

# Initial tooth displacement *in vivo* as a predictor of long-term displacement

P. L. Soenen\*, L. R. Dermaut\* and R. M. H. Verbeeck\*\*

Departments of \*Orthodontics and \*\*Dental Materials Science, University of Gent, Belgium

**SUMMARY** In the past, the dry skull has been used as a hypothetical model to test initial orthodontic and orthopaedic force systems. However, the question as to whether this hypothetical model can be used as a predictor of long-term displacements *in vivo* remains unanswered.

In this study, an attempt was made to compare initial tooth displacement with the long-term effect after application of the force system for a longer period of time, in six adult dogs.

Tooth displacement was obtained by applying a force by means of a coil spring (push) system. Following application of a force of 50 g in the first series ( $n = 3$ ) and 80 g in the second series ( $n = 3$ ), initial displacements were registered by means of speckle interferometry. The long-term displacement was registered by means of standardized cephalometry in the same dog by leaving the force system in place for 5 weeks. The mean values of the displacement vectors of the second premolars in the six dogs were compared. A paired *t*-test revealed no significant differences between the initial and long-term displacements in any of the dogs.

The results show that both groups of measurements belong statistically to the same sample and that initial tooth displacement measured by means of speckle interferometry is a valuable predictor for forecasting long-term displacement *in vivo* after 5 weeks.

## Introduction

If one intends to treat a patient orthodontically, it is necessary to thoroughly understand the biomechanical aspects of the orthodontic device. Dry skulls have been used as a hypothetical model to test force systems (Nakanishi, 1973; Emata, 1976; Dermaut and Beerden, 1981; Dermaut *et al.*, 1986). So far, however, there is no scientific evidence that this hypothetical model is a suitable predictor of long-term displacements.

Tooth displacement can be measured in different ways. In the past, several studies have been published on the measurement of physiological tooth movement (Lundquist, 1955; Mühlemann, 1960; Parfitt, 1960).

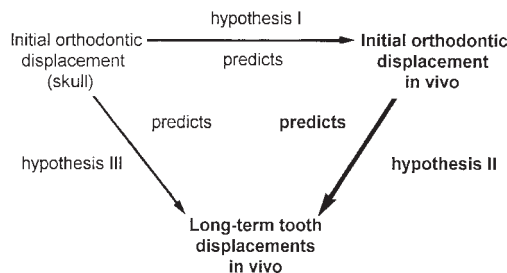
Strain gauges have been introduced as a method of registering physiological tooth mobility (Gould and Picton, 1962; Picton, 1962, 1963), and a two-dimensional model was developed in an attempt to indicate zones of bone apposition and

resorption after force application (Haack and Weinstein, 1963).

In an earlier study, tooth displacements after force application were measured *in vivo* (Hofman and Diemer, 1962). In most previous investigations, displacement curves were measured by means of an electronic device.

According to the literature, the strain gauge technique has been applied extensively on dry human skulls in an attempt to register initial displacements (Lanyon and Smith, 1970; Sugimura *et al.*, 1983, 1984; Ichikawa *et al.*, 1984). This technique has been used *in vivo* (Kannan, 1982), as well as on autopsy material (Pedersen *et al.*, 1991a,b).

Double exposure holography has been used to register orthodontic tooth movement (Burstone *et al.*, 1978; Burstone and Pryputniewicz, 1980, 1982). Laser measuring techniques have an important advantage over the previously described



**Figure 1** Hypothetical model.

methods, since they are non-invasive and the displaced object is not touched by the measuring device (non-destructive testing). Double exposure and real time holography, and the 'laser reflection technique' have been used in orthodontic research over the last 20 years, but only small displacements can be registered with these techniques (Ryden *et al.*, 1979; Dermaut and Beerden, 1981; Duterloo, 1985; Dermaut and Vanden Bulcke, 1986; Vanden Bulcke *et al.*, 1986, 1987; Vanden Bulcke and Dermaut, 1990). Speckle interferometry was introduced by Goldin *et al.* (1980), in an attempt to measure larger displacements, and investigations using this technique have been carried out (Kleutghen *et al.*, 1982; Dermaut *et al.*, 1986; De Clerck *et al.*, 1990).

