorbed root contour and a negligible resorbed root area while subject 8 in the same 100 cN group exhibited a large number of root resorptions

with a large resorbed root contour and root area.

The individual variations were large in both magnitude of tooth movement and root resorptions. For example, tooth displacement varied >6 mm between the extreme subjects with a force of 100 cN during 7 weeks (2.2–8.3 mm). The number of root resorptions when a controlled force of 50 cN was applied for 4 weeks was 4 in one subject and 22 in another individual. Also the resorbed root contour varied considerably, between 1.7 and 10.8 per cent when a force of 100 cN had been applied for 7 weeks (Fig. 7A, B).

The apical radiographs failed to reveal any root resorptions.

Discussion

This clinical study in humans analysed and compared the effect of a commonly-used and recommended orthodontic force magnitude for

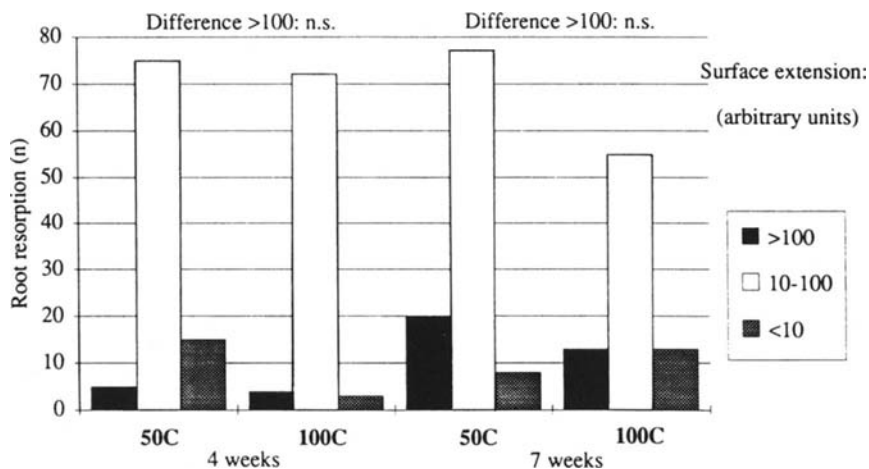


Figure 4 Distribution of surface extension of root resorptions after application of a continuous force of 50 cN or 100 cN for 4 and 7 weeks. The difference in root resorptions with large surface extension (> 100 arbitrary units) was not significant when the 50 cN group was compared with the 100 cN group.

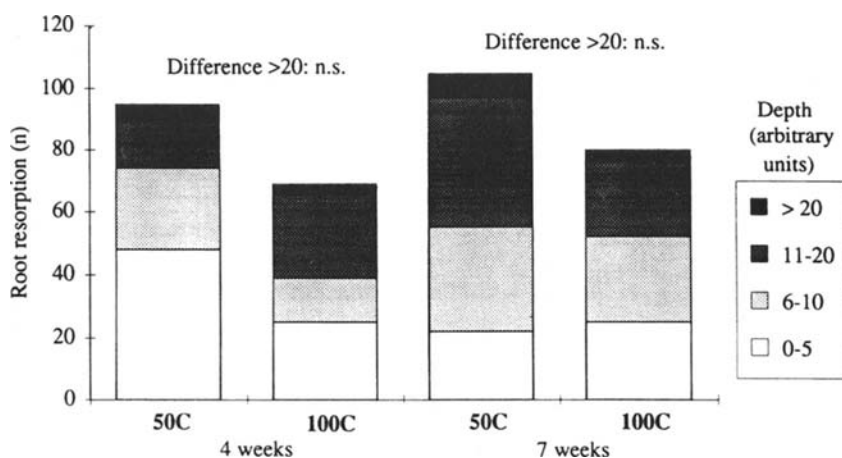


Figure 5 Distribution of depth of root resorptions after application of a continuous force of 50 cN or 100 cN for 4 and 7 weeks. The difference in root resorptions with large depth (> 20 arbitrary units) was not significant when the 50 cN group was compared with the 100 cN group.

premolar tipping (50 cN) (Kvam, 1972; Bench *et al.*, 1978; Kurol *et al.*, 1995a) with a doubled force (100 cN) regarding rate of tooth movement and the 'price', i.e. frequency and severity of root resorptions.

