Continuous versus interrupted continuous orthodontic force related to early tooth movement and root resorption

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The reactions of the supporting tissues during the application of orthodontic forces have often been discussed. The magnitude of the applied force is believed to be an important factor in this context. Many studies have been published on the relationship between the magnitude of applied force and either the amount of tooth movement[1-5] or the presence of adverse tissue reactions, i.e., root resorption.[4,6,7] The association between tooth movement and force magnitude was recently confirmed, while root resorption seems to be less force-sensitive.[8,9]

The type of applied force, however, should also be considered when evaluating orthodontic treatment. Teeth and supporting tissues may react differently to continuous force and to force interrupted by rest periods. Earlier investigations primarily evaluated orthodontic tooth movement in relation to continuous force systems.[3,5,6,10-14] It is known, however, that functional appliances[15,16] and headgear[1,17] also produce orthodontic tooth movement with less than full-time wear. According to earlier investigations of the effect of short-term forces on orthodontic tooth movement in animals, interrupted forces[18] and pulsating forces[19] are able to produce tooth movement equivalent to that produced by continuous force. It is believed that periods of rest favorably affect cell proliferation in the supporting tissues, which in turn promotes further tissue change when the appliance is reactivated.[20] Moreover, in cases with root resorption, periods of rest may

Abstract

The aim of the present clinical investigation was to assess the effects of continuous and interrupted continuous forces of the same magnitude (50 cN≈ 50 g) on orthodontic tooth movement and related adverse tissue reactions, i.e., root resorption. Thirty-two maxillary first premolars in 16 patients, 8 boys and 8 girls (mean age 13.9 years), were moved buccally by means of a fixed orthodontic appliance with a sectional arch. The patients were divided into two groups of 8, for experimental periods of 4 and 7 weeks.The continuous force was checked and reactivated weekly to 50 cN. The interrupted continuous force applied to the contralateral premolars was left uncontrolled for 3 weeks, after which the arch was made passive for 1 week for tissue rest and recovery. Tooth movements were studied on dental casts using a coordinate measuring machine (Validator 100, TESA SA, Renens, Switzerland). Horizontal tooth movement with continuous force was more effective than with interrupted continuous force after 7 weeks. Histological sections of the experimental teeth, however, showed no difference in the amount or severity of root resorption between the two forces. Individual variations in both the magnitude of tooth movement and the amount and severity of root resorption for both of the two force systems were great.

Key Words

Adolescence • Force • Tooth movement • Root resorption

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Table 1
Resorptive areas with large surface extension (>1.33 mm) and great depth (>0.27 mm) in eight patients following continuous and interrupted continuous force application

	Large surface extension		Great depth	
Patient	C	IC	C	IC
1	1	0	0	1
2	5	0	1	3
3	3	5	2	1
4	2	0	1	2
5	4	5	4	2
6	4	0	0	0
7	0	3	0	0
8	1	0	0	0
Total (n)	20	13	8	9

C = continuous force
IC = interrupted continuous

allow the resorption cavities to be repaired with secondary cementum.[20] To our knowledge, however, there is no systematic study comparing the effects, in humans, of a continuous orthodontic force with an interrupted continuous force.

The purpose of this investigation was to compare the effects of two force systems, continuous and interrupted continuous, of the same magnitude (50 cN ≈ 50 g), on achieved tooth movement in relation to root resorption.

Material and methods

Experimental design and orthodontic appliance

The material consisted of 32 maxillary first premolars from 16 individuals (8 boys and 8 girls) 11.8 to 15.8 years old (mean age 13.9 years). All subjects had been referred for specialist treatment and showed bimaxillary crowding or maxillary protrusion. The proposed orthodontic treatment included bilateral extraction of the maxillary first premolars. The extractions were postponed in order to use the teeth as test teeth for this experiment.

