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The effects of a four-fold increased orthodontic force magnitude on tooth movement and root resorptions. An intra-individual study in adolescents

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SUMMARY This clinical and histological study was designed as an intra-individual study to investigate the effect on tooth movements and adverse tissue reactions (root resorption) when a fixed orthodontic appliance was activated with a controlled, continuous force of 50 cN (≈50 g) or with a four-fold larger force (200 cN ≈ 200 g). The first premolar on both sides of the maxilla in eight individuals, six boys and two girls (mean age 13.0 years), was moved buccally during 7 weeks with 50 cN and 200 cN alternately on the right or left side. During the first week a force reduction of 18 and 28 per cent (on average) was registered in the 50 cN and 200 cN group respectively. Tooth movements were studied by means of dental casts using a coordinate measuring machine. The magnitude of the mean horizontal crown movement increased 50 per cent when a force of 200 cN was applied compared with a 50 cN force (3.4–5.1 mm on average) and the difference was significant. Root resorptions were registered in histological sections of the extracted test teeth with no significant difference in frequency or severity between the two forces used. Individual variations were large regarding both tooth movement and root resorption. Possible reasons to explain the results as well as the clinical implications of the findings are discussed.

Introduction

An optimal orthodontic force is characterized by a maximal cellular response from the tooth-supporting tissues, including apposition and resorption of alveolar bone, at the same time as maintenance of the vitality of these tissues is secured (Burstone, 1985). Many studies have been performed to investigate the relationship between magnitude of applied force and amount of tooth movement (Storey and Smith, 1952; Reitan, 1960; Burstone and Groves, 1961; Andreasen and Johnson, 1967; Hixon *et al.*, 1969, 1970; Boester and Johnston, 1974; Andreasen and Zwanziger, 1980; Maltha *et al.*, 1993) as well as between the magnitude of applied force and root resorptions (Reitan, 1964, 1974; Stenvik and Mjör, 1970; Harry and Sims, 1982; Vardimon *et al.*, 1991). Considering that many children are treated orthodontically, it is surprising that the association between the three factors: applied force, achieved tooth movements and amount of root resorption, has received so little attention in the form of systematic studies in humans. Therefore, a clinical inter-individual study was recently carried out to investigate tooth movements and adverse reactions of the tooth-supporting tissues when the applied continuous force was doubled from 50 cN to 100 cN (Owman-Moll *et al.*, 1995). The results demonstrated that the rate of tooth movement and severity of root resorption (surface extension and depth of root resorption or resorbed root contour and resorbed root area on histological sections) showed no significant difference when 100 cN was applied compared with 50 cN. An additional investigation was therefore undertaken to determine whether a further substantial increase of the force magnitude would result in faster movement of the teeth without deleterious side effects, which would be of clinical importance from a cost-benefit point of view. In order to evaluate the reported individual variations regarding both tooth movement (Hixon *et al.*, 1970; Mitchell *et al.*, 1973; Maltha *et al.*, 1993) and tissue response (Henry and Weinmann, 1951; Reitan, 1974; Zachrisson, 1976; Linge and Linge, 1980, 1983) and in particular also on well controlled orthodontic forces (Lundgren *et al.*, 1995a; Kurol *et al.*, 1995b; Owman-Moll *et al.*, 1995), it was decided to design a study with an intra-individual design in which a very high force was compared with a clinically commonly used one. The aim of this investigation was therefore to compare intra-individually the effect on the magnitude of tooth movements and frequency and severity of root resorption of well-controlled continuous forces of 50 cN and 200 cN.

Subjects and methods

Experimental design and orthodontic appliance

The first maxillary premolars bilaterally in eight individuals, six boys and two girls aged 12.1–13.6 years (mean age 13.0 years), constituted the test teeth. 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, which were postponed 7 weeks in order to utilize the teeth in the investigation. The design of the study was approved by the Ethics Committee of the Medical Faculty of the Göteborg University, Sweden.

A fixed orthodontic appliance according to Lundgren *et al.*, 1995a (Fig. 1) was inserted the day the experimental period started and consisted of molar bands on the first maxillary molars joined with a half round 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 teeth. The buccally directed tooth movement was performed with a sectional arch (Sentalloy 0.018″ heavy when 50 cN was applied and Australian 0.018″ regular when 200 cN was applied) attached to the molar band and ligated to a bonded 0.018″ bracket on the test premolar bilaterally. An orthodontic, continuous force of 50 cN ($\approx$50 g) and 200 cN ($\approx$200 g) was applied alternately on the right or left side for 7 weeks. The force magnitude was controlled weekly and reactivated to 50 cN and 200 cN respectively, and was measured to the nearest 1 cN with a strain gauge (Haldex®, Halmstad, Sweden).

