OXFORD

Original article

Slow and fast orthodontic tooth movement: an experimental study on humans

Catherine Giannopoulou*, Alexander Dudic**, Nikolaos Pandis***,**** and Stavros Kiliaridis*****

*Department of Periodontology, University of Geneva, Switzerland, **Department of Orthodontics & Paediatric Dentistry, University of Zurich, Switzerland, ***Department of Orthodontics and Dentofacial Orthopedics, Dental School, Medical Faculty, University of Bern, Switzerland, ****Private Practice, Corfu, Greece, and *****Department of Orthodontics, University of Geneva, Switzerland

Correspondence to: Catherine Giannopoulou, Department of Periodontology, Dental School, University of Geneva, Rue Barthélemy-Menn 19, 1205 Geneva, Switzerland. E-mail: ekaterini.giannopoulou@unige.ch

Abstract

Introduction: The aim of this study was to investigate the variation in the amount of the orthodontically induced tooth movement in humans and potential associations between the amount of tooth movement with age and location in the mandible or maxilla.

Subjects and methods: This study included 11 participants (7 females, 4 males) with an age range of 11.3–28.6 years. In a standardized experimental orthodontic tooth movement protocol, two premolars of each participant were moved buccally during 8 weeks with the use of 1 N force. No functional or localized obstacles were affecting the displacement. Plaster models before and after the experimental tooth movement were constructed, digitized, and superimposed, to evaluate the amount of tooth movement of each tooth. Random effects linear regression analysis was performed to examine associations between tooth displacement, age, and tooth location.

Results: The mean displacement of the teeth was $2.7 \pm 1.4\,mm$. The range of tooth movement varied substantially between individuals (0.6–5.8 mm). The displacement of the teeth within the same individual was highly correlated ($R^2 = 0.78$, $P < 0.001$). The tooth displacement decreased with age; however, this finding did not reach statistical significance ($\beta = -0.11$, 95% CI: −0.28, 0.05, $P = 0.172$). The tooth movement was higher in the maxilla than in the mandible ($\beta = 0.47$, 95% CI: 0.81, 0.86, $P = 0.018$).

Conclusion: Wide range of tooth displacement revealed slow and fast movers in this sample. Larger displacements were recorded in the maxilla compared to the mandible and in younger individuals.

Introduction

Orthodontic tooth movement is a complex process involving the application of mechanical force, a biologic response as well as the genetic and environmental interaction. The tooth displacement varies according to the magnitude, frequency, and duration of the applied force, and according to the biological response of the periodontal ligament and bone (1, 2). The velocity of tooth movement may be altered by the use of pharmacological agents, by application of physical stimuli, such as heat and electric devices or by surgical means (3). In addition, several factors such as age, diet, systemic conditions, and genetic predisposition have been shown in animal studies to influence the rate of tooth movement (2, 4). In a clinical environment, differences in the rate of tooth movement within the same patient may be observed in the presence of inter-arch and/or intra-arch obstacles (5).

Experimental animal studies have shown that even with standardized, constant, and equal forces, the rate of orthodontic tooth movement

may vary substantially among and within individuals ([6], [7]). From the aforementioned studies it was concluded that a wide range of forces induces orthodontic tooth movement, the rate of which depends mainly on individual characteristics. Thus, based on the above-mentioned animal studies, the concept of slow versus fast movers was established. Although these findings can be observed in everyday clinical practice, to our knowledge, no clinical study has confirmed these findings in humans.

Our hypothesis was that during experimental tooth movement in humans, great inter-individual variation in the amount of tooth displacement was to be expected. The extent of this displacement may depend on factors related to the subject's biological profile and the location of the displaced teeth. Thus, the aim of the present investigation was to study the variation of the orthodontically induced tooth movement between and within a group of individuals by using the experimental clinical model applied by Owman-Moll et al. ([8], [9]) and to explore potential associations of tooth displacement with age and tooth location.