A number of investigations to test the validity of the dry skull as a model are being undertaken at the Department of Othodontics, University of Gent. In the first series of experiments, the value of the hypothetical model as a predictor of initial orthodontic displacements *in vivo* was tested (hypothesis I, Figure 1). Immediately after force application, teeth start to move. This initial displacement is tooth-movement within the socket before bone remodelling begins.

However, it remains unknown whether initial tooth displacement *in vivo* gives an indication of the long-term effects (including bone remodelling), which will take place after a well-defined time interval (hypothesis II, Figure 1). The hypothesis tested in this study (hypothesis II) is part of the second series of experiments carried out to describe a hypothetical model, which could be

used to predict the effects of applied orthodontic force systems. If both hypotheses are confirmed, it may be concluded that the skull can be used as a suitable model to predict long-term changes brought about by induced force systems (hypothesis III, Figure 1).

In this study, an attempt was made to find a correlation between initial tooth displacement, caused by force application, and its long-term effect in adult dogs. This hypothesis was tested by means of 'speckle interferometry', to measure initial displacements, and 'standardized cephalometry', to determine long-term effects.

## Materials and methods

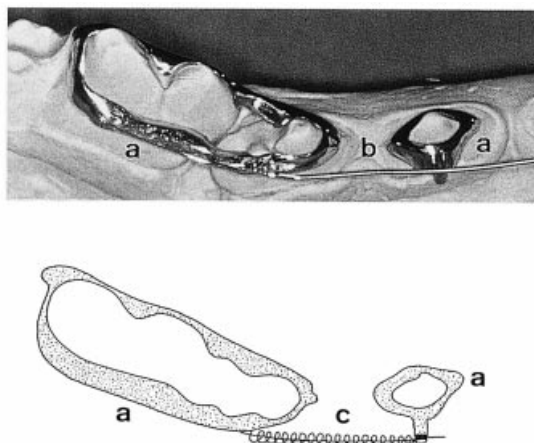
### Experimental device

The dog was chosen as the model as different experimental parameters were required to be constant during the study period. Jaw morphology was not the main consideration. The dog is easy to house, and resistant to infection and the long-term effects of anaesthesia. The specific parameters in selecting the lower jaw as the experimental area were:

- (1) the teeth are large enough for the application of an orthodontic device;
- (2) in the experimental area there are no sutures to interfere with initial displacement;
- (3) dogs show an open bite in the premolar area which facilitates the orthodontic force application without occlusal interferences.

A 'unipoint contact bracket' (TP Orthodontics, La Porte, Indiana, USA) soldered on a chrome-cobalt (Cr-Co) band was fitted around the second premolar in the lower left quadrant of the animal (Figure 2). The anchor teeth (third premolar and first molar) were connected to each other by means of Cr-Co bands on which a section of Australian 0.18-inch wire had been soldered. A push coil spring system was used to tip the second premolar mesially.

Displacement vectors of the second premolar were constructed for six animals. This was carried out for the initial, as well as for the long-term displacements.

