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Factors related to the rate of orthodontically induced tooth movement



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Introduction: The purpose of this study was to investigate the variations of orthodontically induced tooth movement in the maxillary and mandibular arches between patients and the factors such as age, sex, and presence of an interference that might influence the amount of tooth displacement. **Methods:** By using a standardized experimental orthodontic tooth movement in 30 subjects, 57 premolars were moved buccally during 8 weeks with the application of a 1-N force. Forty-four contralateral premolars not subjected to orthodontic tooth movement served as the controls. Plaster models from before and after the experimental tooth movement were digitized and superimposed to evaluate the amounts of tooth movement. Differences in tooth movement between the experimental and control groups were tested by an unpaired *t* test. For the experimental teeth, subject-related factors (age and sex) and tooth-related factors (location in the maxillary or mandibular dental arch, and the presence or absence of an intra-arch or interarch obstacle such as neighboring touching teeth or teeth interfering with the occlusion) were examined with analysis of variance. Multiple linear regression analysis was performed to determine correlations between tooth displacement, age, sex, tooth location, and presence of an interference. **Results:** Each subject contributed at least 2 experimental premolars and 1 control premolar. The displacement of the orthodontically moved teeth was 2.42 mm (range, 0.3-5.8 mm). Younger subjects (<16 years; *n* = 19; number of teeth, 36) had significantly greater amounts of tooth displacement compared with older subjects (≥ 16 years; *n* = 11; number of teeth, 21): 2.6 ± 1.3 mm vs 1.8 ± 0.8 mm; *P* < 0.01. When an interarch or intra-arch obstacle was present, the amount of tooth movement was significantly less (2.6 ± 1.3 mm vs 1.8 ± 0.8 mm) (*P* < 0.05). Neither sex nor the location of the experimental teeth in the mandible or the maxilla had any effect. **Conclusions:** Younger patients showed greater tooth movement velocity than did older ones. An interarch or intra-arch obstacle decreased the amount of tooth displacement. (Am J Orthod Dentofacial Orthop 2013;143:616-21)

Orthodontic tooth movement has been defined as “the result of a biologic response to interference in the physiologic equilibrium of the dentofacial complex by an externally applied force.”¹ Only small amounts of force might be required to effect this outcome, which is accompanied by remodeling changes in the periodontal ligament and alveolar bone.²⁻⁵ The sequence of cellular, molecular, and tissue-reaction events during orthodontic tooth movement has been

extensively studied.⁶ Several factors, alone or in combination, might influence remodeling activities and ultimately tooth displacement. Among these, the concept of “an optimal orthodontic force” has been the subject of investigation for several years. However, animal research has shown that even with standardized, constant, and equal forces, the rate of orthodontic tooth movement can vary substantially among and even within subjects.^{7,8} It was concluded that a wide range of forces can be applied to induce orthodontic tooth movement, and the rate is based mainly on patient characteristics. Several factors, such as age, drug consumption, diet, several systemic conditions, and other intrinsic genetic factors, have been shown to influence the rate of tooth movement.^{9,10}

Clinically, differences in the rate of tooth movement even in the same patient can be observed. In certain cases, the role of neighboring touching teeth or occlusal interferences by antagonist teeth seem to influence the amount of the tooth displacement. However, no study has investigated the role of such interferences on the rate of tooth displacement.

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Owman-Moll et al¹¹ and Owman-Moll¹² introduced an experimental clinical model mainly to evaluate root resorption in previously moved and finally extracted premolars. Using the same model, our aims were (1) to study the variations of orthodontically induced tooth movement between subjects; (2) to identify factors such as age, sex, and location of the tooth in the mandible or the maxilla that could influence the amount of tooth displacement; and (3) to elucidate the importance of intra-arch (neighboring touching teeth) or interarch (occlusion-interfering antagonist) obstacles in the interference with the amount of tooth displacement.