Materials and methods

Participants

Eleven participants (seven females and four males) were included in this study. The mean age of the patients was 15.9 years (range of 11.3–28.6 years). The participants were part of a sample included in a previously published study and were consecutively recruited at our University from a pool of patients starting orthodontic treatment ([5]). All these patients fulfilled the following inclusion criteria: 1. good general and oral health, 2. no previous orthodontic treatment, 3. scheduled to begin orthodontic treatment and needing four first or second premolar extractions, and 4. teeth that were free of an obstacle such as neighbouring touching teeth or occlusal interferences ([5]). The latter inclusion criterion was the main difference as compared to the original material which included all orthodontically moved teeth, independently of the presence or absence of an obstacle. A *post hoc* power analysis was performed based on the 11 individuals with probability of type I error (alpha) 0.05 and correlation coefficient ≥0.88 (www. StatsToDo.com). It was found that the power estimation of the study was 0.99.

Before the beginning of the study written informed consent was obtained from all patients. The protocol was approved by the Medical Ethics Committee of our University.

Prior to entering the study, all participants underwent a session of supragingival scaling and received detailed oral hygiene instructions.

Standardized experimental orthodontic tooth movement

In order to control the force and time factors, a standardized experimental tooth movement was carried out. In each patient, two premolars ($n = 22$) were tipped buccally for 8 weeks according to the method reported by Dudic et al. ([5]). A transpalatal arch and lingual arch were utilized for anchorage. A sectional archwire (0.019×0.025 TMA) was activated buccally and attached with a ligature to the bracket of the experimental tooth (one point contact without wire engagement into bracket slot) in order to exert an initial force of 1N (statically determinate force system). After 4 weeks of movement, the amount of force was controlled and adjusted with an appliance reactivation.

Evaluation of the amount of tooth displacement

Dental casts were taken before and after the experimental tooth movement. The models were scanned at 600 dpi, 24 gray scale and saved in the TIFF format and then superimposed on stable dental structures (teeth that were not moved during the relatively short experimental period). The superimpositions and cast measurements were performed using the Adobe Photoshop Software (Adobe Photoshop Elements 6, Version 6.0, Adobe Systems Incorporate, San Jose, California, USA). The actual tooth movement was measured as the distance between the pre-treatment tooth positions compared to the post-experimental tooth position at the respective centroids on the occlusal surface. The centroid point was defined as geometric centre of the tooth in the occlusal plane. On the superimposed cast images, the distance on the line connecting the two centroid points, represents the estimated tooth movement ([6]).

Statistics

Descriptive statistics for the inter-individual differences in tooth movement were calculated. At the individual level, the correlation between the amount of tooth movement in matched teeth was expressed by the Pearson's correlation coefficient. Random effects multiple linear regression analysis was performed to examine associations between tooth displacement (dependent variable) and age and tooth location (independent variables). The statistical analyses were processed with IBM® SPSS® Statistics (Release 23.0.0, SPSS Inc., an IBM Company, Chicago, Illinois, USA) and Stata 13 (Stata Corp, College Station, Texas, USA).

Error of the method

The error of the method in measuring the tooth displacement was evaluated after performing the superimposition at the casts a second time 2 weeks later, and measuring again the amount of tooth displacement. The Dahlberg's formula ($Se^2 = \sum d^2/2n$, where d is the difference between measurements from superposition 2 and superposition 1) ([10]) was used to calculate the coefficient of reliability ($CR = 1 - Se^2/S_t^2$) (S_t = standard deviation of measurements from superposition 1). The result ($CR = 0.997$) shows an excellent reliability of this method and the error of the method was $Se = 0.13$ mm. Furthermore, a paired *t*-test was performed showing that no systemic error exists ($P = 0.264$).

Results

Individual patient characteristics and amount of tooth movement are presented in Table 1. After 2 months of force application, the range of the mean tooth movement calculated from the two displaced teeth per individual, varied substantially between individuals (0.6–5.5 mm). The mean amount of tooth displacement in the maxilla was 3.06 mm and that in the mandible 1.97 mm. The amount of displacement of the teeth within the same individual ($R = 0.885$) and between jaws ($R = 0.948$) were highly correlated (Figure 1A and 1B respectively).

The results from the random effects linear regression are shown in Table 2. The results indicate that for every year there is a mean decrease in tooth movement by 0.11 mm (95% CI: –0.28, 0.05, $P = 0.172$) after adjusting for location; this finding is not statistically significant. In the maxilla the mean displacement is 0.47 mm more than in the mandible after adjusting for age (95% CI: 0.81, 0.86, $P = 0.018$); this finding was statistically significant.