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 formalin 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 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 three levels, i.e. three 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 μm).

The following definitions were used:

Small surface extension of root resorptions: $<$10 arbitrary units $\approx$0.13 mm.

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

Large surface extension of root resorptions: $>$100 arbitrary units $\approx$1.33 mm.

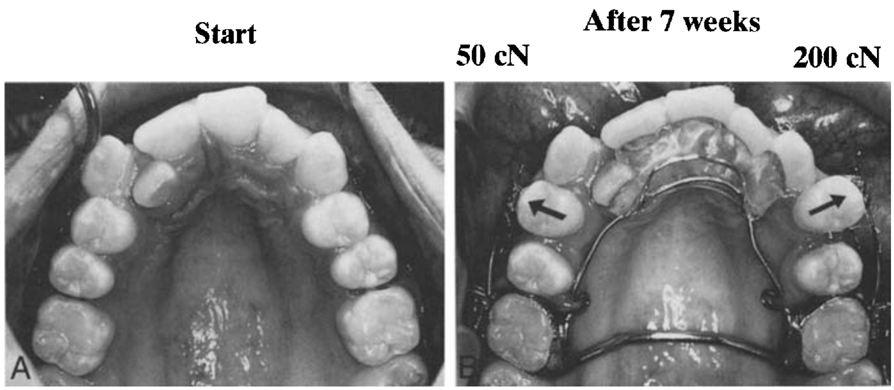

Figure 1 (A) Occlusal view of the fixed orthodontic appliance in a 13 year 11 month old girl at the start of the experiment. ((B) The maxillary first premolars were buccally moved with a continuous, weekly controlled and reactivated force of 50 cN and 200 cN alternately on the right and left side for 7 weeks.

Small depth of root resorptions: <20 arbitrary units ≈0.27 mm.
Large depth of root resorptions: >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 of the teeth were measured in a stereomicroscope (Olympus SZH10, Japan) with a PC-based image analysis system (MicroMACRO AB®, Göteborg, Sweden). The mean value of root contour and root area were calculated in order to describe the:

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. 2A) (Kurol *et al.*, 1995b).

Resorbed root area (%). The sum of the resorbed root area (extension × 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. 2B) (Kurol *et al.*, 1995b).

Radiographic registrations

Periapical radiographs using a long cone parallel technique were taken within a week before the start of the tooth movement and immediately before extraction of the teeth. All measurements on dental casts as well as histological and radiographic registrations were performed by one of the authors (PO-M).

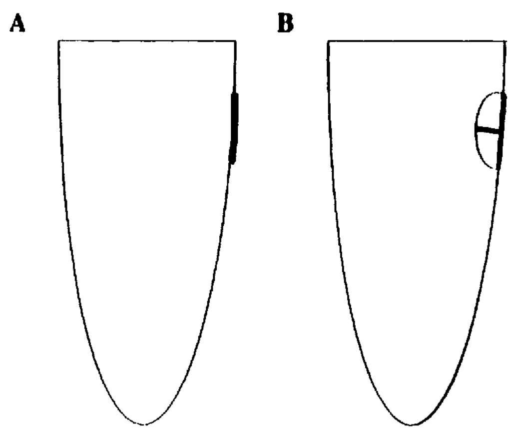

Figure 2 Schematic illustration of registrations of root resorptions (A) Resorbed root contour (length in arbitrary units). (B) Resorbed root area (length × depth in arbitrary units).

Statistical analyses

Analysis of variance was performed by means of the StatView 4.0 (Abacus Concepts, Inc., Berkeley, CA, USA, 1992) statistical computer program.

Results

The orthodontic force magnitude declined on average from 50 to 41 cN ± 3.07 (18 per cent) and on average from 200 to 145 cN ± 9.26 (28 per cent) during the first experimental week. A similar pattern of force reduction was registered following reactivation after each of the experimental weeks.

After application of a continuous force of 50 cN for 7 weeks, the tooth displacements varied between 1.5 and 5.9 mm (mean 3.5 ± 1.2 mm). When a continuous force of 200 cN was applied, the movements varied between 1.9 and 7.9 mm (mean 5.1 ± 1.9 mm) (Table 1). The difference in horizontal tooth movement was significant ($P=0.0201$) with a 95 per cent confidence interval of 1.8 ± 1.4 mm.