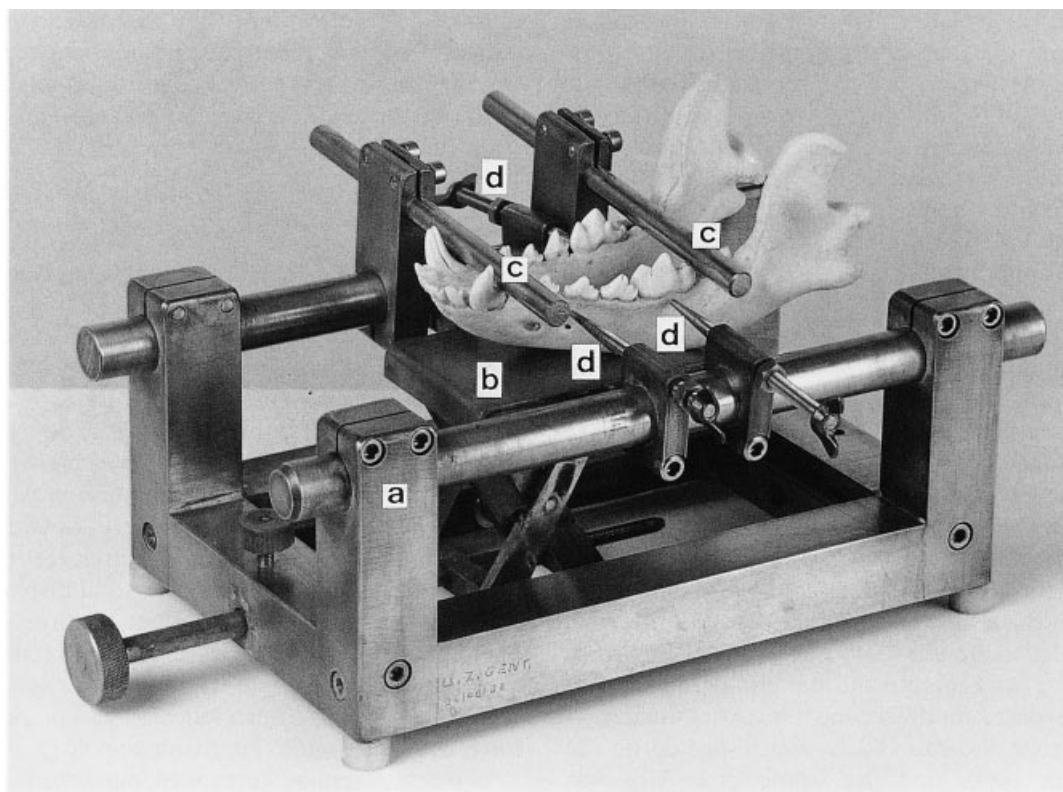


**Figure 2** Cr-Co bands (a), with attached 0.018-inch Australian wire (b) and coil (c).

In order to measure initial displacements, it was necessary to design a rigid fixator (Figure 3). The fixator comprised a 'basic frame', which clasped the jaw from beneath, and was fixed to a horizontal table. By raising the table, the jaw could be firmly clamped against two transverse bars, passing distal to the canines and mesial to the second molars. Four bone-screws prevented lateral movement, thus totally immobilizing the mandible.

For the long-term displacements, standardized radiographs of the displaced tooth were taken at regular intervals by means of a specially-designed cephalostat.

The reliability of this device was verified by comparing ten duplicate measurements on the same dog (according to Dahlberg,  $s = 0.9$  degrees).



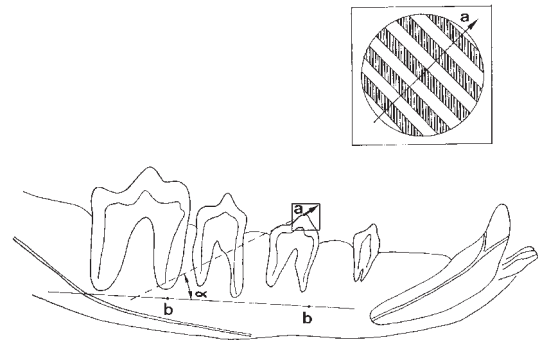
**Figure 3** Rigid fixator with (a) basic frame, (b) table, (c) clamping the lower jaw, two horizontal bars, and (d) four bone screws.

### *Determination of the initial displacement after initial force application*

To determine the initial displacement, speckle interferometry was used (De Clerck *et al.*, 1990). Speckle interferometry is based on the combination of the phenomenon of Young and the formation of speckles. After a subject is exposed homogeneously to laser light (Argon-type 165, 500 mW, 514 nm), the reflected ray is directed towards a photographic plate, called a specklegram. This plate is exposed twice, once before and once after force application, which results in two superimposed speckle patterns that are stored on the emulsion of the specklegram. Depending upon the amount of displacement, both speckle patterns are microscopically displaced with respect to each other. When the developed photographic plate is exposed to laser light, a fringe-pattern is created. The direction of the displacement vector is perpendicular to the direction of the registered fringe-pattern. In this study, four measuring plates (sand-blasted copper) were fixed to the displaced tooth, the anchor teeth, at the lingual surface of the alveolar process in the area of the displaced tooth and on the fixator. The plate on the fixator was used to test the stability of the device and to control unwanted side-effects after force application.

After comparing the effects of different force levels, 50 g was chosen as the optimum experimental force as this produced tipping of the experimental tooth without causing bone displacement.

