European Journal of Orthodontics 21 (1999) 671–678

Initial orthopaedic displacement compared with longitudinal displacement of the maxilla after a forward force application. An experimental study in dogs

G. A. M. de Pauw, L. R. Dermaut and R. M. H. Verbeeck*
Departments of Orthodontics and *Dental Materials Science, University of Gent, Belgium

SUMMARY The aim of this study was to compare the initial orthopaedic displacement of the maxilla *in vivo* and the longitudinal changes after a forward force application. The sample consisted of five 1-year-old dogs. An anterior force of 5 N on the maxilla was applied by a coil spring system pushing between Brånemark implants and a maxillary splint. The initial displacement of the maxilla after force application was measured by means of speckle interferometry. The longitudinal displacement of the maxilla after a force application during 8 weeks was measured by superimposing standardized lateral cephalograms.

The initial, as well as the longitudinal, displacement of the maxilla of the dogs was in a forward direction with some counterclockwise rotation. There was no statistical difference between the initial and longitudinal displacement. The biological response after force application during 8 weeks can be predicted by the initial orthopaedic displacement.

Introduction

The effects of force application on the craniofacial complex have been studied extensively in humans (Delaire *et al*., 1978; Nanda, 1980a; Petit, 1983; Shapiro and Kokich, 1984). Moreover, the ability to modify the position of the nasomaxillary complex after anterior extra-oral traction in animals has been demonstrated by a number of investigators (Dellinger, 1973; Kambara, 1977; Nanda, 1978, 1980b; Jackson *et al*., 1979; Nanda and Hickory, 1984; Smalley *et al*., 1988). These 'longitudinal' orthopaedic changes or 'secondary' displacements represent the biological response of the bone to the force application after a period of time.

Different models, such as the dry skull (Kragt *et al*., 1979, 1982; Dermaut and Beerden, 1981; Kragt and Duterloo, 1982, 1983; Dermaut *et al*., 1986; De Clerck, 1987; De Clerck *et al*., 1990), have been used to investigate biomechanics, and the influence of force application on dental and skeletal units. The initial bone displacements after a force application on these models are very small. The question remains, however, as to whether the initial bone displacement of a model can be considered as a predictor for the longitudinal displacement or the induced growth changes (Figure 1).

In an attempt to test the value of the skull as a model for orthopaedic research, two hypotheses have to be confirmed (Figure 1). The first hypothesis questions the prediction of the initial bone displacement of a model with regard to the initial bone displacement *in vivo*. This hypothesis was investigated by De Clerck *et al.* (1990). They measured initial bone displacements in dogs after force application *in vivo*, post-mortem, and *in vitro*, and concluded that the dry skull, as such, cannot be used as a reliable model to predict initial bone displacement. They suggested that changes in environmental factors such as humidity and temperature might improve the model.

To test the second hypothesis, i.e. the initial orthopaedic effect *in vivo* predicts the secondary orthopaedic effect, the initial bone displacement *in vivo* after a force application has to be

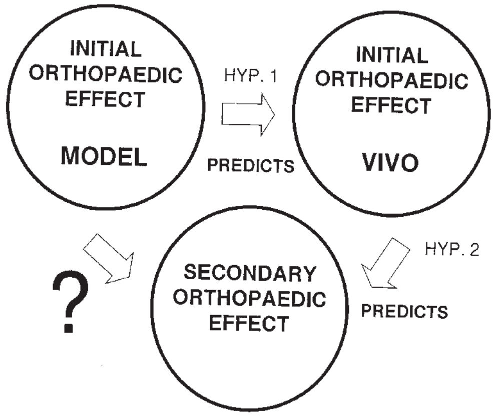

Figure 1 The hypothetical model: can a model predict a secondary orthopaedic effect? Hypothesis 1: the initial orthopaedic effect of a model predicts the initial orthopaedic effect *in vivo*. Hypothesis 2: the initial orthopaedic effect *in vivo* predicts the secondary orthopaedic effect. The question mark suggests the possible prediction between the initial orthopaedic effect of a model and the secondary orthopaedic effect.

measured and compared with the longitudinal displacement (Figure 1).

The aim of this study was to test the second hypothesis by comparing the initial orthopaedic displacement of the maxilla *in vivo* with the longitudinal changes after a forward force application on the maxilla of a dog.