The results showed that there was no significant difference in the amount of buccal premolar displacement after 4 and 7 weeks with a doubled force magnitude of 100 cN compared with 50 cN. This confirms the results from earlier investigations in dogs (Reitan, 1960; Maltha *et al.*, 1993). Our findings are also in agreement with a clinical report by Boester and

Johnston (1974) who found that space closure after premolar extraction proceeded equally rapidly at forces ranging from 5 to 11 ounces (≈ 140 – 310 cN). Only at lower levels, e.g. 2 ounces (≈ 55 cN), did force appear to be the rate-limiting variable. Several studies have demonstrated that increasing the magnitude of force does not produce any increase in tooth displacement (Smith and Storey, 1952; Storey and Smith, 1952; Reitan, 1960; Burstone and Groves, 1961; King and Fischlschweiger, 1982).

However, other investigators (Andreasen and

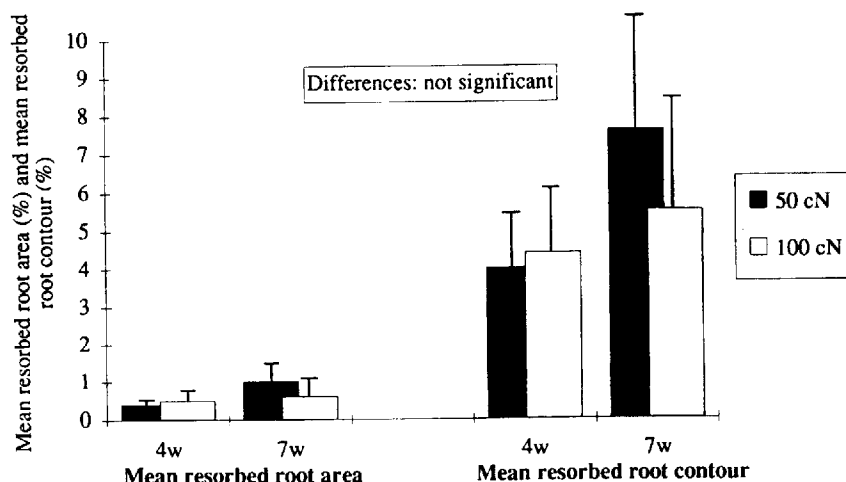


Figure 6 Distribution of percentage of resorbed root area (mean value \pm SD) and percentage of resorbed root contour (mean value \pm SD) after application of a continuous force of 50 cN or 100 cN for 4 and 7 weeks.

Johnson, 1967; Hixon *et al.*, 1969, 1970; Andreasen and Zwanziger, 1980) have reported findings, contradictory to those referred to with larger tooth movement when the force magnitude was increased (Table 1). The difference in results may be due to different types of appliances used, e.g. Kloeht-type headgear (Andreasen and Johnson, 1967), frictionless sectional arch (Boester and Johnston, 1974), full fixed appliance (Andreasen and Zwanziger, 1980), and the varying magnitude of the applied force, 25–1515 cN (Table 1). Moreover, in some reports the direction of tooth movement was mesio-distally directed in spongy bone. In this investigation, however, the tooth movement was buccally directed with, perhaps, more contact with cortical bone, which also restricts comparisons.

Root resorptions are believed to be related initially by the force magnitude (Vardimon *et al.*, 1991) and light forces have long been recommended (Reitan, 1964, 1974, 1985; King and Fischlschweiger, 1982) to reduce adverse tissue reactions (root resorption). It is therefore tempting to assume that 50 cN should cause less root resorption than a doubled force of 100 cN. However, the present investigation revealed more root resorption after 7 weeks when 50 cN was applied compared with 100 cN. In an earlier report concerning intrusion of premolars, Stenvik and Mjör (1970) found similar results; an increased magnitude of force led to a decrease in frequency of root resorption. It does

not seem logical, however, that a smaller force should cause resorption to a larger degree than a larger force, and the differences in frequency of root resorption found in this investigation after 7 weeks may be explained by a difference in composition of the experimental groups, i.e. normal individual variations may overshadow the effect of a doubled force magnitude.

Another more speculative explanation may be that a weekly-activated force of 100 cN is too large for 'optimal' tissue reactions close to the tooth surface. Perhaps the tooth movement is then mainly achieved by an undermining bone resorption as described by Reitan (1985) and that the reaction/activity near the tooth surface is limited due to compression of the tissues. This concept would lead to an even more speculative view that a four or six times larger force would move the tooth by undermining resorption in the bone, causing no root resorption at all due to no possibility of root surface reaction as a result of the hyalinization with sterile necrosis of root surface soft tissues. This should be further analysed.