The resorptions were mainly located in the bucco–cervical and palato–apical thirds of the teeth and there were no large differences when the two force-groups were compared (Figure 3). Cavities in the middle part of the root were most often registered on the palatal root in the bifurcation area.

Root resorptions were registered in all test

Table 1 Mean horizontal tooth movement (mm) of 16 maxillary premolars in eight individuals after application of a continuous force of 50 cN (≈ 50 g) on one side and 200 cN (≈ 200 g) on the other side for 7 weeks.

Tooth movement (mm)	50 cN	200 cN
Mean	3.5	5.1
SD	1.22	1.93
Maximum	5.9	7.9
Minimum	1.5	1.9

teeth and there were no significant difference in number (n) or severity of root resorptions, i.e. surface extension (arbitrary units) and depth (arbitrary units) or resorbed root contour (%) and resorbed root area (%) after application of a 50 cN compared with a 200 cN force (Fig. 4).

The frequency and severity of root resorptions showed great individual variations whether 50 cN or 200 cN was applied (Fig. 5A, subjects 2 and 6; Fig. 5B, subjects 5 and 7). Figure 5A shows that subject 2 exhibited a moderate amount of root resorption, a small resorbed root contour and a small resorbed root area, whereas subject 6 showed almost twice as much root resorption and an almost three times larger resorbed root contour and resorbed root area. According to Fig. 5B, subject 5 exhibited a fairly small amount of root resorption with a large resorbed root contour and a large resorbed root area while subject 7 showed the same number of root resorptions but with an almost three times larger resorbed root contour and an almost four-fold increased resorbed root area.

The apical radiographs did not reveal any root resorptions.

Discussion

A force of 50 cN has often been used and recommended when buccal tipping of premolars is desired (Kvam, 1972, 1973; Bench *et al.*, 1978; Reitan, 1985; Kurol *et al.*, 1995a;

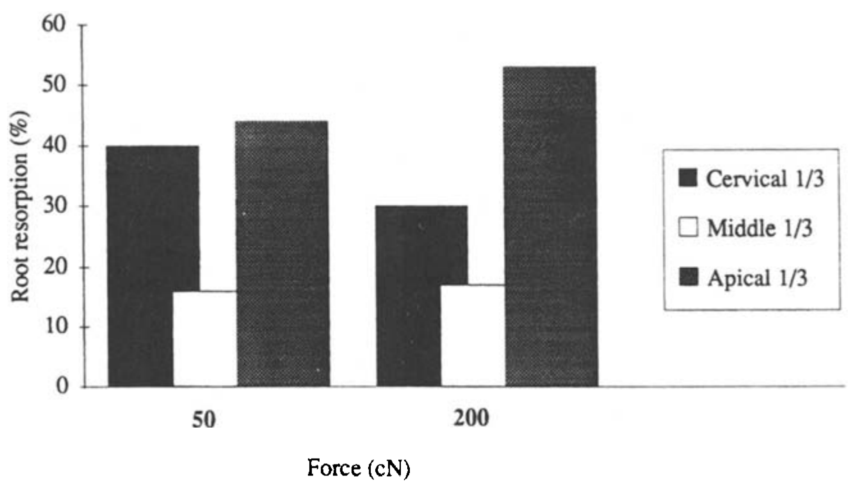

Figure 3 Location of root resorptions in the cervical, middle and apical thirds of the root after application of a continuous force of 50 cN and 200 cN for 7 weeks.

