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A randomized clinical trial of thermoplastic retainer wear

E. Thickett and S. Power
Department of Orthodontics, Royal Bournemouth Hospital, Dorset, UK

SUMMARY The purpose of this study was to determine whether thermoplastic retainers need to be worn full-time for a limited period or whether part-time wear from the outset is adequate to maintain tooth position, arch form, and occlusion. This study was a randomized clinical trail, conducted in a district general hospital. Sixty-two participants were enrolled in the study. Group 1, full-time wear, consisted of 30 patients (12 males and 18 females, aged 13.6 ± 1.5 years) and group 2, part-time wear, 32 patients (14 males and 18 females, aged 13.8 ± 1.5 years).

Each patient was assigned to one of the groups by random number generation. Clinical records in the form of study models were taken at the start of active treatment (T1), at debond (T2), 6 months into the retention phase (T3), and 1 year post-debond (T4). The irregularity index, intercanine width, intermolar width, arch length, overbite, overjet, and Peer Assessment Rating (PAR) scores were measured on study models using digital callipers. A Mann–Whitney test was used to evaluate the treatment changes within each group.

The only statistically significant difference was found to be at T3 and T4 for overbite ($P = 0.05$ and $P = 0.02$, respectively). PAR scoring showed more variable changes in group 2. There was good correlation for the measurement method. There was no statistical difference for the two groups for overjet, arch length, intermolar width, intercanine width, and irregularity index at any time point.

Introduction

Relapse has been defined as a return of teeth to their original position or a shift in arch relationship at the end of treatment. The aetiology of relapse is multifactorial and can be divided into three main areas: physiological recovery, unfavourable growth, or 'true relapse' due to the placement of the teeth in an unstable position.

Relapse is also subject to individual variation. Reitan (1967) showed that the periodontal ligament takes 232 days to reorganize and can derotate teeth after 1 year. The periodontal ligament requires 3–4 months' masticatory stimulation for the organization of its fibres. In addition, research has shown that alveolar bone is laid down after 1 month and supracrestal fibres require 1 year to remodel. Several measures have been suggested in order to minimize relapse (Table 1).

Many articles have been published concerning the reasons for relapse, such as one type of retainer versus another, but there is very little evidence for an appropriate retention regimen. Littlewood *et al*. (2006) stated that there was an urgent need for randomized controlled trials to determine appropriate retention regimens for clinical practice. Destang and Kerr (2003) investigated maxillary retention with the use of Hawley retainers. They determined that a regimen of 1 year of 6 months full-time and 6 months of night-time only wear was clinically beneficial.

Ponitz (1971) described an alternative to the traditional removable retainer—the clear thermoplastic retainer. This type of retainer is durable, aesthetic, easy to clean, and approximately one-third less expensive than a conventional Hawley device (Hichens *et al.*, 2007), although the durability has been questioned by some authors. As there has been an increase in the use of thermoplastic retainers in current orthodontic practice, it would be helpful to have evidence to support the regimen of wear required for optimum stabilization of the teeth with thermoplastic retainers.

The aim of this study was thus to determine whether thermoplastic retainers need to be worn full-time or whether part-time wear is adequate to maintain tooth position, arch form, and occlusion. The null hypothesis tested was that there is no difference in the control of tooth position, arch form, and occlusion between full- and part-time thermoplastic retainer wear following fixed appliance therapy.

Subjects and methods

Ethical approval for the study was sought and granted from the East Dorset Local Research Ethics Committee (Ref no. 05/Q2201/76). The participants and parents (as appropriate) were invited to take part in the study after their recall from the treatment waiting list in preparation for active orthodontic therapy. After discussion, only those willing to provide fully informed consent were included.

Sixty-two participants were enrolled in the study. Group 1 (full-time) comprised 30 patients (12 males and 18 females, mean age 13.6 ± 1.5 years) and group 2 (part-time) 32 patients (14 males and 18 females, mean age 13.8 ± 1.5 years).

Clinical records in the form of study models were obtained at the start of active treatment (T1), at debond

(T2), 6 months into the retention phase of treatment (T3), and 1 year post-debond (T4). The retention regimen is shown in Table 2.

The sample size was determined to allow the study a statistical power of 0.988 to detect a 2 mm difference in lower incisor position at the significance level of $P = 0.05$. Each patient was assigned to one of the groups by random number generation. The majority of participants had either a Class I or a mild Class II division 1 incisor relationship with crowding (Class I, 29; Class II division 1, 29; Class II division 2, two; Class III, two, with a uniform distribution between groups 1 and 2).

