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The effect of constant height bracket placement on marginal ridge levelling using digitized models

Carlos Suárez* and Teresa Vilar**
*Department of Orthodontics, Université de Genève, Switzerland and **Department of Odontostomatology, Universitat de Barcelona, Spain

SUMMARY Bracket placement is an important phase of orthodontic treatment. Final compensatory archwire bends or bracket repositioning may be avoided if brackets are accurately positioned at the outset, so as to correctly express their built-in prescription. The purpose of this study was to investigate the levelling of marginal ridges when a bracket placement protocol, with fixed values from the incisal edges and occlusal surfaces, was used on digitized models. A computerized tool, OrthoCAD®, was used to predict the end result using virtual set-up software. The appliances used for digital simulation were 3M MBT Victory Series 0.022 inch with a 0.019 × 0.025 inch stainless steel final archwire on 42 digitized models. A paired *t*-test was used to investigate differences between the means of the pre- (T1) and post- (T2) treatment marginal ridge heights.

The results showed that most of the marginal ridge points studied deteriorated during digitized treatment prediction compared with T1. Statistical and clinically significant changes ($P < 0.05$) were found for upper premolar and lower molar marginal ridge points. Variability in the facial contour of the teeth seemed to play an important role.

Introduction

The introduction of the straightwire appliance (Andrews, 1976a) provided new treatment possibilities for the orthodontist. Although the straightwire philosophy has a number of advantages, it also has certain limitations. Less than ideal final treatment results may occur if some of these issues are not taken into account. In-built bracket prescriptions allow the orthodontist to focus on important treatment goals rather than the time-consuming in-out, vertical, and mesio-distal considerations for each tooth. Indeed the attractiveness of the straightwire philosophy is that a fully engaged archwire should express the in-out, inclination, angulation, and rotation prescription of each bracket.

However, clinical experience shows that wire bending is still required to achieve ideal results with the straightwire system (Miethke and Melsen, 1999; Armstrong *et al.*, 2007), even with the proliferation of new prescriptions which are available (Creekmore and Kunik, 1993). Clinicians have also recommended the use of different bracket prescriptions depending on the space-closing mechanics to be used and whether or not extractions have been performed (Andrews, 1976b; Roth, 1987).

When brackets are not ideally placed, positional discrepancies may arise. The same bracket prescription can lead to variable expression if it is bonded in different positions, for example along the vertical axis (Thickett *et al.*, 2007). Such discrepancies can be addressed by replacing the bracket in its correct position or compensating the bracket placement error with a bend in the archwire. Over the years, different bracket placement protocols have been recommended for the straightwire system (Roth, 1987; Andrews, 1989; McLaughlin and Bennett, 1995) and this is still the subject of some debate.

These limitations are small compared with the overall advantages of the straightwire appliance but may be responsible for some of the treatment difficulties encountered with the straightwire approach.

Modern orthodontics has also taken advantage of the three-dimensional digitization of plaster casts (Kuroda *et al.*, 1996; Hayasaki *et al.*, 2005; Hildebrand *et al.*, 2008). With the appropriate software, the digitized model can be virtually modified in order to obtain a set-up of the case and undertake treatment planning, considering different strategies. Accurate space measurement can be undertaken by the computer in order to manage tooth alignment, levelling, rotation, tip, and torque. Software packages also allow different appliance set-ups and prediction of tooth movements. This tool allows the influence of bracket positioning on the end treatment results to be considered prior to starting treatment.

To determine the result of orthodontic treatment, different assessment methods have been proposed. Many indices have been introduced (Eismann, 1974, 1980; Berg, 1975; Gottlieb, 1975) including the Peer Assessment Rating Index (Richmond, 1990) and the American Board of Orthodontics (ABO) grading system (Afsharpanah *et al.*, 1995 Feghali *et al.*, 1996; Hassanein *et al.*, 1996). The ABO evaluation system is based on eight criteria that are individually assessed (Casko *et al.*, 1998): alignment, marginal ridge height, buccolingual inclination, occlusal relationship, occlusal contact, overjet, interproximal contact, and root angulation.