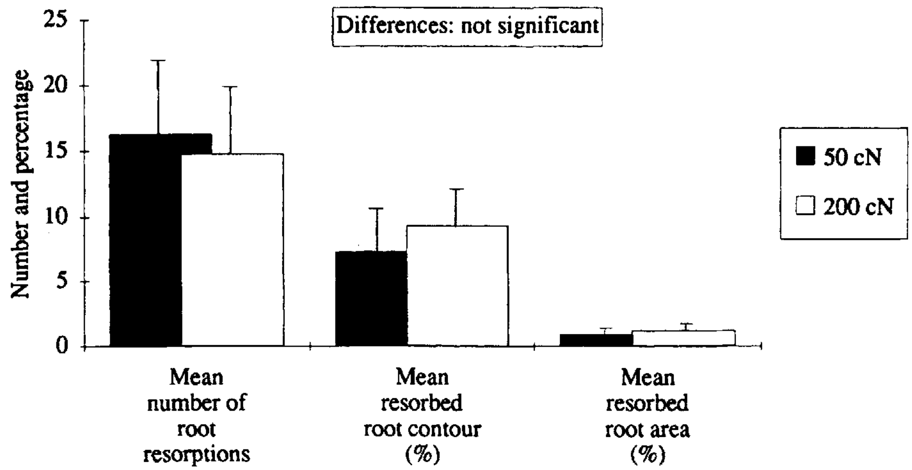

Figure 4 Number of root resorptions (mean ± SD), percentage of resorbed root contour and percentage of resorbed root area (mean ± SD) in 8 individuals after application of a continuous force of 50 cN in eight maxillary premolars and 200 cN in the eight contralateral teeth for 7 weeks.

Lundgren *et al.*, 1995a). A relevant question in an everyday clinical situation is: "Will an increased force magnitude cause a larger tooth movement and also an increase in frequency and severity of root resorption?" Several studies have been carried out to find an optimal force magnitude for orthodontic tooth movement. Many investigators have focused their interest on the relationship between magnitude of applied force and achieved tooth movements (Smith and Storey, 1952; Storey and Smith, 1952; Reitan, 1957, 1960; Burstone and Groves, 1961; Andreasen and Johnson, 1967; Hixon *et al.*, 1969, 1970; Mitchell *et al.*, 1973; Andreasen and Zwanziger, 1980; Maltha *et al.*, 1993) while others have exclusively studied the association between magnitude of applied force and amount of root resorption with no regard to the achieved tooth movement (Stenvik and Mjör, 1970; Reitan, 1974; Harry and Sims, 1982; Vardimon *et al.*, 1991).

In an investigation on the association between the three factors, applied force, achieved tooth movement and amount of root resorption in rats, King and Fischlschweiger (1982) reported that light forces produced more rapid tooth movements with insignificant cemental cratering whereas intermediate or heavy forces resulted in slower displacements and a substantial amount of root resorption. However, there are important differences in both function and morphology between animals and humans (Reitan and Kvam, 1971). Therefore, an inter-individual investigation in humans was recently carried out comparing the effects of a doubled force magnitude of 100 cN with those of a force of 50 cN on tooth movements and adverse tissue reactions (Owman-Moll *et al.*, 1996). That study showed that tooth movements and severity of root resorptions were not significantly affected by doubling of the force magnitude. A somewhat surprising finding in that study was, however, that the number of root resorptions was larger after 7 weeks with 50 cN compared with 100 cN. This is in agreement with Stenvik and Mjör (1970), who found that an increased force caused a decrease in frequency of root resorption when premolars were intruded. The results from the present clinical intra-individual investigation indicate that a four-fold increase in force magnitude caused a significant increase in tooth movement without any significant difference in frequency or severity of root resorption. Whether this is also valid for experimental periods longer than 7 weeks remains to be determined. The experimental model used in this study does not allow long-term investigations due to the limited bucco–lingual extension of the alveolar process. It is therefore necessary to utilize another type of model, permitting tooth movement along the alveolar ridge, if long-term results are to be