Materials and methods

Experimental set-up

The use of the dog in this experimental study was based on the following considerations. The anterior development of the dog's maxilla is very suitable to study the effects of anterior force application on the maxilla. Moreover, resistance to infection and long-term anaesthesia, as well as fast recovery after surgical procedures were considered as the main advantages for using this animal as the experimental model.

The sample consisted of five healthy, adult, randomly-chosen dogs of the same age and weight with a full set of permanent teeth. According to the hypotheses to be tested, it was not important to use a pure-bred sample of dogs. Therefore, the dogs were not of a particular breed.

The following procedures were necessary to prepare the dogs for this experimental study. The animals were anaesthetized for each experimental procedure. Tantalum bone implants were placed in the frontal bone and the maxilla, and were used for superimposition of standardized lateral cephalograms (taken before and after force application during 8 weeks). Three Brånemark titanium implants (NobelBiocare AB, Göteborg, Sweden) were placed in the posterior part of both the left and right zygomatic arch (temporal bone). The implants were standard Brånemark implants 3.75 mm in diameter, and 7, 10, and 15 mm in length, depending on bone height. Surgical placement of these implants was carried out with minimal trauma. Cover screws were placed to prevent bone in-growth. The implants were re-exposed after a healing period of 8 weeks. Standard titanium abutments were attached to the osseo-integrated implants. The two longest implants were connected by a fixed bridge in an attempt to absorb the reactive forces of the applied force system. The third implant served as an unloaded control to test the stability of the implants. The latter will be discussed in another paper.

A chrome-cobalt (Cr–Co) splint was constructed on six maxillary teeth and fixed with Concise^{R} (3M, Minnesota, USA) bonding material and an anterior force of 5 N on the maxilla was applied by a coil spring system pushing between the Brånemark implants and the maxillary splint (Figure 2). The spring system was situated underneath the skin and the mucosa and entered the oral cavity in the area of the second molar. The forward force direction ranged between 5–18 degrees with respect to the occlusal plane.

The initial displacement

The initial displacement of the maxilla after force application (coil spring system) was measured by means of speckle interferometry, a laser technique suited to measuring very small initial displacements (Goldin *et al.*, 1980; Kleutghen *et al.*, 1982; De Clerck, 1987; De Clerck *et al.*, 1990; Govaert and Dermaut, 1997). The displacement of the speckle pattern, between two registrations (double exposed specklegram) on the

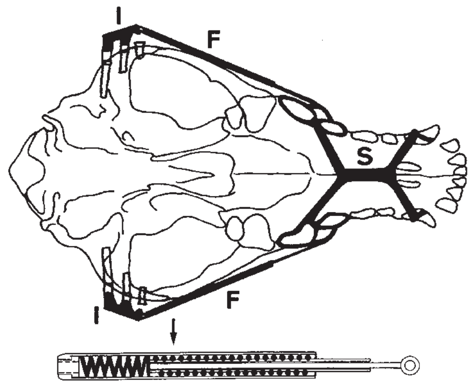

Figure 2 Occlusal view on the skull with the applied force system (F) between the implants (I) and the maxillary splint (S).

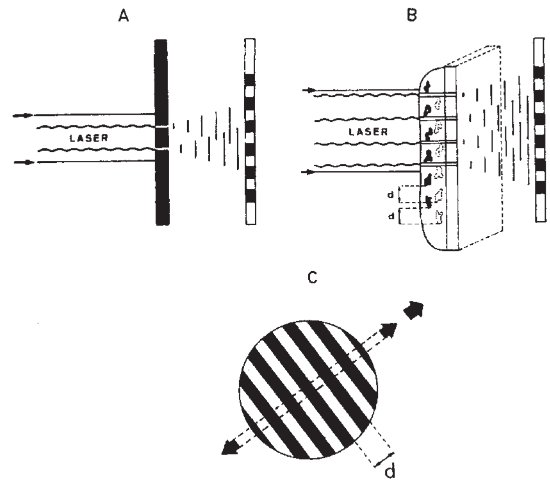

Figure 3 (A) Schematic representation of the creation of Young's fringes when a laser beam is passing through two holes in a screen resulting in a fringe pattern on a holographic plate. (B) Schematic drawing of the displacement (d) of a speckle pattern on a double-exposed holographic plate due to force application. A laser beam passing through the specklegram creates a fringe pattern (Young's phenomenon). (C) The amount of displacement is inversely proportionate to the distance between two fringes (d); the direction of displacement is perpendicular to the orientation of the fringes.

same photographic plate, indicates the direction and magnitude of the initial bone displacement. This technique has the advantage of being non-invasive: the bone has not to be touched during the measuring procedure (Figure 3).