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

The maxillary first premolars were moved buccally with a fixed orthodontic appliance. The appliance consisted of separate sectional arches on each side (Sentalloy 0.018 inch heavy, Tomy, Tokyo, Japan) attached to bonded brackets (0.018 inch) on the experimental teeth and anchored via molar bands cemented to the maxillary first molars. A lingual arch with an anterior bite block disengaging the occlusion was soldered to the molar bands. The appliance was activated to provide a horizontal, buccally directed force of 50 cN (≈ 50 g) on each of the experimental teeth. The force was measured with a strain gauge (Haldex, Halmstad, Sweden) to the nearest 1 cN. The experimental design has been described in detail previously.[21] The experimental setup is shown in Figure 1.

The patients were divided into two groups of eight individuals: one group received 4 weeks of treatment, the other 7 weeks. Each patient in both groups was treated with continuous force applied to one maxillary first premolar and interrupted continuous force applied to the other. The 16 premolars being moved with a continuous force were checked weekly and activated to 50 cN. Forces on the 16 contralateral premolars were left uncontrolled for 3 weeks, after which a passive 0.017 x 0.022 inch sectional wire (Blue Elgiloy, RMO, Denver, Colo) was applied for 1 week to retain the tooth and prevent relapse. The 16 test teeth in the 4-week group were then extracted. In the 7-week group, the interrupted continuous force was reactivated by replacing the passive sectional archwire with a new sectional arch (Sentalloy 0.018 inch heavy) calibrated to 50 cN. The premolars undergoing continuous force were checked weekly and reactivated to 50 cN. After 3 weeks, the 16 test teeth in the 7-week group were extracted.

At the end of the experimental periods the teeth were extracted with forceps and fixed in 4% formalin solution. After routine histological preparation, the teeth were step-serially sectioned longitudinally in a buccopalatal direction (3 levels, 0.3 mm apart) with the microtome set to 4 µm and stained with hematoxylin and eosin.[22] A light microscope with a micrometer fitted into the eyepiece was used to measure surface extension and depth of root resorption.

Dental cast analysis

Dental casts were made from alginate impressions taken immediately before the start and at the end of the experimental period. Points representing the buccal and palatal cusps of each experimental tooth were marked on the casts with a sharp pencil. The horizontal, buccally directed tooth movements were 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.[21,23]