The final criterion, root angulation, is evaluated by means of a panoramic radiograph. Measurements can be carried out directly on the plaster model using special gauges, or by a computer-aided system on digitized plaster models.

The aim of the present investigation was to determine the effect of a constant vertical height bracket-bonding protocol by measuring the changes at the marginal ridge using the levelling criterion of the ABO grading system. The aim was to assess to what extent ideal levelling can be attained. For that purpose, measurements of pre-treatment (T1) values of marginal ridge heights were compared with the post-treatment (T2) values after computerized prediction.

Materials and methods

Forty-seven digitized models were randomly selected for the study (supplied by OrthoCAD© software development centre, Cadent Ltd, Or Yehuda, Israel). All models were of Caucasian patients seeking orthodontic treatment for Class I, Class II division 1, or Class II division 2 malocclusions. Five models were discarded: two due to damage and three because they did not fulfil the inclusion criteria for the present study. The OrthoCAD® software was downloaded from the official website www.orthocad.com and installed on a conventional laptop computer (Toshiba, Tokyo, Japan).

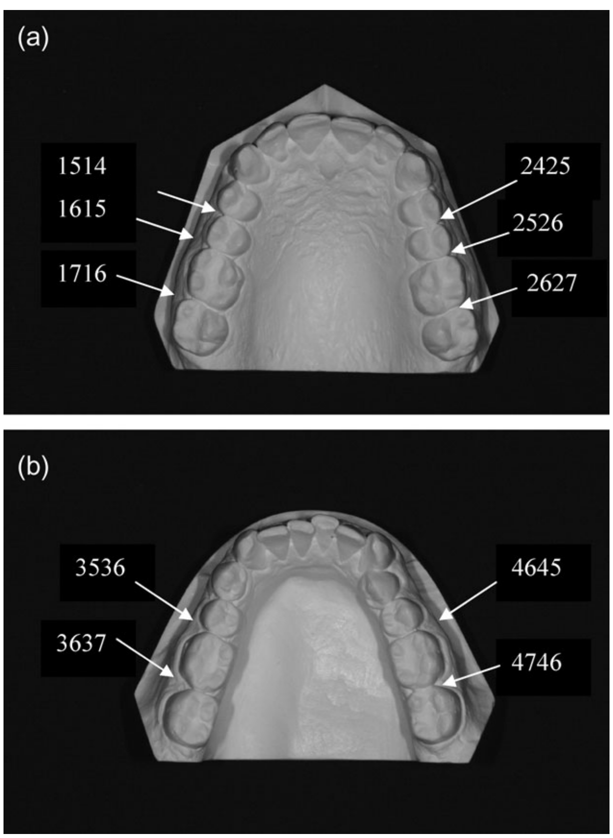

Figure 1 Points measured in the upper (a) and lower (b) arch.

Virtual set-ups were created for all models in order to perform marginal ridge levelling. Marginal ridge heights were measured according to the ABO (2008) criterion with the ABO software tool. Differences were measured digitally in millimetres.

All points (Figures 1 and 2) were identified by the same author (CS). These show the interproximal points as described by the ABO grading system and also how the height was measured. The points are described according to the interproximal point to which they refer using the Federation Dentaire Internationale nomenclature. For example, the interproximal point between the upper right premolars was labelled as 1514 and the interproximal point between the upper left first molar and second premolar as 2526. The digital model was rotated in three dimensions in order to identify the correct marginal ridge points. Given that bracket placement should be performed exactly as a one-off task, no error study was undertaken.