Patient selection

The inclusion criteria for patient entry into the study were a malocclusion requiring the extraction of all first premolars and no previous orthodontic treatment. The exclusion criteria were patients requiring fixed retention, functional appliance treatment, extra oral orthopaedic force, craniofacial anomalies, or orthognathic surgery.

Treatment protocol

The treatment procedure was as follows:

1. All participants were treated by the same operator (SP).
2. All first premolars were extracted approximately 1–2 weeks prior to fitting of the appliances.
3. Upper and lower fixed appliances using Dyna Lock pre-adjusted edgewise brackets (3M Unitek, Loughborough, Leicestershire, UK) from the non-extraction series (Andrews' values for tip and torque using a 0.022 inch slot).
4. All retainers were made using Essix B material (GAC International, Bohemia, New York, USA) to a similar design, fabricated by the same laboratory and fitted on the same day as the fixed appliances were removed. The fit of the retainers was checked at each visit.

The following measurements were made by one author (ET) on the study models using digital callipers (Digimatic, Mitutoyo, Andover, Hampshire, UK) accurate to 0.001.

Irregularity index: the summed labiolingual displacement of the five linear distances from one anatomical contact point to the adjacent contact point of the anterior teeth (Little, 1975; Figure 1).

Intercanine width: the distance between the cusp tip points of the right and the left canines (Figure 2).

Intermolar width: the distance between the distolingual cusp tips of the right and the left first permanent molars. The estimated cusp tips were used in cases of excessive wear (Figure 2).

Arch length: a point measured midway between the incisal edges of the central incisors, bisecting the line connecting the mesial marginal ridges of the right and the left permanent molars (Figure 2).

Overbite: the mean overlap of the maxillary to the mandibular central incisors.

Overjet: the distance parallel to the occlusal plane from the incisal edge of the most labial maxillary central incisor to the most labial mandibular central incisor.

Peer Assessment Rating (PAR) score.

Table 1 The different measures that can be undertaken to minimize relapse.

	Action	Author
Arch form	Maintain existing arch form	Felton *et al.* (1987)
Intercanine width	Maintain intercanine width	Little *et al.* (1988)
Antero-posterior position of the lower labial segment	Maintain antero-posterior position of the lower labial segment	Mills (1968)
Rotations	Correct early on and consider circumferential fiberotomy before debond	Reitan (1967); Edwards (1988)
Interproximal contact	Interdental stripping for triangular lower incisors to increase contact	Peck and Peck (1972)
Growth	Active retention of skeletal change throughout growth	Nanda and Nanda (1992)
Midline diastema	Fraenectomy prior to debond	Edwards (1988)
Edge centroid	Correct to maintain incisor relationship	Houston (1989)
Control of upper incisor	Upper incisors under control of lower lip	Proffit (1978)

Table 2 Retention regimens.

Group	0–3 months post-debond	3–6 months post-debond	6–9 months post-debond	9–12-months post-debond
1	Full-time wear	Part-time wear (10 h/day)	Alternate nights	1–2 times per week
2	Part-time wear (10 h/day)	Part-time wear (10 h/day)	Alternate nights	1–2 times per week

Statistical analysis

All statistical analyses were performed using the Minitab statistical package (version 14, Minitab, Coventry, Warwickshire, UK) and masked to group membership. A Mann–Whitney test was used to evaluate the treatment changes within each group.

Error of the method

The error of method was calculated to determine the reproducibility and reliability of the study cast measurements. All study models were remeasured by the same examiner at three different times, 3 weeks apart, for two of the interventions, overbite and lower intercanine width. Intraclass correlation was calculated using StatsDirect (Altrincham, Cheshire, UK, v.2.6.2).

Results

Group characteristics

Patients in the two groups were matched for age at T1 (group 1: full-time wear, mean age 13.6 ± 1.5 years and group 2: part-time wear, mean age 13.8 ± 1.5 years). Treatment time was similar at T2–T1 (group 1, 17.1 ± 2.5 months and group 2, 17.1 ± 2.3 months). There was a similar gender distribution between the two groups.

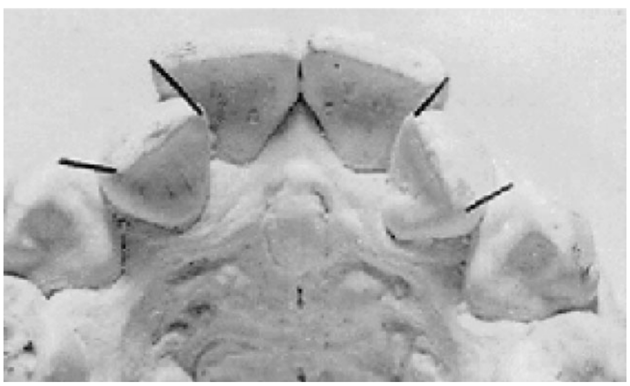

Figure 1 Measurement of the irregularity index by adding the sum of all the contact point displacements.