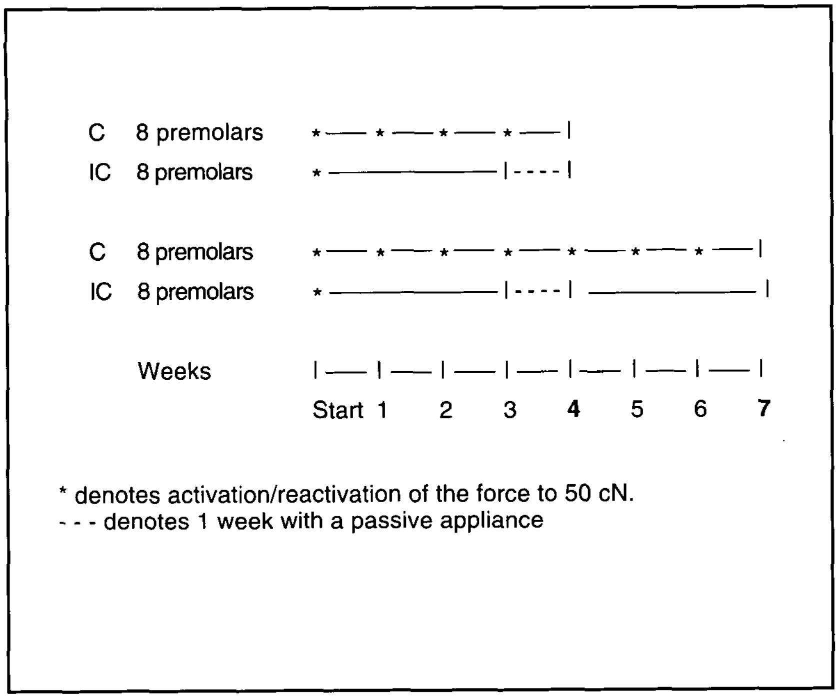

Figure 1

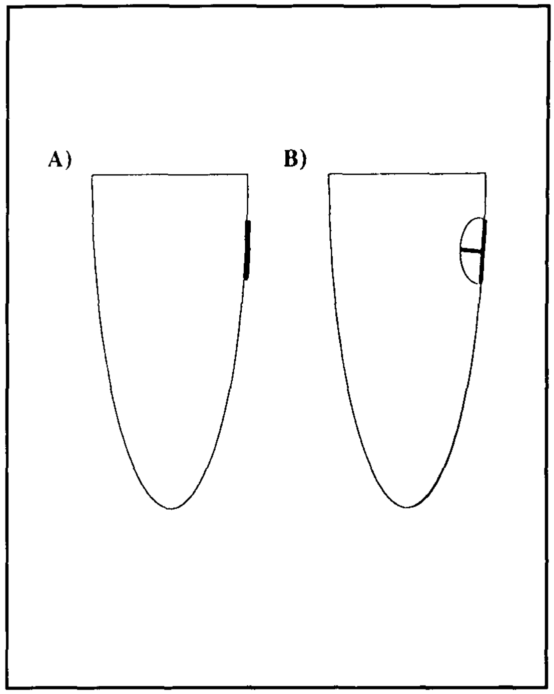

Figure 2

Figure 1
Experimental outline. Two types of orthodontic forces of 50 cN were applied to two maxillary premolars in each of 16 patients. Continuous (C) force was applied on one side and interrupted continuous (IC) on the other side. A total of 32 teeth were tested: 16 for 4 weeks and 16 for 7 weeks.

Figure 2
Schematic illustration of resorptive areas in histologic sections.
A: Resorbed root contour (length in arbitrary units; marked with bold line).
B: Resorbed root area (length x depth in arbitrary units; marked with bold lines).

Registration of root resorption

According to an earlier investigation,[22] areas of root resorption were registered on one randomly chosen section at each of three levels in the histological sections, i.e., in three sections on each tooth. The surface extension and depth of each resorption lacuna was measured to the nearest arbitrary unit (13.3 μm, 0.0133 mm) on a scale placed in the eyepiece of the microscope. Areas of resorption that extended five arbitrary units (65 μm 0.07 mm) or more were registered. Small resorptive areas (< 5 arbitrary units) close together were registered as a single resorption. The following registrations were made:

- Large surface extension of root resorption: > 100 arbitrary units, 1.33 mm.
- Large depth of root resorption: > 20 arbitrary units, 0.27 mm.
- Resorbed root contour (%): The sum of the extension of each resorption along the root surface in three longitudinal and buccopalatal histological sections of each tooth was registered and related to a previously calculated total root contour (Figure 2A).[22]
- Resorbed root area (%): The sum of the resorbed root area in three longitudinal and buccopalatal histological sections was registered and related to a previously calculated total root area (Figure 2B).[22]

Radiographic registration

Conventional periapical radiographs using a long cone parallel technique were taken the week before tooth movement was initiated and again immediately before extraction. The apical radiographs were examined using a magnifying viewer over a bright-light lamp, framed to prevent stray light.

All dental cast measurements as well as histological and radiographic registrations were performed by one author (P.O.M.).

Statistical analysis

Analysis of variance was performed using the StatView 4.0 statistical computer program (Abacus Concepts, Inc, Berkeley, Calif).

Results

The magnitude of the continuous force was found to decline from 50 cN to an average of 39 ± 5.6 cN (22 %) during the first week. Similar reductions in force were found each week during the 4- and 7-week experimental period. The magnitude of the interrupted continuous force showed a reduction from 50 cN to an average of 33 ± 5.6 cN (34 %) after 3 weeks without activation.