MATERIAL AND METHODS

Thirty patients (19 female, 11 male) were consecutively recruited from patients starting orthodontic treatment at the University of Geneva in Switzerland. Their mean age was 17.7 years, with a range of 11.3 to 43.0 years. The patients had to meet following criteria: (1) good general, dental, and periodontal health; (2) no previous orthodontic treatment; (3) severe crowding in both jaws; and (4) scheduled to begin orthodontic treatment with at least 2 or 4 first or second premolar extractions. Informed consent in written form was obtained from the patients before the beginning of the study. The protocol was approved by the medical ethics committee of our university.

In all the patients, standardized experimental tooth movement was carried out. Each patient contributed at least 1 experimental and 1 control premolar. Fifty-seven premolars, randomly assigned to the experimental group, were tipped buccally for 8 weeks. For this movement, a sectional archwire (0.019 × 0.025 beta-titanium alloy) was activated buccally and attached with a ligature to the bracket of the experimental tooth (1-point contact without the wire in the bracket slot engagement) to exert an initial force of 1 N (statically determinate force system) (Fig 1). In the middle of the experimental movement (after 4 weeks), the amount of force was controlled and adjusted. A transpalatal arch and a lingual arch were placed as anchorage. Forty-four contralateral premolars bonded with brackets but not subjected to orthodontic tooth movement served as the controls.

Dental casts from before and after the experimental period were scanned at 600 dpi, 24 gray scale, and saved in TIFF format. The scanned models were superimposed on stable dental structures: teeth that were not moved during the relatively short experimental period. We made the superimpositions and measured the casts directly on the computer screen using Adobe Photoshop software (Elements 6, version 6.0; Adobe Systems, San Jose, Calif). The actual tooth movement was measured as the distance between the pretreatment tooth position



Fig 1. Application of force in the occlusal view.

compared with the postexperimental tooth position at the respective centroids on the occlusal surface. The centroid point was defined as the geometric center of the tooth in the occlusal plane. On the superimposed cast images, the distance on the line connecting the 2 centroid points represented the estimated tooth movement (Fig 2).

For the experimental teeth, subject-related factors, such as age (<16 years/≥16 years) and sex, and tooth-related factors, such as location in the mandible or the maxilla and presence or absence of an intra-arch or interarch obstacle, were examined. An intra-arch interference was defined as a neighbor-touching tooth situation, and interarch interference meant an obstacle such as an occlusion-interfering antagonist. The evaluation was done on the dental casts at the molar level by moving them apart 1 mm and checking whether antagonists were interfering at this position.

Statistical analysis

Differences in tooth movement between the experimental and control groups were tested by an unpaired *t* test. For the experimental teeth, analysis of variance (ANOVA) was used to test the influence of the factors of age, sex, tooth location, and intra-arch or interarch obstacle on the amount of tooth displacement. The mean age of the patients was 17.7 years, and the median was 15.1 years. We used the cutoff of 16 years to have a reasonable distribution between the “young” and “old” groups. Multiple linear regression analysis was performed to determine correlations between tooth displacement, age, sex, tooth location, and the presence of an interference. The statistical analysis was processed with IBM SPSS software (release 19.0.0; IBM SPSS, Chicago, Ill).

To evaluate the error of our method, we repeated the superimpositions and measurements of the casts of 40 teeth 2 weeks later. A paired *t* test was used to estimate

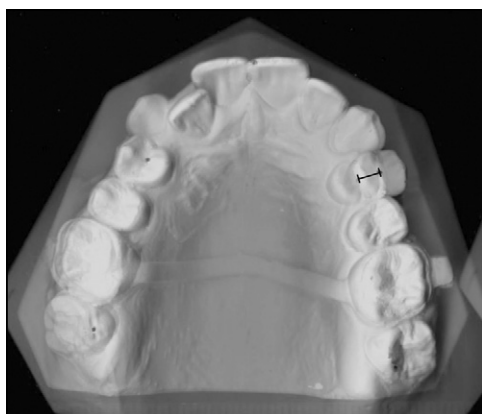


Fig 2. Dental casts obtained before and after the experimental period were scanned and superimposed to measure actual tooth movement. The centroid point was defined as the geometric center of the tooth in the occlusal plane. On the superimposed cast images, the distance on the line connecting the 2 centroid points represents the estimated tooth movement.

the differences in the measurements from these 2 superimpositions and to evaluate the systematic error. No differences were found at a significance level of 0.05.