It seems logical to assume that when a tooth is moved over a longer distance, more remodelling of the surrounding tissues is required. This may expose the tooth to more adverse tissue reactions. VonderAhe (1973) noted that the severity of root resorption increased as the amount of tooth movement increased. However, our study has not been able to verify this finding and this may be due to a shorter duration of

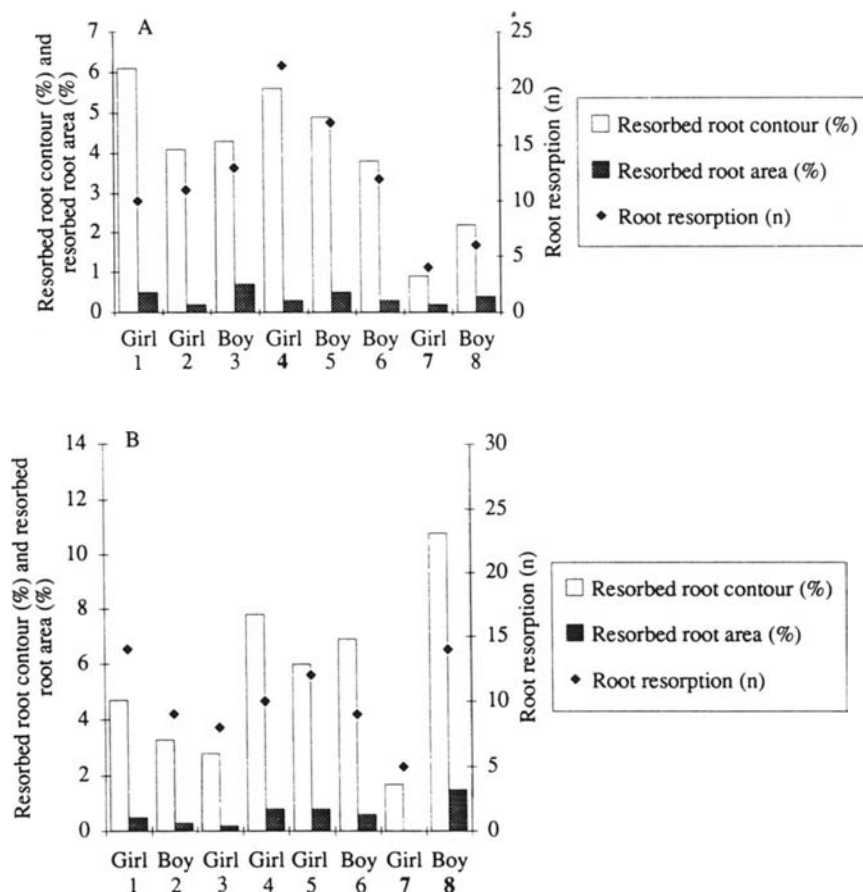


Figure 7 (A) Number of root resorptions (n), extension of resorbed root contour resorbed root area (percentage) in eight test teeth after application of a continuous force of 50 cN for 4 weeks. (B) Number of root resorptions (n), extension of resorbed root contour and resorbed root area (percentage) in eight test teeth after application of a continuous force of 100 cN for 7 weeks.

tooth movement, 4 to 7 weeks, compared with 9 to 68 months in that study.

Each force system will probably show a certain amount of force reduction, which is important to analyse when comparisons are to be made. Very few studies have analysed the force reduction regularly with short intervals. Rygh *et al.* (1986) reported a force decline of 50 per cent after 14 days and 70 per cent after 28 days when an initial force of 30 cN had been applied to rat molars. In a few clinical studies, force reduction has been reported – 13 per cent after 3 hours and 16 per cent after 2–3 days when elastics were used (Hixon *et al.*, 1970), 17 per cent after 1 day (Lundgren *et al.*, 1995b) and 24 per cent after 7 days (Lundgren *et al.*, 1995a)

when 50 cN was applied with the same type of appliance.

Individual variations have been reported to be an important factor for both tooth movement (Hixon *et al.*, 1970; Maltha *et al.*, 1993; Lundgren *et al.* 1995a; and root resorption (Henry and Weinmann, 1951; Massler and Malone, 1954; Zachrisson, 1976; Kvam, 1972; Reitan, 1974; Linge and Linge, 1980, 1983; Kuroi *et al.*, 1995b). This clinical study confirms these findings. Thus, the individual reactions may have more impact than the increase in amount of force or length of the experimental period on both the tooth movement achieved and occurrence of root resorption. These differences have traditionally been ascribed to the

orthodontic treatment procedure itself, including the skills of the orthodontist, but this may now be questioned.

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Acknowledgements

This study has been supported by the Swedish Dental Society and the Country Council of Jönköping. We would like to express our gratitude to Mr Tommy Jonsson, Göteborg University, for statistical assistance and Ms Lisa Tengqvist, Jönköping, for histological preparations.

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