After application of a continuous or an interrupted continuous type of force for 4 weeks, tooth movements were on average 1.7 ± 0.9 mm and 1.2 ± 0.5 mm, respectively, and after 7 weeks 4.3 ± 1.5 mm and 2.8 ± 0.6 mm, respectively. After 7 weeks, continuous force was found to be more effective than interrupted continuous force in achieving tooth movement ($p = 0.0115$). Both force systems caused a significant increase in tooth movement after 7 weeks compared with 4 weeks.

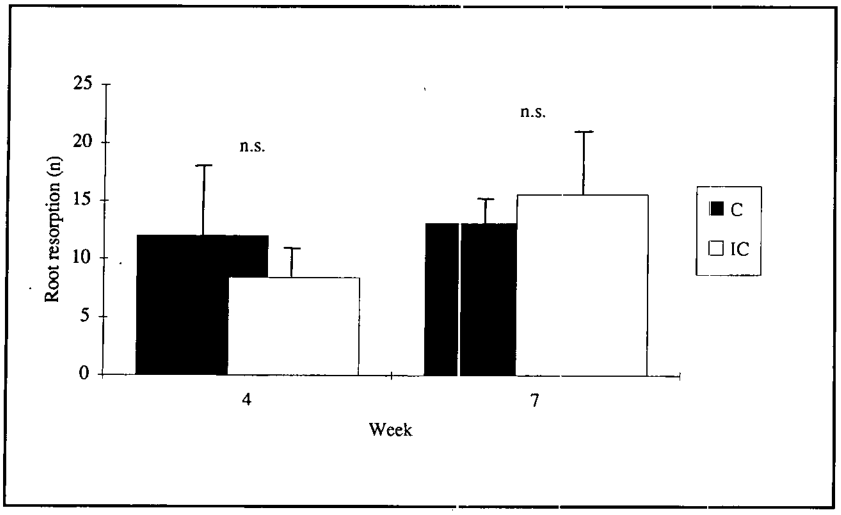

Figure 3

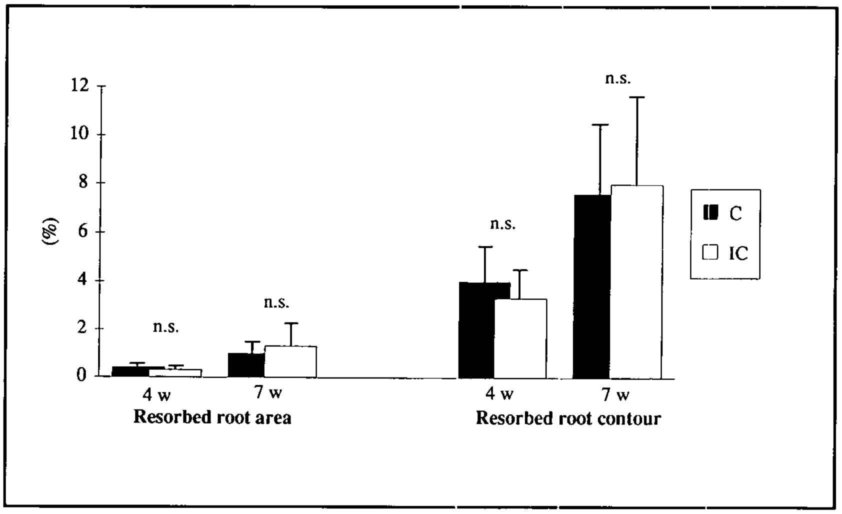

Figure 4

Figure 3
Number of resorptive areas (mean + SD) in histological sections after application of a buccally directed force of 50 cN, either continuous (C) or interrupted continuous (IC), for 4 or 7 weeks.

Figure 4
Percentage of resorbed root area (mean + SD) and resorbed root contour (mean + SD in histologic sections after application of a bucally directed force of 50 cN, either continuous (C) or interrupted continuous (IC), for 4 or 7 weeks.