The set-up models were treated virtually with MBT Victory Series 0.022 inch brackets (3M Unitek Dental Products, Monrovia, California, USA). Brackets were placed as recommended by McLaughlin *et al.* (2001), measuring from the incisal or occlusal edges of the upper (U) and lower (L) teeth in millimetres: $U_7 = 2.0$, $U_6 = 3.0$, $U_5 = 4.0$, $U_4 = 4.5$, $U_3 = 5.0$, $U_2 = 4.5$, $U_1 = 5.0$, $L_7 = 2.5$, $L_6 = 2.5$, $L_5 = 3.5$, $L_4 = 4.0$, $L_3 = 4.5$, $L_2 = 4.0$, and $L_1 = 4.0$. Bracket placement was carried out using the digital height window in the software, marking the exact measurement recommended in the protocol. The final archwire was 0.019 × 0.025 inch stainless steel, as recommended by the MBT philosophy and because good engagement with sufficient torque expression should be achieved with the 0.022 inch slot brackets. Marginal ridge heights were measured again on the T2 virtual set-up view in order to study the change achieved by levelling during computerized prediction.

Descriptive statistical analysis was performed in order to describe T1 and T2 measurements and to compare the changes after simulation. A paired *t*-test was used to investigate differences between the means of the T1 and T2 marginal ridge heights ($P < 0.05$).

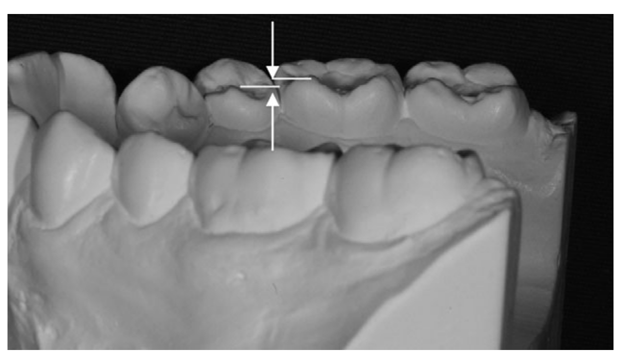

Figure 2 Marginal height difference measurement for point 4645.

Results

The mean, standard deviation, and ranges for T1 and T2 marginal ridge heights are shown in Table 1. The mean measurements increased for all points, except for 4645 and 3536 for which there was a slight decrease. According to the ABO criteria, values above 0.5 mm require correction. Therefore, values above 0.5 mm were set as clinically important and requiring correction. The means of all T2 points were above 0.5 mm at the end of simulation.

Probability plots for T1 and T2 values show that the data were normally distributed. The plot of 1716 is shown as an example in Figure 3.

Table 1 Descriptive values of marginal ridge heights at the start (T1) and following (T2) virtual treatment (mm).

Point	T1			T2		
	Mean	SD	Range	Mean	SD	Range
1716	0.67	0.65	0–2.2	0.75	0.58	0–2.1
1615	0.5	0.44	0–1.7	0.64	0.52	0–2.3
1514	0.41	0.4	0–2.4	0.63	0.45	0–2.1
2425	0.35	0.34	0–1.9	0.58	0.49	0–2.1
2526	0.48	0.44	0–1.7	0.73	0.62	0–3.5
2627	0.74	0.71	0–3.8	0.97	0.63	0–2.8
4645	0.57	0.67	0–2.9	0.51	0.36	0–1.5
3536	0.67	0.52	0–2.3	0.62	0.48	0–1.6
3637	0.5	0.49	0–2.3	0.84	0.75	0–3.7

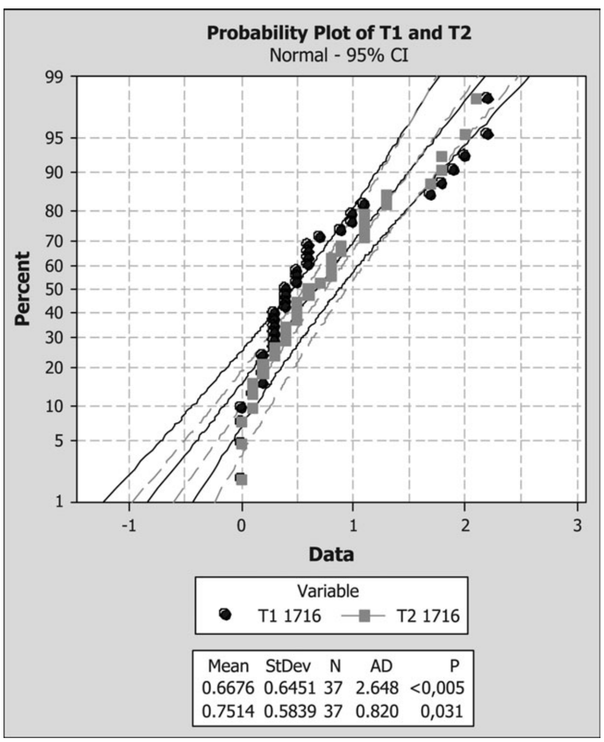

Figure 3 Probability plot for the initial (T1) and final (T2) values of point 1716 at T1 and T2.