Dahlberg's formula ($Se^2 = \sum d^2/2n$) (d is the difference between measurements from the 2 superimpositions) was used to calculate the coefficient of reliability ($CR = 1 - Se^2/S_t^2$) (S_t is the standard deviation of measurements from superimposition 1).¹³ The result ($CR = 0.997$) showed excellent reliability of this method, and the error of the method was $SE = 0.13$ mm.

RESULTS

Significant differences were observed in the amounts of tooth movement between the orthodontically moved teeth and the controls: the former showed a mean displacement of 2.4 mm (± 1.2 mm), and the latter showed only a slight mean displacement of 0.2 mm (± 0.2 mm) ($P < 0.001$) (Fig 3).

Concerning the influence of age, it was found that the amount of tooth displacement in younger subjects (< 16 years; $n = 19$; 36 teeth) was significantly greater than the amount of tooth displacement of the 21 teeth of the older subjects (≥ 16 years; $n = 11$) (2.6 ± 1.3 mm vs 1.8 ± 0.8 mm; $P = 0.007$) (Table I). No difference was found in the amount of tooth displacement between the sexes or between teeth displaced in the maxilla and the mandible.

Teeth without an obstacle moved significantly more than those with an obstacle (interarch or intra-arch). Thirty-three of 57 experimental teeth met no obstacle during their movement and showed a mean displacement

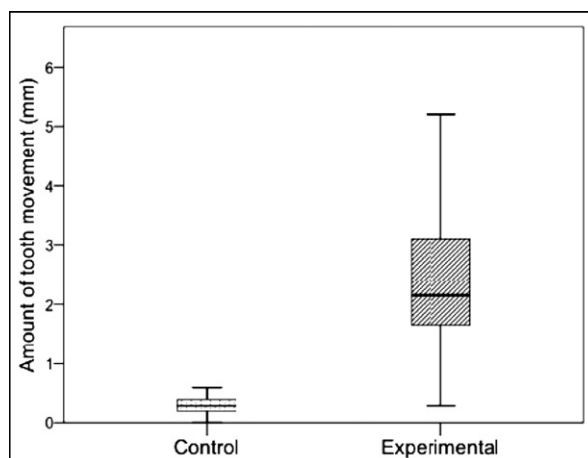


Fig 3. Box plots based on the medians, quartiles, and extreme values for the amounts of tooth displacement of the experimental and control teeth.

of 2.6 mm (± 1.3 mm), whereas the 24 experimental teeth meeting an obstacle during movement showed a mean displacement of 1.8 mm (± 0.8 mm); the difference was statistically significant ($P = 0.017$). More specifically, teeth with an interarch obstacle ($n = 17$) moved significantly less, with a mean displacement of 2.0 ± 1.3 mm ($P = 0.041$). Less tooth displacement was found in the intra-arch obstacle group ($n = 7$), with a mean displacement of 1.6 ± 0.3 mm ($P = 0.044$).

The multiple regression analysis showed that the amount of tooth displacement was associated with age and the presence of an obstacle (adjusted $R^2 = 0.20$; $P = 0.003$). No associations were found between tooth movement and sex and tooth location (Table II).

DISCUSSION

This study has shown great variations in the amount of orthodontically induced tooth displacement between patients. Part of this variation was explained by the patients' ages and by the presence of an interarch or intra-arch obstacle. Experimental tooth movement was conducted in 30 patients during 8 weeks by using the experimental model described by Owman-Moll.¹² Although this was not an ideal model to evaluate tooth displacement like that applied by van Leeuwen et al⁸ (mesiodistal tooth movement), it nevertheless allowed us to study the same type of tooth movement (buccal tipping) using standardized force levels and times.