For the experimental set-up a measuring plate was fixed on the maxilla and the frontal bone of the dog, with the head of the dog clamped rigidly between four pins (De Clerck *et al.*, 1990). The photographic plate was exposed twice during 15 seconds, first after a force application of 5 N for 1 minute and a second time after a relaxation time of 2 minutes. The amount of displacement in this investigation was comparable to the registered displacements in previous studies (De Clerck, 1987; De Clerck *et al.*, 1990). The error of the method has been reported previously (De Clerck *et al.*, 1990). According to that study, measurement errors of approximately 1 degree and 1 μm were found for displacements smaller than 10 μm. As every displacement in each dog was larger than 10 μm, this measuring error was considered as being within acceptable limits. Due to the sensitivity of the technique, approximately 15 specklegrams were taken each time and the average values were used.

By constructing a perpendicular line to the registered fringes on the photographic plate, the centres of rotation of the initial displacement could be constructed. From these centres of rotation, it was possible to calculate the angles between the initial displacement vector and

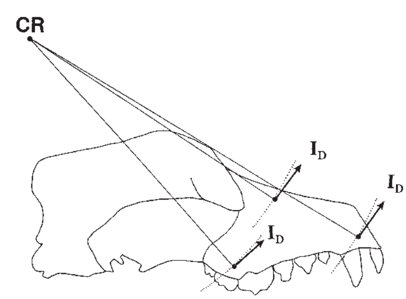

Figure 4 The centre of rotation (CR) of the initial maxillary displacement in dog 1 after forward force application. The angulation of the initial displacement (I_D) vector in each point of the maxilla can be calculated.

the occlusal plane at each point on the maxilla (Figure 4).

The construction of the centres of rotation is a very sensitive procedure in which obvious differences in position do not necessarily indicate changes in the direction of the displacement vector. The centres of rotation were used in this study to translate indirectly the initial displacement vectors towards the cephalograms (see later). Displacement vectors were used to describe the initial displacement of the maxilla.

The longitudinal displacement

The longitudinal displacement of the maxilla after force application during 8 weeks was measured by superimposing standardized lateral cephalograms taken before and after loading. This experimental period was chosen to be comparable with the treatment interval between orthodontic consultations.

Six tantalum bone markers were placed in the right frontal bone and the right maxilla near the mid-sagittal plane. Theoretically, two bone markers in the maxilla are sufficient to analyse the displacement of the maxilla, provided that these markers do not alter their position in the maxilla during the experimental period. In this study, six bone markers were placed in the maxilla and only those whose position was considered to have remained stable during the experiment were used.

Radiographs of the dog's head were taken before and after force application with a specially constructed cephalostat. On the cephalogram, the bone markers in the frontal bone and the maxilla were traced. Each time (before and after a treatment period of 8 weeks) four cephalograms were taken independently to test the reliability of positioning the dog's head in the cephalostat.

By taking four cephalograms before as well as after force application, each bone marker could be traced four times on both the first and second series of radiographs. After superimposition on the markers in the frontal bone, this procedure theoretically must result in one position for each bone marker at the two experimental periods provided that no error is involved. However, in reality a combined error occurs, which is composed of a positioning error in the cephalostat, a tracing error and a superimposition error. The error of method was calculated for the mean longitudinal displacement in each dog (Table 1).

For each bone marker, four displacement vectors were constructed by connecting each marker point (series 1 = before force application) with the randomly chosen corresponding marker traced on the post-treatment cephalograms (series 2 = ±8 weeks after force application). To obtain an overall impression of the displacement of the maxilla, a central point was defined by calculating the average X and Y co-ordinate from the group of bone markers in each cephalogram.

Table 1 The error of the method for the mean longitudinal displacement (d) in each dog (D).

	d (mm)	Error (mm)
D_1	2.3	0.1
D_2	2.5	0.2
D_3	1.8	0.1
D_4	1.8	0.1
D_5	1.6	0.1

Initial displacement compared with the longitudinal displacements

To compare the initial and longitudinal displacement, the structures of the dog's head on the specklegrams were magnified to the size of the cephalograms.