At T1, all points except those for initial values of 1514 and 2425 had a large proportion of marginal ridge heights above the 0.5 mm limit (Figure 4). It can also be seen that all points appeared to deteriorate after simulation (T2), increasing the height values for the marginal ridge relationship.

Table 2 shows the percentages of values outside the clinically acceptable range at T1 and T2. All points, with the exception of 3536, deteriorated, with a tendency for a poorer marginal ridge relationship at T2. In the upper arch, 13.5–33.4 per cent of marginal ridges worsened compared with T1. The lower arch showed smaller values, ranging from 5.1 to 24.3 per cent of the marginal ridge points. There was an improvement in marginal ridge values for 3536 as shown by the negative difference. In all, 2.6 per cent of ridges that were initially above the 0.5 mm limit became clinically acceptable resulting in values below 0.5 mm. Statistically significant differences ($P < 0.05$) were found for 1514, 2425, 4746, and 3637 (Table 3), for which the changes showed a deterioration.

The marginal ridge points were allocated to one of three categories: improved, no change, and worsened (Figure 5). Marginal ridges deteriorated between 41 and 71.4 per cent

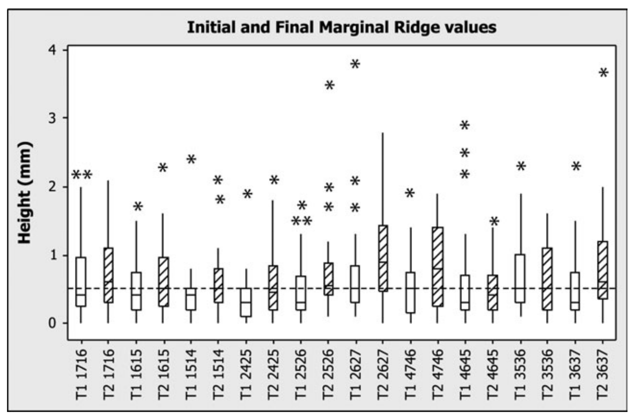

Figure 4 Changes in the descriptive statistics of marginal ridges from the start (T1) to following (T2) virtual treatment.

Table 2 Percentage of points with a marginal ridge relationship greater than 0.5 mm at the start (T1) and following (T2) virtual treatment.

Point	T1	T2	Change
1716	40.5	54	13.5
1615	29.7	45.9	16.2
1514	20	48.5	28.5
2425	11	44.4	33.4
2526	30.5	50	19.5
2627	42.8	68.5	25.7
4647	48.6	62.1	13.5
4645	30.7	35.8	5.1
3536	48.7	46.1	−2.6
3637	35.1	59.1	24.3

Table 3 Statistically significant changes from the start (T1) to following (T2) virtual treatment.

Point	*P* value
1716	0.571
1615	0.077
1514	0.033*
2425	0.039*
2526	0.078
2627	0.159
4647	0.017*
4645	0.611
3536	0.62
3637	0.019*

*$P < 0.05$.

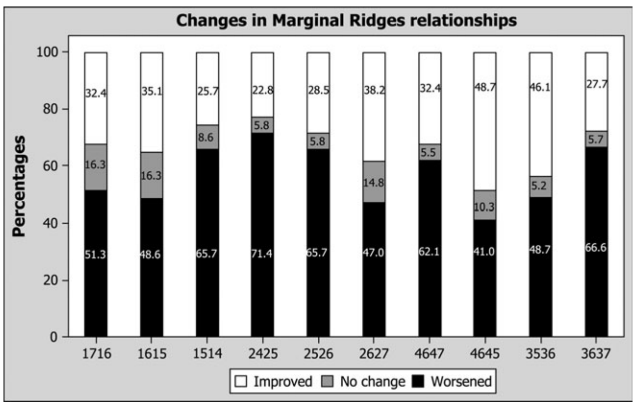

Figure 5 Changes in marginal ridge points (values in %).