Intraclass correlation

The interventions repeated on three occasions showed good correlation (overbite group 1 = 0.995 and group 2 = 0.996; lower intercanine width group 1 = 0.981 and group 2 = 0.977).

As the data were not normally distributed, non-parametric statistical tests were used. Friedman tests revealed that there was a statistically significant difference for all categories measured when compared at all time points (Table 3).

In order to determine whether there was a difference between groups 1 and 2 for each time period, Mann–Whitney tests were carried out. The only significant difference was at T3 and T4 for overbite ($P = 0.05$ and $P = 0.02$, respectively; Table 3; Figure 3).

PAR score

Figure 4 illustrates the changes in PAR scores at T2 and T4. The most significant changes were found in group 2. There was no statistical difference between the groups.

Discussion

The number of subjects who failed to finish the study was small (group 1, $n = 5$ and group 2, $n = 3$), although the initial sizes of the groups were also relatively small.

As expected, there were general trends for the measurements to decrease significantly between T1 and T2 as a result of treatment.

Irregularity index

There was no statistical difference between full- or part-time wear at any time point, although the degree of irregularity was seen to increase by T4, albeit not significantly. Rowland *et al.*

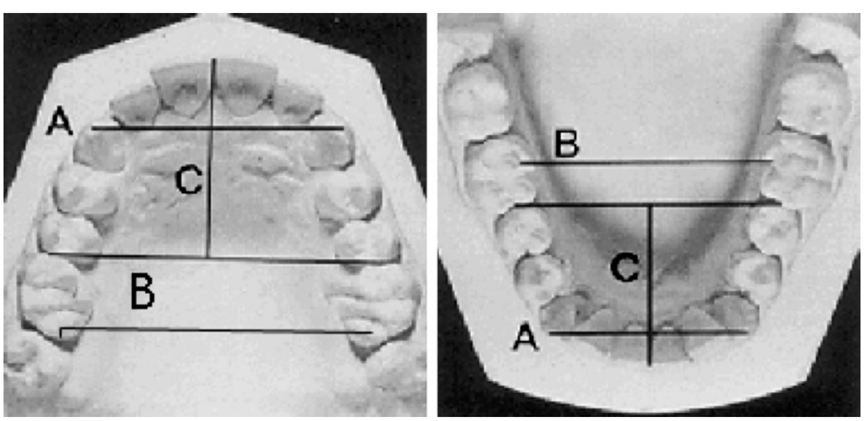

Figure 2 Measurements of intercanine and intermolar width and arch length. A, intercanine width; B, intermolar width; and C, arch length.

Table 3 The medians for full- (group 1) and part-time (group 2) wear and the *P* value at the start of active treatment (T1), at debond (T2), 6 months into retention phase (T3), and 1 year post-debond (T4).

Mann–Whitney test—Medians

	T1			T2			T3			T4		
	Group 2	Group 1	*P* value	Group 2	Group 1	*P* value	Group 2	Group 1	*P* value	Group 2	Group 1	*P* value
Total lower incisor crowding	9.31	8.72	0.48	0.14	0.04	0.46	0.29	0.15	0.08	0.89	0.71	0.5
Total upper incisor crowding	12.12	14.92	0.06	0.14	0.21	0.14	0.46	0.35	0.67	1.09	1.08	0.8
Lower interncaine width	26.1	26.56	1	27.07	27.24	0.22	26.75	27.43	0.31	26.47	27.07	0.65
Lower intermolar width	36.93	38.45	0.92	33.32	34.09	0.52	33.82	33.67	0.69	33.6	34.35	0.61
Lower arch length	26.05	25.88	0.43	21.02	21.1	0.44	19.88	20.57	0.14	20.14	21.28	0.06
Upper intercnanine width	33.92	34.76	0.95	34.79	35.49	0.08	34.79	34.95	0.34	34.56	34.93	0.52
Upper intermolar width	41.92	42.23	0.88	39.57	40.23	0.35	39.72	39.93	0.62	39.39	40.34	0.68
Upper arch length	31.09	30.29	0.73	24.19	24.98	0.22	24	24.57	0.4	25.15	25.07	0.97
Overjet	3.9	4.13	0.76	2.36	2.54	0.6	2.68	2.32	0.55	2.39	2.76	0.37
Overbite	4.26	4.26	0.68	3.31	2.86	0.14	3.73	2.96	0.02*	3.74	3.14	0.05*

*$P < 0.05$.