Discussion

The present study has shown that in absence of local and functional obstacles, large variations exist in the amount of tooth movement in healthy individuals. Teeth located in the maxilla moved on average

Table 1. Individual patient characteristics and amount of tooth displacement.

Subject	Gender	Age (years)	Location	Displacement (mm)	Mean
1	F	15.0	Maxilla	0.6	0.6
			Mandible	0.6	
2	F	28.6	Maxilla	2.9	2.25
			Mandible	1.6	
3	M	11.7	Maxilla	4.2	4.05
			Maxilla	3.9	
4	F	14.3	Maxilla	4.6	3.75
			Mandible	2.9	
5	F	14.5	Maxilla	2.0	1.6
			Mandible	1.2	
6	M	15.2	Maxilla	3.6	3.4
			Mandible	3.2	
7	M	17.8	Maxilla	2.4	2.25
			Mandible	2.1	
8	F	12.8	Maxilla	3.0	2.65
			Mandible	2.3	
9	M	17.1	Maxilla	1.5	2.65
			Mandible	0.7	
10	F	11.3	Maxilla	5.2	5.5
			Mandible	5.8	
11	F	16.8	Maxilla	2.8	3.05
			Mandible	3.3	

faster than those in the mandible during the 8 weeks experimental period.

These results can be confirmed in the daily clinical work, where we often find faster movement in orthodontic space closure in the maxilla than in the mandible and easier to perform space closure in young patients compared to adults.

Large individual variations were found in bodily tooth movement in experimental studies in beagle dogs. These variations were attributed to differences in bone density, differences in supra-alveolar fibres, structure of collagen fibres, differences in cellular activity in the periodontal ligament and in root surface area (11, 12). Our study is in agreement with the model proposed by Pilon *et al.* (6) derived from beagle dog, where each individual has its own optimum force for tooth movement. Under this scenario, in the 'slow movers' group, the optimum force may have not been applied.

The continuity of the force could also play an important role in the amount of tooth movement, as suggested by Lundgren *et al.* and Owman-Moll *et al.* (8, 13), who used the same experimental design as in this study but with weekly archwire reactivations to prevent force dacay. However, the same authors found no statistically significant differences in the amount of tooth displacement when the applied force ranged from 50 to 100 cN. In the present study, instead of reactivating the archwire weekly, we chose a force level of 100 cN to give a greater force decay tolerance margin. When the amount of force was measured after 4 weeks, the force level did not drop below 50 cN for any patient.

The location of the teeth in the maxilla or the mandible was associated with the amount of tooth displacement, with larger displacement observed for teeth located in the maxilla than those in the mandible. 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 (14). In

that study, tooth movement occurred faster in the maxilla than in the mandible in the distal direction. The authors attributed these differences to the variation in bone density between maxilla and mandible.

Another possible reason for the differences detected between the teeth located in the maxilla and the mandible could be the more pronounced effect of an uncontrolled tipping that took place in the maxilla. The vestibular displacement of the premolars located in the mandible has more restricted movement because of the limited thickness of their alveolar base.

In our sample a small variation in age was found between participants as all patients were between 11.3 and 17.8 years old, except from one who was 28.6 years. Animal studies have repeatedly shown that the initial tooth movement is significantly faster in younger compared to older rats (15–18). Our research team has recently confirmed on a group of 30 patients, that age is a significant factor affecting the amount of tooth displacement, as younger subjects (<16 years) showed significantly higher amount of experimentally induced tooth displacement as compared to older subjects (>16 years) (5). In the present study, older patients showed smaller displacement compared to younger patients; however, this difference did not reach statistical significance. Thus, results dealing with age and the amount of tooth displacement should be interpreted with caution since the age range of the subjects was between 11.3 and 28.6.