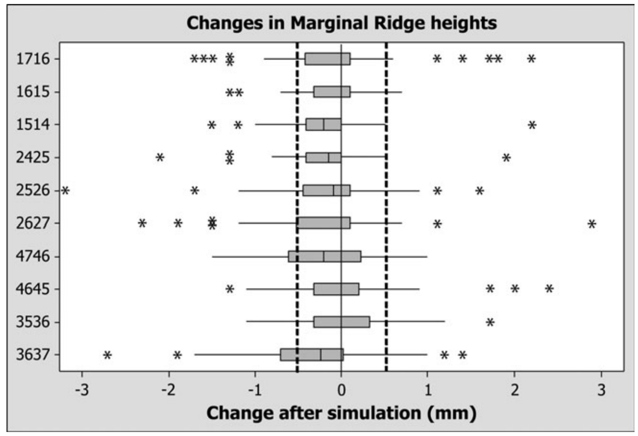

Figure 6 Changes in marginal ridges heights (values in mm).

of cases and improved in 22.8–48.7 per cent. Greater improvements in marginal ridge values were recorded for 4645 and 3536, at 48.7 and 46.1 per cent, respectively. The marginal ridge heights remained unaltered in 5.2–16.3 per cent of all cases.

Figure 6 illustrates the change in marginal ridge heights which occurred during simulation. A negative value implies a worsening in the marginal ridges, while a positive value implies that the relationship improved. The majority of values were negative. Changes appeared to be in equilibrium for 3536 and 4645. The differences which occurred as a result of treatment simulation remained under the threshold of 0.5 mm for all marginal ridges (1716, 1615, 1514, 2425, 2526, 2627, 4746, 4645, 3536, and 3637).

Discussion

The results of the present study show a tendency for marginal ridge values to deteriorate after levelling using computer prediction, when brackets are positioned at fixed heights from the incisal or occlusal edges.

Correction of marginal ridges following the protocol used in the present study is far from ideal. The clinician may be able to accept that marginal ridge relationships remain unaltered, but it is more difficult to accept that marginal ridges may deteriorate. The results show that brackets placed according to the fixed vertical position lead to poorer marginal ridge relationships compared with T1 for between 5.1 and 33.4 per cent of cases (Table 2).

All brackets were placed at fixed vertical positions measured from the incisal or occlusal reference. This does not take into account two important factors: the total length of the clinical crown and the convexity in the vertical and horizontal axes of the tooth. These two factors are likely to be responsible for the different expression of the bracket prescriptions. Therefore, no matter what vertical height bracket placement protocol is used, the same problem will arise if the reference is taken from the incisal or occlusal edge.

It should be noted that, in the upper arch, the points that initially showed the best marginal ridge relationship (1514 and 2425, Table 2) experienced the greatest deterioration compared with the other points. It should also be noted that although changes are clearly seen when the clinical limit of 0.5 mm is set, the statistical analysis of the means at T1 and T2 showed statistically significant changes ($P < 0.05$) only for 1514, 2425, 4746, and 3637 (Table 3). These findings are in agreement with the ABO experience for points 4647 and 3637. The ABO state that the most difficult points to obtain a good marginal ridge post-treatment are 1716, 2627, 4647, and 3637 (ABO, 2008).