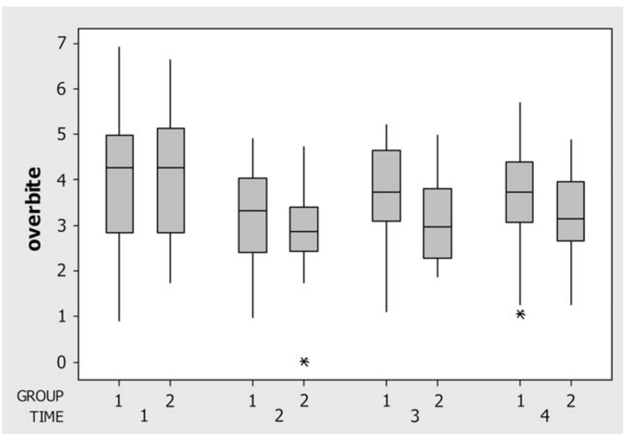

Figure 3 Boxplot showing the variation for overbite for group 1 (full-time) and group 2 (part-time) at the start of active treatment (T1), at debond (T2), 6 months into retention (T3), and 1 year post-debond (T4).

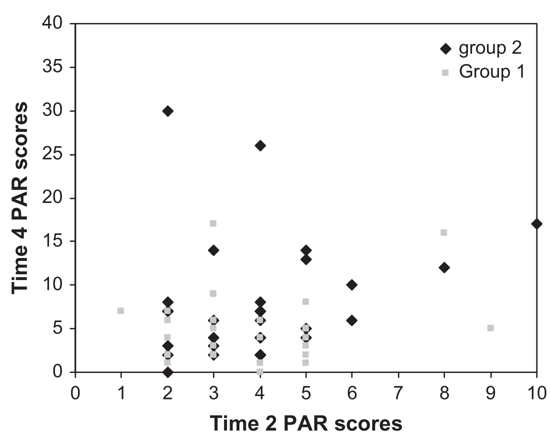

Figure 4 Peer Assessment Rating (PAR) scores for T2 (end of active treatment) and T4 (1 year into retention) for full- (group 1) and part-time (group 2) wear.

(2007) found when comparing Hawley and vacuum-formed retainers that the only statistical difference was for irregularity of the incisors. This was not the case in this present study.

Intercanine and intermolar width

The widths were generally well maintained and no statistically significant differences were observed at any time interval between the two groups; therefore, the arch relationships were maintained during both active treatment and retention.

Arch length

As a consequence of extractions, arch length was reduced in both groups. During retention, there was no significant difference between the two groups. Therefore, it can be concluded that the retention regimens were equally effective in maintaining arch length, although by T4 the decrease in arch length was approaching significance ($P = 0.06$).

Overbite

There was a significant difference in the increase in overbite between the two groups both at T3 and T4 ($P = 0.02$ and $P = 0.05$, respectively), with group 2 showing an increase in overbite (Figure 3). This may reflect more rapid settling in this group. Gill *et al.* (2007) also found no significant change in the irregularity index, overjet, intercanine width, or intermolar width between debonding and 6 months into retention. However, contrary to the current findings, they found no statistical difference for overbite.

Overjet

There was no significant difference between the two groups in overjet at any time point.

PAR score

There was an increase in PAR score for group 1 between T2 and T4 when compared with group 2 (Figure 4). The differences were related to overjet and growth changes rather than an increase in the irregularity index when the outliers were analysed for both groups.

Conclusions

The following conclusions can be made:

1. There was good correlation for the measurement method.
2. There was no statistical difference for the two groups for overjet, arch length, intermolar width, intercanine width, and irregularity index for each time period.
3. There was a statistical difference at T3 and T4 for overbite between groups 1 and 2.

There is no real difference in retention of tooth irregularity whether thermoplastic retainers are worn on a full- or part-time basis. The finding that there was a statistically significant increase in overbite between the two groups at T3 and T4 may not be clinically significant as the difference was 0.6 mm. It is therefore suggested that part-time wear can be advised for patients who have undergone fixed appliances in conjunction with extractions.