In the last decades, in an effort to develop clinical tools to measure and accelerate tooth movement in humans, the measurement of specific markers in the gingival crevicular fluid (GCF) has been introduced (19). Previous studies have shown that some of these markers are key regulators of bone remodelling during orthodontic movement and that their levels in GCF may change after application of orthodontic force (20–22). For example, receptor activator of nuclear factor-kappa B ligand (RANKL) increases and osteoprotegerin (OPG) decreases after 1 day at sites of compression in patients undergoing maxillary canine distalization (23, 24). Grant *et al.* (25) also reported after 42 days of force application, that RANKL was significantly increased at canine compression sites. OPG showed a significant increase and no associations were found for these biomarkers with the speed of tooth movement. Similarly, osteocalcin levels were found to increase during orthodontic tooth movement (21).

Recently, a number of osteoclast regulation markers, osteoclast activity markers and osteoblast markers were selected by Baloul *et al.* (26) in order to study the morphologic changes in the alveolar bone in response to selective alveolar decortication-facilitated tooth movement. All markers were involved at different time points in the coupled mechanism of bone resorption and bone formation during the early stage of treatment. As there is grown evidence that the constituents of GCF are a reflection of systemic as well as local conditions (27) it may be possible to identify different traits of bone metabolism between individuals. These traits can result in different GCF mediators' levels that could influence and/or predict the rate of tooth movement during orthodontic force application.

The application of new methods in the field of molecular biology has resulted in the identification of several genes that control the cellular and extracellular matrix components associated with orthodontic tooth movement (28). Thus, genetic variations between individuals can be the underlying reason for the inter-individual variation observed in our study.

In conclusion, in the present study, large variation with 'slow movers' and 'fast movers' was identified. A part of this variation was attributed to the location of the teeth in the mandible or maxilla. At the individual level, the rate of tooth movement was highly correlated within the same subject. Larger studies and application of molecular biological methods could further elucidate this field.
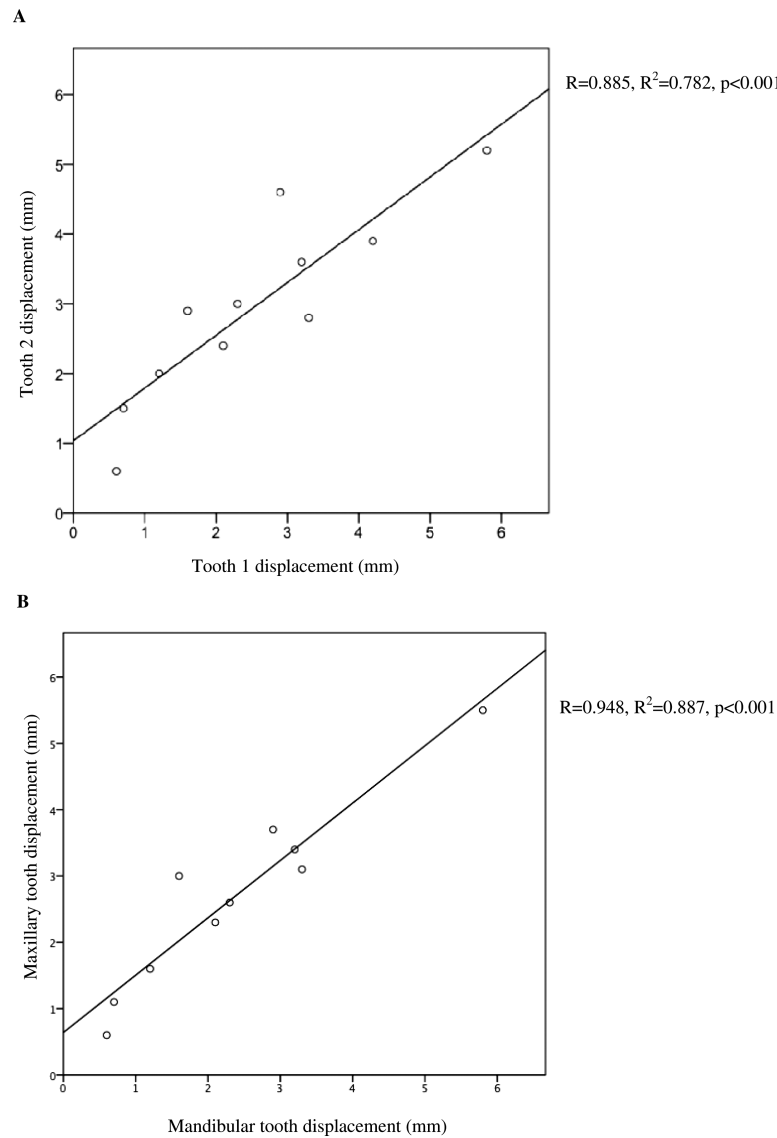
A