The centres of rotation of the initial displacement of the maxilla can be projected on the first series of cephalograms. As has been explained before, the angles of the initial displacement vector in each bone marker of the maxilla can be constructed starting from the centres of rotation (Figure 4).

The initial displacement of the entire maxilla was measured at a central point on the maxilla according to the calculated average maxillary point on the radiographs (see longitudinal displacement).

To compare the initial and the longitudinal displacement vectors of the maxilla of the five dogs, a weighted regression analysis was carried out for the central point of the maxilla.

Results

The initial displacement

The mean initial displacement of the maxilla after force application resulted, in each dog, in

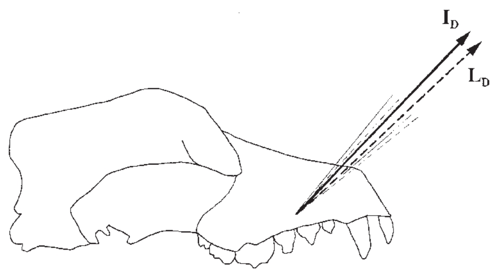

Figure 5 The mean initial (I_D —) and the mean longitudinal (L_D - - - -) displacement of the central maxillary point with one standard deviation in both directions after a forward force application in dog 4.

a forward translation with a counterclockwise rotation (Figure 5). The procedure to measure the initial displacement of the maxilla was repeated 12–15 times in each dog. The mean values and standard deviations of the displacement vectors in the central maxillary point are listed in Table 2. The magnitude and the direction of the displacement vectors differed from dog to dog, but were in the same direction.

The longitudinal or secondary displacement

After a force application of 6–8 weeks, a secondary orthopaedic displacement of the maxilla was found in each dog. The maxillae of the dogs were translated forward with some small upward rotation. The mean secondary orthopaedic displacement of the maxilla, measured at the central point, is shown in Table 2.

Minor mesial movement of the maxillary teeth, fixed in the splint, was observed. However, tooth displacement was not measured since this was not the purpose of this study.

Comparison of initial and longitudinal displacement

The angles of the initial displacement vector were calculated at a central maxillary point (on the first radiograph) and compared with its longitudinal displacement vector (Table 2).

There were small differences between the initial and the longitudinal displacements at the central maxillary point. A weighted regression analysis shows that the relationship between the initial (Δx_I) and the longitudinal (Δx_L) displacement in the central maxillary point is linear, and at the 95 per cent confidence level is given by the formula:

$$\Delta x_L = (3.40 \pm 4.43) + (0.89 \pm 0.11)\, \Delta x_I \qquad (1)$$

with $r = 0.996$, which shows that there was no systematic deviation and the displacements were positively correlated. There appears to be no proportional deviation as the slope equals 1 within the experimental error.

Hence, initial orthopaedic displacement of the maxilla apparently provides a good prediction of the longitudinal orthopaedic displacement.

Discussion

In the past, several studies have been carried out to test and improve the value of the skull as a model for orthopaedic research (Dermaut and Beerden, 1981; Kleutghen *et al.*, 1982; Dermaut *et al.*, 1986; De Clerck *et al.*, 1990; Govaert and Dermaut, 1997). It has been found that the dry skull has some important limitations which should be taken into account.

First of all, the dry skull is an *in vitro* model and does not correspond perfectly with the *in vivo* situation (Figure 1, hypothesis 1). De Clerck *et al.*

Table 2 Mean angle (standard deviation) of the initial displacement vector (Δx_I) and the longitudinal displacement vector (Δx_L), measured in the central maxillary point for the different dogs (D).

		D_1	D_2	D_3	D_4	D_5
Initial displacement (degrees)	Δx_I	5.2 (4.1)	46.8 (3.1)	30 (5.4)	48.2 (4.7)	46.8 (4.1)
Longitudinal displacement (degrees)	Δx_L	8.6 (3.8)	44.1 (7)	28.4 (2.1)	45.3 (4)	47.2 (7.2)

(1990) compared the displacements of the maxilla *in vivo*, post-mortem, and *in vitro* (dry skull) after a forward force application on a dog's maxilla. They concluded that the dry skull cannot be used as a reliable model to simulate the *in vivo* situation. The loss of all fibrous connective tissues, caused by maceration, leads undoubtedly to a different sutural interdigitation and may result in a different initial reaction of the bone to force application. Humidity and temperature could be also important factors because these parameters could have an influence on shape and interdigitation of the bone structures (Govaert and Dermaut, 1997).