At the start of each experiment, the coil to be applied was squeezed and ligated with a steel ligature to the anchor tooth. By doing so, the tooth to be measured was unloaded. At that moment a photographic plate was exposed (<1 second) for the first time. By cutting the steel ligature the tested tooth was loaded with a force of 50 g for 1 minute and the photographic plate was exposed for the second time. After the second exposure, the coil system was re-ligated on the anchor tooth and the whole procedure was repeated 10–14 times on each dog. According to De Clerck *et al.* (1990), the error of the method using speckle interferometry makes multiple measurements necessary.



**Figure 4** Initial displacement 'vector' (a) and its angulation to the metallic implants (b). Insert = fringe pattern.

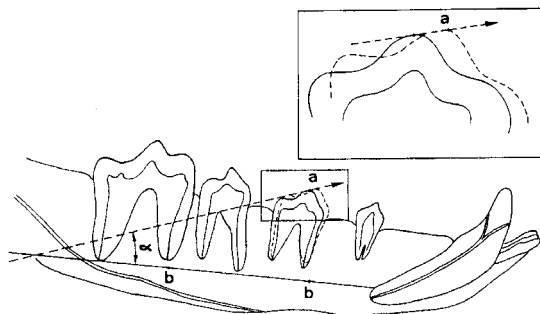
On each of the double-exposed specklegrams, displacement vectors were constructed perpendicular to the direction of the registered fringe pattern. The direction of the displacement vector was determined and expressed as the angulation of the vector to a reference line (Figure 4).

### *Determination of the displacement after long-term force application*

To determine the long-term displacement of a tooth after force application, bone markers (Björk, 1963) were inserted in the cortical bone of the mandible as reference points.

Six experimental animals were used in this study. In animals 1, 2 and 3, a force of 50 g was applied for 5 weeks. This period was chosen in order to simulate the clinical situation in which an orthodontic patient returns every 4–5 weeks for activation of the appliance. This force-level was chosen to coincide with the initial displacements in which the same amount of force was applied. However, the long-term displacement turned out to be minimal. Therefore, in a second series involving three other animals, the amount of force was increased to approximately 80 g.

Two cephalograms were taken, one before and one 5 weeks after force application. From both radiographs the bone markers together with a fixed point on the crown of the tooth to be measured were traced. Both cephalograms were



**Figure 5** Angulation  $\alpha$  of the long-term displacement 'vector' (a) after superimposition on metallic implants (b). Insert = detail of the displacement.

superimposed several times on the bone markers in the six dogs and the angulation ( $\alpha$ ) of the displacement of the premolar was registered (Figure 5). This procedure was repeated 25 times per dog in order to test the reliability of the method.

#### *Comparison of the initial and long-term displacement vectors*

The long-term displacement vectors were constructed after superimposition of the cephalograms before and after treatment (Figure 5). Since the amount of tooth displacement was very small, magnification of the radiographs was undertaken ( $\times 2$ ) to reduce the error of the method. Furthermore, as explained, superimposition of both cephalograms was carried out 25 times for each dog. Average values and standard deviations of these measurements are listed in Table 1.

To make comparison possible between initial and long-term displacements, tooth structures visible on the specklegrams were traced and magnified to the size of the cephalograms so that a common reference line could be used (Figure 4).

It must be emphasized that the reference lines are different for each dog. Comparison of the angulation of the displacement vectors between dogs is not possible. Therefore, in this study initial displacements versus long-term displacements were tested for each dog separately.

**Table 1** Average values (in degrees) of the displacement vectors for both initial and long-term displacements.

Dog	Initial	Long-term	<i>t</i> -test
1	34.0	30.7	NS
2	6.2	-6.3	NS
3	3.7	-3.3	NS
4	-2.3	1.2	NS
5	4.6	-0.6	NS
6	12.0	6.0	NS

NS:  $P = 0.071$ .

## **Results**

The average values of the angulation ( $\alpha$ ) of the initial displacement vectors and the long-term displacement vectors were compared for each of the six dogs (Table 1). Differences between both displacements were tested by means of the paired *t*-test for each dog.

The average angulations were normally spread ( $P = 0.460$ ) and the mean values (mean  $\pm$  SD) were  $9.7 \pm 5.2$  for the initial displacements, and  $4.8 \pm 5.4$  for the long-term displacements.

The paired *t*-test (Table 1) revealed no differences between the initial and long-term displacement in any of the dogs ( $P = 0.071$ ). The initial displacement seemed to be indicative of the long-term effect (see Figure 1, hypothesis II).