An important uncontrolled factor that should be considered is anatomical variability. The findings of studies on facial contour variation have reported large intra-individual variations in tooth morphology and this may explain the findings of the present study (Germane *et al.*, 1989; Miethke and Melsen, 1999). Germane *et al.* (1989) found that facial surface contours were not consistent among teeth of the same type. Standard deviations in a sample of 600 maxillary and mandibular teeth ranged from ±2.6 to ±6.4 degree for the points studied. Those authors also noted that variability in facio-lingual contours increased progressively between teeth from anterior to posterior in both the upper and lower arches. This is in agreement with ABO (2008) results regarding difficulties in achieving marginal ridge levelling interproximally for 1716, 2627, 4647, and 3637 and also, to some extent, with the results obtained in the present study. The third conclusion reached by Germane *et al.* (1989) was that vertical bracket placement errors of 1 mm were found to alter torque values by up to 10 degrees and this may also contribute to problems in marginal ridge levelling.

The straightwire philosophy and the resulting pre-adjusted appliance has been a great advance that most orthodontists acknowledge. However, pre-adjusted appliances cannot assume responsibility for nature's variability and asymmetry and appliances will never be responsible for an optimal orthodontic treatment by themselves.

A recent study (Armstrong *et al.*, 2007) focused on the accuracy of bracket placement when comparing two techniques. The authors concluded that using distances from incisal edges lead to more accurate bracket placement in the vertical dimension for the upper and lower teeth. However, they also noted that the extent of error in bracket placement, regardless of the placement technique, necessitates either bends being placed in the archwire or sometimes bracket repositioning. It is this point which was the focus of the present study. Prior to giving advice on bracket placement protocols, an initial and more fundamental question should be addressed: will all teeth move in the expected way when a bracket placement protocol is followed? The results of this study suggest that even though bracket placement errors exist, anatomical variation acts as an additional and fundamental factor whose effects will need correction by arch bending or readjustment of the bracket position. Therefore, further computerized studies may assist in finding both new bracket placement and new prescription values that, taking into account anatomical variation, will lead the pre-adjusted straightwire philosophy to come closer to the ideal occlusal outcome. Therefore, variations in facial surface contours may have affected the results obtained in this study, but this fact should be proven.

Both the validity and the reliability of the software used in this study have been investigated previously. According to Zilberman *et al.* (2003), the accuracy of OrthoCAD is clinically acceptable and Santoro *et al.* (2003) also concluded that differences were sufficiently small to be considered clinically acceptable. A study by Costalos *et al.* (2005) concluded that measurements which were undertaken on study models were not significantly different between plaster and digital models.

In contrast with these studies, Okunami *et al.* (2007) found significant differences between measurements taken on plaster and digital models for some of the variables they measured, but they did not find significant differences when comparing alignment and marginal ridge heights (which are similar to the variables measured in the current study). Hildebrand *et al.* (2008) also noted statistically significant differences for alignment, occlusal contact, and overjet measurements but not for marginal ridge height measurements, which again suggests that measurement of this variable with OrthoCAD is reliable when compared with plaster models.

Although the present study was based on a computerized treatment planning tool, it has some advantages over 'real-life' studies in that inter- and intra-operator variability are minimized as the position of the brackets is performed automatically by the software.

The marginal ridge parameter was chosen for the present study because it is clearly related to the vertical bracket position, although other parameters are also corrected during treatment. It is well known that the occlusion has to be adjusted towards the end of treatment and marginal ridge compensations and corrections may take place for instance using elastics. This is beyond the scope of the present study, but it should be borne in mind.

Conclusions

The clinically relevant difference for marginal ridge heights was set at 0.5 mm, in accordance with ABO standards. Points 1514, 2425, 4746, and 3637 showed both statistically significant and clinically relevant deterioration in marginal ridge relationships.

Vertical placement bracket protocols which ignore individual labial crown convexities and crown lengths may introduce an initial bracket placement error which may lead to poor marginal ridge levelling at the end of treatment.

Computerized simulations adjusting bracket heights to perfect marginal ridge relationships are possible with this type of software and may lead to new height bracket placement protocols in the future.

Address for correspondence

Dr Carlos Suárez
Université de Genève
Faculté de Medecine
Section de Médecine Dentaire (Division d'Orthodontie)
Rue Barthélemy-Menn 19
1205 Genève
Switzerland
E-mail: carlos.suarez@medecine.unige.ch

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