R=0.885, R²=0.782, p<0.001

B

R=0.948, R²=0.887, p<0.001

Figure 1. (A) The amount of tooth displacement for both experimentally displaced teeth within the same individual is shown. The fitted line represents the intra-individual correlation of tooth movement within the same subject. (R = 0.885, R^2 = 0.782, P < 0.001). (B) The amount of tooth displacement in the maxilla and mandible within the same individual. The fitted line represents the intra-individual correlation of tooth movement between the maxilla and the mandible (R = 0.948, R^2 = 0.887, P < 0.001).

Table 2. The results from the random effects linear regression.

Predictor		Multivariable	
		β (95% CIs)	*P*-value
Age	(per unit)	−0.11 (−0.28, 0.05)	0.17
Location	Mandible	Reference	0.02
	Maxilla	0.47 (0.81, 0.86)	

Funding

References

1. Proffit, W.R. (2007) Biologic basis of orthodontic therapy. In Proffit, W.R., Fields, H.W. and Sarver, D.M. (ed.), *Contemporary Orthodontics*. Mosby, St. Louis, MO, 4th edn, pp. 331–358.

2. Ren, Y., Maltha, J.C. and Kuijpers-Jagtman, A.M. (2003) Optimum force magnitude for orthodontic tooth movement: a systematic literature review. *The Angle Orthodontist*, 73, 86–92.

3. Davidovitch, Z. and Murphy, N. (2009) The adaptation and development of biological concepts in orthodontics. In Kishnan, V. and Davidovitch, Z. (ed.), *Biological Mechanisms of Tooth Movement*. Wiley-Blackwell, Oxford, UK, 1st edn, pp. 1–18.

4. Davidovitch, Z. and Krishnan, V. (2009) Effects of systemic diseases on orthodontic tooth movement. In Kishnan, V. and Davidovitch, Z. (ed.), *Biological Mechanisms of Tooth Movement*. Wiley-Blackwell, Oxford, UK, 1st edn, pp. 143–166.

5. Dudic, A., Giannopoulou, C. and Kiliaridis, S. (2013) Factors related to the rate of orthodontically induced tooth movement. *American Journal of Orthodontics and Dentofacial Orthopedics*,143, 616–621.

6. Pilon, J.J., Kuijpers-Jagtman, A.M. and Maltha, J.C. (1996) Magnitude of orthodontic forces and rate of bodily tooth movement. An experimental study. *American Journal of Orthodontics and Dentofacial Orthopedics*, 110, 16–23.

7. van Leeuwen, E.J., Maltha, J.C. and Kuijpers-Jagtman, A.M. (1999) Tooth movement with light continuous and discontinuous forces in beagle dogs. *European Journal of Oral Sciences*, 107, 468–474.

8. Owman-Moll, P., Kurol, J. and Lundgren, D. (1995) Continuous versus interrupted continuous orthodontic force related to early tooth movement and root resorption. *The Angle Orthodontics*, 65, 395–401.

9. Owman-Moll P. (1995) Orthodontic tooth movement and root resorption with special reference to force magnitude and duration. A clinical and histological investigation in adolescents. *Swedish Dental Journal. Supplement*, 105, 1–45.

10. Houston W.J. (1983) The analysis of errors in orthodontic measurements. *American Journal of Orthodontics*, 83, 382–390.

11. Devlin, H., Horner, K. and Ledgerton, D. (1998) A comparison of maxillary and mandibular bone mineral densities. *The Journal of Prosthetic Dentistry*, 79, 323–327.

12. Chugh, T., Jain, A.K., Jaiswal, R.K., Mehrotra, P. and Mehrotra, R. (2013) Bone density and its importance in orthodontics. *Journal of Oral Biology and Craniofacial Research*, 3, 92–97.

13. Lundgren, D., Owman-Moll, P. and Kurol, J. (1996) Early tooth movement pattern after application of a controlled continuous orthodontic force. A human experimental model. *American Journal of Orthodontics and Dentofacial Orthopedics*,110, 287–294.