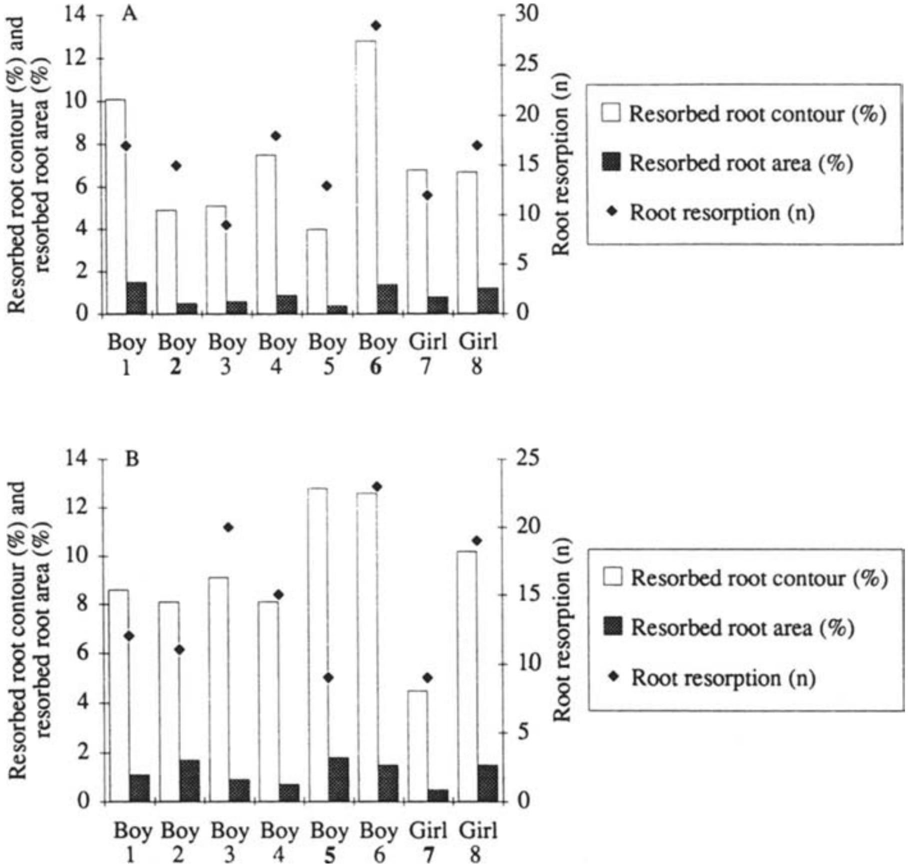

Figure 5 (A) Individual values of root resorption (n), mean resorbed root contour (%) and mean resorbed root area (%) in eight test teeth after application of a continuous force of 50 cN for 7 weeks. (B) Individual values of root resorption (n), mean resorbed root contour (%) and mean resorbed root area (%) in eight test teeth after application of a continuous force of 200 cN for 7 weeks.

studied. However, this would probably not be possible in humans for practical and ethical reasons.

One of the main findings in this investigation was that the individual variations in tooth movement as well as in frequency and severity of root resorption were large. This is in agreement with earlier investigations in the same series of clinical studies comprising 56 (Kurol *et al.*, 1995b) and 32 (Owman-Moll *et al.*, 1996) subjects respectively, (mean age 13.5 years). The results from these two studies and the present, in all based on data from 96 individuals, showed the same degree of individual variations when the force, controlled and reactivated weekly, differed between 50, 100 and 200 cN. This is in agreement with earlier findings that individual factors determine the relationship between applied force and tooth movement (Hixon *et al.*, 1970; Mitchell *et al.*, 1973; Maltha *et al.*, 1993). These results indicate that the major source of variation is probably not the magnitude of force but variation in metabolic response. It is well known that prostaglandins play a major role in many resorption processes (Klein and Raisz, 1970; Somjen *et al.*, 1980; Ngan *et al.*, 1988; Brudvik and Rygh, 1991). It is therefore tempting to believe that this may be one of the reasons for the great variability. However the variations in prostaglandins between individuals remain to be elucidated and further scientific documentation has to be carried out before any definite conclusions can be drawn.

The results of this study showed that when the applied, continuous force increased fourfold to 200 cN tooth movement increased 50 per cent without any significant increase in root resorption. It may be speculated that a force magnitude of 200 cN may be too large to express cellular reactions close to the root surface and that tooth movement may take place mainly by undermining resorption of the alveolar bone (Reitan, 1985). Where adverse tissue reactions are concerned, heavy force application may primarily prevent cellular reactions on the root surface. Still, the higher forces may have influenced the root surface so that in a longer perspective when the force is reduced, due to tooth movement, extensive root resorption may take place. This study of early tissue reactions in adolescents can not answer the assumption due to limitations of the experiment.

In this connection, it seems prudent to emphasize that according to earlier investigations there is also a small risk group of patients who may reveal severe root resorptions (>3 mm root shortening or root surface resorptions half-way to the pulp or more) (DeShields, 1969; Hollender *et al.*, 1980; Levander and Malmgren, 1988; Linge and Linge, 1991; Kurol *et al.*, 1995b). In order not to mislead clinicians to use higher forces, some reservation should be taken at this premature stage that a general application of higher forces might increase root resorptions in those patients. Further animal studies over a longer period of time are therefore indicated.

It is concluded that the present results can be of value for cost-benefit evaluation as well as for deciding clinical strategies regarding orthodontic treatment. These data might also be of value for judging insurance issues in connection with adverse events as they might warrant an altered attitude as to what is to be regarded as maltreatment.

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