The amount of tooth movement was measured in the digitized dental casts obtained before and after the experimental period, just before the extractions. In the assessment of malocclusion and orthodontic treatment

Table I. ANOVA results to test the significance of the independent factors on the amount of tooth movement

	df	Mean square	F	Significance	n	Amount of tooth movement (mm)			
						Mean	SE	95% CI	
Age (y)	1	10.648	8.058	0.007	<16	36	2.685	0.248	(2.185-3.186)
					≥16	21	1.844	0.266	(1.308-2.380)
Obstacle	1	8.096	6.127	0.017	No obstacle	33	2.671	0.253	(2.161-3.181)
					Obstacle	24	1.860	0.260	(1.335-2.385)
Sex	1	3.281	2.483	0.123	Male	18	2.074	0.300	(1.469-2.679)
					Female	39	2.484	0.216	(2.047-2.921)
Location	1	0.053	0.040	0.842	Maxilla	31	2.374	0.223	(1.924-2.824)
					Mandible	26	2.221	0.279	(1.659-2.783)

Table II. Multiple regression analysis to test the significance of age, obstacle, sex, and location on the amount of tooth movement

Dependent variable (Y): amount of tooth movement
 $Y = 2.846 + b_1 \text{ age} + b_2 \text{ obstacle} + b_3 \text{ sex} + b_4 \text{ location}$

Variable	Coefficient b	SE	Significance
Age	-0.776	0.304	$P = 0.014$
Obstacle	-0.876	0.298	$P = 0.005$
Sex	0.357	0.316	$P = 0.263$
Location	-0.056	0.296	$P = 0.852$

Significance of the model: $R = 0.512$; $R^2 = 26\%$; adjusted $R^2 = 20\%$; $P = 0.003$.

Multiple regression analysis: $Y = b_0 + b_1 \text{ age} + b_2 \text{ obstacle} + b_3 \text{ sex} + b_4 \text{ location}$. Independent variables: age (<16/≥16 years) + obstacle (no obstacle/obstacle) + sex (male/female) + location (maxilla/mandible).

b_0 , Constant; b_1 , b_2 , b_3 , b_4 , regression coefficients; R , correlation coefficient; R^2 , percentage of explained variance.

need, 2-dimensional digital images can be used as an alternative to traditional orthodontic casts.¹⁴ The use of digital models was found to be an accurate and reliable method for assessing patients' final occlusions.¹⁵

In our study, age was found to be a significant factor affecting the amount of tooth movement: younger subjects (<16 years) showed significantly greater amounts of tooth displacement compared with older subjects (>16 years). The effect of age on the tissue response to orthodontic force has been the subject of many investigations, since orthodontic procedures seem to be more time-consuming in adults than in juveniles. Reitan^{16,17} studied histologic sections of teeth and their surrounding tissues and concluded that the periodontal ligament is less cellular in adults than in children. However, when a lingual molar movement was performed in young and old rats, the compensatory alveolar bone apposition was similar in both groups.¹⁸ The age effect on orthodontic movement in rats was studied by Ren et al,¹⁹ who reported faster mesiodistal initial tooth movement in juvenile rats than in adult rats. Once tooth movement had reached

the linear phase, the rate of tooth movement did not differ between the 2 groups. The same authors have also shown that in young rats, the maximum number of osteoclasts at periodontal ligament compression sites is reached after 2 weeks of treatment; in adult animals, this level is reached after 4 weeks.²⁰ Interestingly, in the following weeks, the number of osteoclasts in the adult group was twice as high as in the young group, but the velocity of tooth movement was the same in both groups. The authors concluded that osteoclasts in young animals are more efficient than those in old animals, and that more osteoclasts are needed to achieve a certain rate of tooth movement in adult rats than in young rats. Furthermore, based on the biochemical analysis of certain mediators in gingival crevicular fluid, it was reported that mediator levels in juveniles are more responsive than the levels in adults, confirming the finding that the initial tooth movement in juveniles is faster than in adults and starts without delay.²¹ More recently, it was suggested that the age-related decrease in the amount of tooth movement might be related to a decrease in the RANKL/OPG ratio in gingival crevicular fluid during the early stages of orthodontic tooth movement. However, the amount of tooth movement was measured after only 7 days of application of a retracting force.²²