Areas of root resorption were found on all the test teeth. The number of resorptive areas in three histological sections of each tooth after application of a continuous or an interrupted continuous force for 4 weeks was on average 12.0 ± 5.6 and 8.4 ± 2.5, respectively, and after 7 weeks 13.1 ± 2.4 and 15.6 ± 5.8, respectively (Figure 3). Both resorbed root contour and resorbed root area in histological sections had increased significantly after 7 weeks compared with 4 weeks for both types of force systems. There was, however, no significant difference in the number of resorptive areas (Figure 3), the percentage of resorbed root contour (Figure 4) or the percentage of resorbed root area (Figure 4) between teeth in the 4-week group subjected to a continuous force and those subjected to an interrupted continuous force; likewise, in the 7-week group. In the 7-week group, resorptive areas with a large surface extension were more frequent when a continuous force was applied (Table 1). The number of resorptive areas in teeth subjected to an interrupted continuous type of force was significantly higher in the 7-week group than in the 4-week group ($p = 0.0059$); in teeth subjected to a continuous force, the increase was insignificant.

The individual variation in amount of tooth movement achieved as well as the amount and severity (surface extension and depth [arbitrary units], resorbed root contour [%] and resorbed root area [%]) of resorption was large. In the 7-week group, teeth subjected to continuous force moved between 2.7 mm and 7.1 mm (Figure 5).

The periapical radiographs did not reveal any areas of root resorption on the 32 test teeth.

Discussion

This clinical study showed that buccal tipping of maxillary premolars was less efficiently performed with an interrupted continuous force than with a continuous force of 50 cN after 7 weeks of tooth movement. There was, however, no difference in number or severity of related areas of root resorption between the two force systems.

A substantial reduction in applied orthodontic force during experimental periods has been reported earlier in both animals[24] and man.[3,8,9,21,22] In this report the mean difference in force magnitude between continuous and interrupted continuous force after 7 weeks was 6 cN, i.e., 39 - 33 cN (12 %) plus 1 week with a passive sectional arch. One may still, however, speculate on the length and frequency of the rest periods needed in an interrupted continuous force system to achieve the most effective tooth movement with as little related tissue damage as possible. It has recently been demonstrated that doubling the force magnitude to 100 cN does not cause a significant increase in tooth movement.[8] The difference in tooth displacement is perhaps better explained by the longer period of force exposure in the continuous force system.

It has been suggested that bone has a strain memory which is created by mechanical distortion of its extracellular matrix, probably proteoglycans.[25,26] Gibson et al.[27] found a similar tooth movement kinetic when 40 g (≈40 cN) was applied for 1 hour, 24 hours, or 14 days, although the magnitude of tooth movement was significantly larger with the continuous type of force. It is well known that functional appliances generate tooth movement with less than full-time wear.[16,18,20] In rabbit incisors, it was found that a light intrusive force applied during 50% of the time produced essentially the same intrusive effect as a continuous force.[28] The findings in the present investigation revealed, however, that tooth movement was achieved more effectively after 7 weeks with a continuous force than with an interrupted continuous force applied 86% of the time (3 weeks on, 1 week off, 3 weeks on). Surprisingly, few investigations have commented on the value of rest periods. Earlier investigations concerning the effect of short-term forces have generally dealt with pulsating forces[19,29,30] and cannot be fully compared with the interrupted type of force in this paper. One may still, however, speculate on the length and frequency of the rest periods needed in an interrupted force system to achieve the most effective tooth movement with as little related tissue damage, i.e., root resorption, as possible.

In an interrupted force system with no weekly activation and a rest period, one would expect less tissue strain and possibly a more linear tooth movement with less root resorption. There was, however, no significant difference in the amount of root resorption after the application of a continuous or an interrupted continuous force in either group. Two previous studies in this series of investigations with the same type of appliance found that neither the depth nor the surface extension of root resorption was affected by doubling the continuous force from 50 cN to 100 cN in an interindividual experiment,[8] and no change was seen when the force was increased four times to 200 cN in an intraindividual study.[9] It thus seems that root resorption is less force-sensitive and that a fairly large difference in force magnitude is required to reveal differences in the resorption pattern.