Secondly, it has not been proven so far that the initial displacement of skeletal units after a force application on a dry skull corresponds with the longitudinal or secondary displacements after a period of time (Figure 1, hypothesis 2). Initial displacements of skeletal units are small and are the immediate result of the force application. The longitudinal or secondary displacements are the long-term results of the application of a force. The longitudinal displacements are also influenced by factors other than force parameters. Skeletal remodelling due to facial growth will also influence the secondary displacement. The use of adult animals in this investigation excludes the effect of natural growth. Moreover, in this study the effect of growth is minimal since the experimental period was limited to 8 weeks. To achieve a final treatment result, the patients have to be controlled regularly and the biomechanical force system has to be adapted at regular times. Therefore, the effect of the force system has to be evaluated over a short period of time.

In this study, the initial orthopaedic displacement *in vivo* was compared with the secondary orthopaedic displacement after a forward force application on the maxilla of the dog during 8 weeks.

The initial bone displacement was measured by speckle interferometry. In the past, this laser measuring technique has proved valuable (feasible, accurate, and reproducible) in several other studies (Goldin *et al.*, 1980; Kleutghen *et al.*, 1982; De Clerck, 1987; De Clerck *et al.*, 1990; Govaert and Dermaut, 1997). The secondary displacement was measured by conventional radiographs and bone markers. Tracing, superimposition, and migration errors have to be taken into account using this measuring procedure. In this study, an attempt has been made to minimize the errors by using bone markers, a home-constructed cephalostat, and by taking four radiographs at each experimental time.

The initial as well as the longitudinal displacement of the maxilla of the dogs was in a forward direction with some counterclockwise rotation. The differences in maxillary displacement between the dogs can be explained by the individual skull morphology and by small differences in force direction. These results correspond with the findings of other experimental studies (Dellinger, 1973; Kambara, 1977; Nanda, 1978, 1980b; Jackson *et al.*, 1979; Nanda and Hickory, 1984; Smalley *et al.*, 1988). In a longitudinal study in primates, Nanda (1978) also found a forward and upward displacement of the maxilla. He noted a more horizontal displacement of the maxilla when the force direction was orientated more parallel to the occlusal plane. Forces passing through the centre of resistance produce a translation, whilst those passing at a distance from the centre of resistance will generate a combined translation and rotation.

The centre of resistance of the maxilla has not yet been localized experimentally. However, the force vector on the maxilla in this study was probably passing underneath the centre of resistance of the maxilla, resulting in a counterclockwise rotation of the nasomaxillary complex of the dog. The proportion of rotation in the total displacement of the maxilla is relatively small, indicating that the force vector is passing close to the centre of resistance.

A mesial movement of the maxillary teeth, fixed in the splint, was found. Anchorage on teeth for orthopaedic force application often results in undesirable dental changes. To prevent these dental side-effects, force application to osseo-integrated structures, such as dental implants on the maxilla is a preferable procedure. Since it was not the aim of this study to look for perfect anchorage, a splint was used. Therefore, skeletal displacement was only defined as the displacement of the bone markers.

According to a weighted regression analysis, the initial orthopaedic displacement did not differ significantly from the longitudinal displacement in this investigation. This longitudinal or secondary displacement of a bone structure is the biological result of remodelling after force application during a short period of time, which is comparable to the time interval between two orthopaedic consultations.

In conclusion, it can be stated that this biological response after 8 weeks of anterior force application on the maxilla can be predicted by the initial orthopaedic displacement. It has to be emphasized that the conclusions of this study cannot be transferred automatically to other force applications and further research is needed.

Address for correspondence

G. A. M. De Pauw
Department of Orthodontics
De Pintelaan 185
9000 Gent
Belgium

Acknowledgements

This study was supported by NobelBiocare. The authors wish to thank Dr H. De Bruyn, for the surgical procedures, 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. We also wish to thank Mrs B. Jouret for typing the manuscript and Mr G. Dermout for the photographic work.

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