In our study, for the age range studied, sex had no influence on the amount of tooth movement. The influence of sex on the amount of tooth movement has been mainly studied in relation to estrogen deficiency or estrogen replacement therapy in osteoporotic women, since the activities of osteoblasts and osteoclasts are controlled by various cytokines and hormones—in particular, sex hormones. In osteoporotic women, there is increased bone resorption with normal bone formation, but the increased bone formation that normally occurs in response to a mechanical force is diminished. Estrogen deficiency increases bone remodeling changes, whereas treatment with estrogen decreases them^{23,24}; thus, tooth movement will be slower in patients taking an estrogen replacement

drug. Furthermore, the velocity of tooth movement can be influenced by the hormonal changes during pregnancy: a 3-week period of experimental tooth movement in rats showed that the mean value of expansion was significantly greater among the pregnant rats compared with the nonpregnant rats.²⁵ In addition to the above conditions related to hormonal changes, other systemic conditions have been identified that can modulate the pattern and the velocity of tooth movement: eg, diabetes, allergies, and cancer.¹⁰ The therapeutic intake of bisphosphonates has been associated with the inhibition of tooth movement,²⁶ and the systemic administration of leptin, a central hormone, with the inhibition of bone formation.²⁷ Nonsteroidal anti-inflammatory drugs, the most common medications used in orthodontics to effectively reduce pain, can slow tooth movement by inhibiting the inflammatory reaction.²⁸

The location of the moved teeth—mandible or maxilla—had no effect on the amount and the rate of tooth movement in the buccolingual direction. Our results confirm earlier studies on canine retraction and in the mesiodistal direction, when no significant difference in the rate of tooth movement between the maxillary and mandibular canines was found.²⁹ On the other hand, structural differences such as geometry and mass of the different types of bone have been described between the mandible and the maxilla; thus, we hypothesized that the response to orthodontic force would be different. An experimental study in dogs showed significantly greater amounts of tooth movement in the maxillary teeth compared with the mandibular teeth during 12 weeks of orthodontic tooth movement.³⁰ The authors attributed these differences to the fact that the maxilla is composed of relatively thin cortices compared with the mandible and has a higher rate of bone resorption, which initiates more rapid bone turnover. The impact of bone turnover has been investigated on the amount of tooth movement by Verna and Melsen,³¹ who showed that high bone turnover increased the amount of tooth movement compared with normal or low bone turnover.

To our knowledge, no study has investigated the interference of an intra-arch (neighboring-touching teeth) or interarch (occlusion-interfering antagonist) obstacle with the amount of tooth displacement. In this study, both intra-arch and interarch obstacles significantly reduced the amount of tooth displacement compared with orthodontically moved teeth without obstacles. On one hand, with an intra-arch obstacle, the neighboring teeth absorb part of the applied force; thus, it might be necessary to move the obstacle tooth first to create space for the main tooth displacement.

In our experimental model, the force was applied only on 1 tooth and not directly to the neighboring ones, as in the case of a multibracket system when all teeth are involved, and force is exerted by the wire to all teeth engaged. On the other hand, the interarch obstacle might interfere either when teeth are in occlusion or when there is a contact in the relaxed position. In this project, we did not differentiate clinically between these 2 situations. It is quite possible that in case of interferences blocking tooth movement while the patient is in the relaxed position, the vertical position might need to be temporarily increased by either adding resin on the posterior teeth surfaces or using posterior bite-blocks to increase tooth movement. Nevertheless, a more systematic approach is needed to elucidate these points.

Based on these results, considerable interpatient variations in the rate of tooth movement were observed, with age and intra-arch and interarch obstacles representing major factors associated with these variations. Obviously, great individual variations in response to applied forces were observed. Individual characteristics and intrinsic genetic factors of the experimental subjects might have contributed to much of the variation that was not explained by the studied factors: age and obstacle. The underlying molecular and biologic events need to be identified.

CONCLUSIONS

Younger patients showed greater tooth movement velocity than did older ones. An interarch or intra-arch obstacle decreased the amount of tooth displacement.

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