This investigation, together with previous studies in this series of systematic clinical investigations concerning the association between different force magnitudes, extension of tooth movement, and root resorption,[8,9,21,22] shows that individual variation in both tooth movement and root resorption seems to be an overwhelming factor, making prediction of the outcome of the duration, magnitude and type of force difficult. A longer test period could possibly have revealed any significant differences in tooth movement and root resorption. It seems, however, on the basis of the 7-week time period used in this study that individual variations overshadow the effect of the magnitude of force as well as the type of force when tooth movement and root resorption are concerned.

From a cost-benefit point of view, orthodontic treatment should be performed as quickly as possible without jeopardizing surrounding tissues. According to an earlier investigation, a four-fold increase in the magnitude of the continuous force from 50 cN to 200 cN caused 50% more tooth movement after 7 weeks without any increase in the amount or severity of root resorption.[9] This report, dealing with the effects of two different types of forces, revealed that tooth movement was achieved more effectively with a continuous force than with an interrupted continuous force without any increase in root resorption. Individual variation, however, was large for both tooth movement and root resorption, in agreement with previous reports.[8,9,21,22,31] Thus, one must keep in mind that some individuals may still show root resorption of considerable surface extension and depth.[8,9,22] A previous investigation showed that after buccal tipping of maxillary premolars, most areas of root resorption were located on the buccal and palatal root surfaces,[22] making them difficult to detect in apical x-rays.[32] Although the radiograph is not an adequate tool for detecting root resorption,[32,33] it

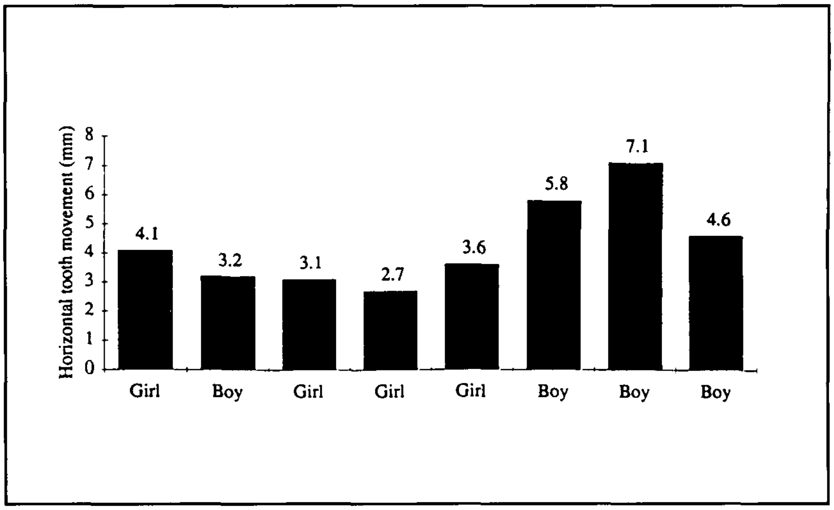

Figure 5

Figure 6

Figure 5
Individual variations in horizontal tooth movement (mm) in 8 test teeth after application of a continuous force of 50 cN for 7 weeks. Figures above columns denote the magnitude of tooth displacement.

Figure 6
Number of resorptive areas (n), extension of resorbed root contour (%), and resorbed root area (%) in 8 test teeth after application of an interrupted continuous force of 50 cN for 7 weeks.

is still the only tool available for this purpose in daily clinical practice.

Root resorption seems to be an inevitable, adverse tissue reaction when orthodontic forces are applied. What will happen with the resorptive area when treatment is finished? Will there be any repair and, if so, how much and how soon? These are questions that remain to be answered.

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Commentary: Continuous versus interrupted continuous orthodontic force related to early tooth movement and root resorption

Gregory J. King, DMD, DMSc

The orthodontic profession critically needs clinical data on the relative efficiencies of different biomechanical strategies of tooth movement. Which approaches provide the most rapid orthodontic tooth movement with the least damage to the teeth and their supporting structures? This study provides a comparison of two force prescriptions—continuous and interrupted continuous—and follows two important clinical variables—tooth movement and root resorption.