14. Deguchi, T., Takano-Yamamoto, T., Yabuuch, I T., Ando, R., Roberts, E. and Garetto, L. (2008) Histomorphometric evaluation of alveolar bone turnover between the maxilla and the mandible during experimental tooth movement in dogs. *American Journal of Orthodontics and Dentofacial Orthopedics*, 133, 889–897.

15. Reitan K. (1967) Clinical and histologic observations on tooth movement during and after orthodontic treatment. *American Journal of Orthodontics*, 53, 721–745.

16. Shimpo, S., Horiguchi, Y., Nakamura, Y., Lee, M., Oikawa, T., Noda, K., Kuwahara, Y. and Kawasaki, K. (2003) Compensatory bone formation in young and old rats during tooth movement. *European Journal of Orthodontics*, 25, 1–7.

17. Ren, Y., Maltha, J.C., Van 't Hof, M.A. and Kuijpers-Jagtman, A.M. (2003) Age effect on orthodontic tooth movement in rats. *Journal of Dental Research*, 82, 38–42.

18. Ren, Y., Kuijpers-Jagtman, A.M. and Maltha, J.C. (2005) Immunohistochemical evaluation of osteoclast recruitment during experimental tooth movement in young and adult rats. *Archives of Oral Biology*, 50, 1032–1039.

19. Iwasaki, L.R. and Nickel, J.C. (2009) Markers of paradental tissue remodeling in the gingival crevicular fluid of orthodontic patients. In Kishnan, V. and Davidovitch, Z. (ed.), *Biological Mechanisms of Tooth Movement*. Wiley-Blackwell, Oxford, UK, 1st edn, pp. 123–142.

20. Oshiro, T., Shiotani, A., Shibasaki, Y. and Sasaki, T. (2002) Osteoclast induction in periodontal tissue during experimental movement of incisors in osteoprotegerin-deficient mice. *The Anatomical Record*, 266, 218–225.

21. Alfaqeeh, S.A. and Anil, S. (2011) Osteocalcin and N-telopeptides of type I collagen marker levels in gingival crevicular fluid during different stages of orthodontic tooth movement. *American Journal of Orthodontics and Dentofacial Orthopedics*, 139, e553–559.

22. Barbier, I.G., Solano, P., Alarcón, J.A., Vernal, R., Rios-Lugo, J., Sanz, M. and Martin, C. (2013) Biochemical markers of bone metabolism in gingival crevicular fluid during early orthodontic tooth movement. *The Angle Orthodontist*, 83, 63–69.

23. Kawasaki, K., Takahashi, T., Yamaguchi, M. and Kasai, K. (2006) Effects of aging on RANKL and OPG levels in gingival crevicular fluid during orthodontic tooth movement. *Orthodontics & Craniofacial Research*, 9, 137–142.

24. Nishijima, Y., Yamaguchi, M., Kojima, T., Aihara, N., Nakajima, R. and Kasai, K. (2006) Levels of RANKL and OPG in gingival crevicular fluid during orthodontic tooth movement and effect of compression force on releases from periodontal ligament cells in vitro. *Orthodontics & Craniofacial Research*, 9, 63–70.

25. Grant, M., Wilson, J., Rock, P. and Chapple, I. (2013) Induction of cytokines, MMP9, TIMPs, RANKL and OPG during orthodontic tooth movement. *European Journal of Orthodontics* 35: 644–651.

26. Baloul, S.S., Gerstenfeld, L.C., Morgan, E.F., Carvalho, R.S., Van Dyke, T.E. and Kantarci, A. (2011) Mechanism of action and morthologic changes in the alveolar bone in response to selective alveolar decortication-facilitated tooth movement. *American Journal of Orthodontics and Dentofacial Orthopedics*, 139, S83–S101.

27. Ebersole, JL. (2003) Humoral immune responses in gingival crevice fluid: local and systemic implications. *Periodontology 2000*, 3, 135–166.

28. Zaichner-David, M. (2009) Genetic influences on orthodontic tooth movement. In Kishnan, V and Davidovitch, Z. (ed.), *Biological Mechanisms of Tooth Movement*. Wiley-Blackwell, Oxford, UK, 1st edn, pp. 54–80.