## **Discussion**

Several studies have been published on the use of the 'dry' skull as a hypothetical model to predict orthodontic and orthopaedic changes. Prediction of long-term tooth displacements after force application provides information for the orthodontist. As a result, the validity of new orthodontic methods and techniques can be tested.

For practical reasons, initial displacements after force application cannot be measured in each patient. A valid model is therefore essential to



measure initial displacements. Since the morphology of a patient's head might be different, a universal model does not exist. In this study, however, tooth movement within one jaw (without sutures) was tested initially, as well as longitudinally. It can be anticipated that the morphology of the jaw does not affect tooth movement to a great extent. The proposed model (lower jaw), therefore, can be used to test different mechanical orthodontic devices. A sensitive measuring technique is, however, required to measure initial displacements on the model.

In this study, hypothesis II was tested: initial tooth displacements, as measured by speckle interferometry, are an indication of long-term displacements due to bone remodelling. Speckle interferometry is a very sensitive measuring device, so repeated measurements are needed. This was also suggested by De Clerck *et al.* (1990).

The initial displacements were measured 10–14 times, and it was found that the displacement vectors varied quite extensively within the investigated dogs.

The main contributing factor for this phenomenon is the difference in anatomy of the mandible, as well as the position of the tested teeth for each of the dogs investigated (defining different reference lines).

The long-term displacements were registered by means of cephalograms. In contrast to the initial displacements, these displacements cannot be repeated in the same dog. Since these displacements are very small, magnification of the cephalograms is necessary. In addition, to improve measuring accuracy, the same cephalograms were measured several times as previously explained. In the first three dogs, the same magnitude of force (50 g) was applied for both the initial and long-term displacements, and it was found that, after 5 weeks, the long-term displacements were very small. Therefore, in the next three dogs, the force was increased to 80 g in an attempt to improve measuring accuracy.

In all the experimental animals, the paired *t*-test showed no significant difference between the initial and the long-term displacements. Statistically, both groups of displacement vectors

were found to belong to the same sample, which indicates that initial tooth displacements, measured with speckle interferometry, are a good predictor of long-term effects measured after 5 weeks.

### Address for correspondence

Professor Dr L. Dermaut  
Department of Orthodontics  
Universitair Ziekenhuis  
De Pintelaan 185  
9000 Gent  
Belgium

### Acknowledgements

The authors wish to thank Professor Dr P. Boone for his support during the laser experiments, and the technical team of the dental school (Ing F. De Backer, E. Comhaire, W. Heyndrickx, A. Blondia), who prepared the experimental set-up. They also wish to acknowledge Mrs B. Jouret for typing the manuscript and Mr G. Dermout for the photographic work.

### References

- Björk A 1963 Variations in the growth pattern of the human mandible: a longitudinal radiographic study by the implant method. *Journal of Dental Research* 42: 400–411
- Burstone C J, Pryputniewicz R J 1980 Holographic determination of centres of rotation produced by orthodontic forces. *American Journal of Orthodontics* 77: 396–409
- Burstone C J, Pryputniewicz R J 1982 Quantitative measurement of skull deformations. *Journal of Dental Research* 61: 281 (Abstract)
- Burstone C J, Pryputniewicz R J, Bowley W W 1978 Holographic measurement of tooth mobility in three dimensions. *Journal of Periodontal Research* 13: 283–294
- De Clerck H, Dermaut L, Timmerman H 1990 The value of the macerated skull as a model used in orthopaedic research. *European Journal of Orthodontics* 12: 263–271
- Dermaut L R, Beerden L 1981 The effects of Class II elastic force on a dry skull measured by holographic interferometry. *American Journal of Orthodontics* 79: 296–304
- Dermaut L R, Vanden Bulcke M M 1986 Evaluation of intrusive mechanics of the type 'segmented arch' on a macerated human skull using the laser reflection technique and holographic interferometry. *American Journal of Orthodontics* 89: 251–263