The key findings of the study were that more tooth movement was achieved in the continuous force group and there was no difference in root resorption between the two groups. Superficially, this appears to warrant the conclusion that continuous force appliances are more effective and safer than interrupted continuous appliances. This view should be approached, however, with a degree of caution. First, were the sample sizes large enough to provide sufficient power to detect differences? Considering the high degree of variability in the data noted by the authors, this seems unlikely. If power calculations were presented, this issue could have been readily assessed. Second, were the methods of quantifying tooth movement and root resorption sufficiently reliable and sensitive to detect differences? This seems to be the case for tooth movement at 7 weeks, but may not be a valid conclusion for root resorption or tooth movement at the earlier time point. Data on the detection limits and reliability of each of these methods would have been helpful in this regard. Third, was this a valid comparison of continuous versus interrupted continuous force systems? This is not clear because there were also differences in force magnitude and duration between the two groups. Moreover, the continuous force group would probably more appropriately be termed a weekly reactivation group as the forces were not constant throughout the experimental period but fluctuated by 22%, on average.

A slightly altered experimental design may have greatly increased the value of this study. First, tooth movement could have been measured weekly. Because measurements were made on dental casts, there would be no ethical concerns with weekly measuring. Because the relationship between orthodontic tooth movement and time is known not be linear, it would be important to know the kinetics as well as the total movement in the experimental groups. For instance, the delay period may have been longer in the continuous group due to higher average forces. The failure to detect a difference in tooth movement at 4 weeks does seem to suggest that the delay period was occurring during that time. Second, individual variations in tooth movement and root resorption could have been minimized if the data had also been analyzed by first calculating the intraindividual differences and then analyzed for the differences. With this approach, intersubject variability has less influence on the data set. Finally, it may also be helpful to have had an untreated control group as tooth drift and idiopathic root resorption may have also been contributing to the variability in the data.

Gregory J. King, DMD, DMSc, professor and chairman, Department of Orthodontics, College of Dentistry, University of Florida.

Authors' response

We appreciate the comments by Dr. King, and the chance to clarify some factors with a response.

Dr. King discusses the reliability of the measurement methods used. In order to thoroughly investigate the accuracy, i.e. random and systematic errors of force, tooth movement, and root resorption, all measurement methods used were analyzed in a separate paper—reference 23. Different measurement methods were compared, e.g., tooth movement recordings with laser technique versus measurements using a coordinate measuring machine and a slide caliper. All measurement methods used in this investigation were found to be quite satisfactory for the purpose of their application.

Was this a valid comparison of a continuous and an interrupted continuous force system? Yes, we think so. The fact that the continuous force declined 22% over 1 week and the interrupted continuous force declined 34% over 3 weeks is not controversial. Of course the interrupted continuous force declined more than a force of the same initial magnitude (50 cN) activated weekly—that was an essential part of this investigation.

Dr. King suggests that weekly recordings of tooth movement on dental casts would have improved the value of this investigation. However, we think that making alginate impressions to obtain dental casts would have negatively affected the sectional archwires used, introducing side effects that could jeopardize the results. The tooth movement and root resorption pattern in this investigation reflects the influence of the two force systems, continuous versus interrupted continuous, in an unbiased way. This is, in our opinion, more important than presenting minor weekly changes during the process of tooth movement in humans.

The final comment, that it would have been helpful to have an untreated control group, is answered in references 21 and 22, where 56 untreated maxillary first premolars are presented in detail, both clinically and histologically.

We agree that this study of only one variable, i.e., influence of type of force, with all other variables under strict control, will easily lead to questions of the type raised by Dr. King. Since these questions are elucidated and answered in other papers in this series of clinical studies, it is our opinion that inclusion of such supplementary data in the present paper might have made it much longer and perhaps more difficult to read without adding anything new.

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