- Dermaut L R, Kleutghen J P J, De Clerck 1986 Experimental determination of the center of resistance of the upper first molar in a macerated dry human skull submitted to horizontal headgear traction. *American Journal of Orthodontics and Dentofacial Orthopedics* 90: 29–36
- Duterloo H S 1985 Holographic and cephalometric study of the relationship between craniofacial morphology and the initial reactions to highpull headgear traction. *American Journal of Orthodontics* 88: 297–306
- Emata T 1976 The analysis of strain and displacement, produced by the Kloeohn type face bow in the dry skull of the *Maccaca irus*. *Journal of the Japanese Orthodontic Society* 35: 130–149
- Goldin B, Burstone C J, Pryputniewicz R J 1980 Holographic measurement of incisor teeth subjected to lingual force and couple loading. *Journal of Dental Research* 59: 440 (Abstract)
- Gould M S E, Picton D C A 1962 A method of measuring forces acting on the teeth from the lips, cheeks and tongue. *British Dental Journal* 112: 235–242
- Haack C D, Weinstein S 1963 Geometry and mechanics as related to tooth movement studied by means of two-dimensional model. *Journal of the American Dental Association* 20: 158–164
- Hofman M, Diemer R 1962 Ein Berät zur quantitativen und qualitativen Bestimmung der Bewegungsbahn des Zahnes. *Deutsche Zahnärztliche Zeitschrift* 17: 721–730
- Ichikawa K *et al.* 1984 The effects of orthopedic forces on the craniofacial complex utilizing maxillary protraction. *Journal of the Japanese Orthodontic Society* 43: 325–336
- Kannan K 1982 Effects of headgear traction on the facial skeleton of the monkey: a study with strain gauges. *Journal of the Osaka Dental University* 16: 112–136
- Kleutghen J P, Dermaut L R, Boone P M, De Caluwe M 1982 The analysis of extraoral orthodontic forces on a macerated skull by means of speckle interferometry: a preliminary report. *Proceedings of the Society of Photo-Optical Instrumentation Engineers*, Edinburgh
- Lanyon L E, Smith R N 1970 Bone strain in the tibia during normal quadrupedal locomotion. *Acta Orthopædica Scandinavica* 41: 238–248
- Lundqvist C 1955 Objective parodontal registration method. *Odontologisk Revy* 7: 9–43
- Mühlemann H R 1960 Ten years of tooth-mobility-measurements. *Journal of Periodontology* 31: 110–112
- Nakanishi Y 1973 Effects of headgear traction with human facial skeleton: a study with strain gauges. *Journal of the Osaka Dental University* 7: 7–30
- Parfitt G J 1960 Measurement of the physiological mobility of individual teeth in an axial direction. *Journal of Dental Research* 39: 508–618
- Pedersen E H, Andersen K, Melsen B 1991a Tooth displacement analysed on human autopsy material by means of a strain gauge technique. *European Journal of Orthodontics* 13: 65–74
- Pedersen E H, Isidor F, Gjessing P, Andersen K 1991b Location of centres of resistance for maxillary anterior teeth measured on human autopsy material. *European Journal of Orthodontics* 13: 452–458
- Picton D C A 1962 Tilting movements of teeth during biting. *Archives of Oral Biology* 7: 151–159
- Picton D C A 1963 The effect on normal vertical tooth mobility of the rate of thrust and time interval between thrusts. *Archives of Oral Biology* 8: 291–299
- Ryden H, Bjelkhagen H, Södu P O 1979 Movements of healthy and periodontally involved teeth measured with laser reflection technique. *Journal of Periodontology* 53: 439–445
- Sugimura T, Kakudo Y, Matsumoto T, Nagata R 1983 Dynamic responses of teeth and mandible to occlusal force. *Journal of the Osaka Dental University* 17: 51–64
- Sugimura T, Inana G, Sawa S, Kakudo Y 1984 Dynamic responses of the skull caused by loss of occlusal force. *Journal of the Osaka Dental University* 18: 29–42
- Vanden Bulcke M M, Dermaut L R 1990 The interaction between reaction forces and stabilization systems during intrusion of the anterior teeth and its effect on the posterior unit. *European Journal of Orthodontics* 12: 361–369
- Vanden Bulcke M M, Dermaut L R, Sachdeva R C L, Burstone C J 1986 The center of resistance of anterior teeth during intrusion using the laser reflection technique and holographic interferometry. *American Journal of Orthodontics and Dentofacial Orthopedics* 90: 211–220
- Vanden Bulcke M M, Burstone C J, Sachdeva R C L, Dermaut L R 1987 Location of the center of resistance of anterior teeth during retraction using the laser reflection technique. *American Journal of Orthodontics and Dentofacial Orthopedics* 91: 375–384