Address for correspondence

E. Thickett
Department of Orthodontics
Royal Bournemouth Hospital
Castle Lane East
Bournemouth
Dorset BH7 7DW
UK
E-mail: eleanor.thickett@rbch.nhs.uk

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Effects of thermoplastic retainers on occlusal contacts

Müfide Dinçer and Belma Işık Aslan
Department of Orthodontics, Faculty of Dentistry, Gazi University, Ankara, Turkey

SUMMARY The aim of this prospective study was to evaluate the number of contacts in centric occlusion during retention with thermoplastic retainers (Essix retainers) and in the long term. After four premolar extractions and active orthodontic treatment of 15 Class I (10 females, 5 males; mean age 17.20 ± 1.7 years), thermoplastic retainers were used. Occlusal contacts were determined from occlusal registrations taken in centric occlusion at the beginning (T0), end (9 months of retention; T1), and after 2.5 years (T2). The occlusal contacts determined in these patients were compared with the values of 15 'normal' Class I subjects (9 females, 6 males; mean age 17.10 ± 1.60 years) who had not undergone orthodontic treatment. Wilcoxon and a Mann–Whitney *U*-tests were used to evaluate intra- and intergroup differences.

No significant change was observed in the number of posterior contacts during T1, whereas a significant increase was found at T2 ($P < 0.01$) for the second premolars ($P < 0.01$) and second molars ($P < 0.05$). Both 'ideal' and 'non-ideal' contacts increased significantly but only at T2 ($P < 0.05$). The number of ideally located contacts on the posterior teeth at all three periods were lower than normal values ($P < 0.01$); while non-ideal contacts at T1 ($P < 0.05$) and T2 ($P < 0.01$) were found more often when compared with the values of normal subjects. Only the increased number of premolar contacts at T2 was more than normal values ($P < 0.01$). There was no expected increase in occlusal contacts at T2; however, posterior occlusal contacts were increased at T3.

Introduction

Tooth alignment, aesthetics, and function achieved by active orthodontic treatment are kept stable by retention appliances following active treatment. The goal of retention is to achieve occlusal stability. One of the most important factors in occlusal stability is the existence of occlusal contacts (centric stops) that take place on functional cusps. Both increases in the number of occlusal contacts and 'ideally located' contacts are important for occlusal stability. Whereas maximizing tooth contacts in centric occlusion minimizes the stresses distributed on the teeth, ideally located centric contacts cause vertically directed forces parallel to the long axes of the teeth (Dawson, 1989). It has been suggested that good occlusal contacts and intercuspation may be the keys to a stable orthodontic result (Nanda and Nanda, 1992; Storey, 1993).

The length of the retention period is important to prevent relapse and to provide stability of treatment. The ideal retention device should allow settling while ensuring a safety margin and reducing the tendency toward relapse.

Clear thermoplastic appliances have been recommended for use as transitional retainers, finishing appliances (McNamara *et al.*, 1985), and even permanent retention (Sheridan *et al.*, 1993). They are easy to fabricate, inexpensive, aesthetic, and comfortable and thus have a high level of patient acceptance (Sheridan *et al.*, 1992). The major disadvantages are their tendency to open the bite and their low durability (Sheridan *et al.*, 1993).

There are various studies in the literature reporting changes in the occlusion and especially increases in the number of occlusal contacts after orthodontic treatment with the use of conventional retention devices, tooth positioners, or fixed retainers (Durbin and Sadowsky 1986; Haydar *et al.*, 1992; Dinçer *et al.*, 2003; Başçiftçi *et al.*, 2007). In recent years, the use of thermoplastic retainers has increased yet there are no studies evaluating occlusal contact changes with thermoplastic retention appliances. The aim of this study was to determine the changes in occlusal contacts in centric occlusion during retention with full covarage thermoplastic appliances (Essix retainers) and in the long term.

Subjects and method

Fifteen Class I patients (5 males, 10 females; mean age 17.20 ± 1.7 years) treated with first premolar extractions and straightwire mechanics at the Department of Orthodontics, Gazi University, and 15 individuals (6 males, 9 females; mean age 17.10 ± 1.60 years) with a 'normal' occlusion who had not undergone treatment were included in the study.

Final selection of the sample was based upon the following criteria:

1. Patients who had full fixed banded and/or bonded orthodontic appliance treatment (at least 18 months) with or without auxiliary appliances treated to an optimum occlusion with the treatment objectives satisfied.
2. Patient availability for long-term follow-up recording.

The normal values of the untreated Class I sample were compared with the number of occlusal contacts in the treated group at the end of active orthodontic treatment (T0), at the end of the 9 month retention period (T1), and in the long term (T2), that is after 2.5 years. The normal values were obtained from dental students with Class I occlusions, all teeth present except third molars, no history of orthodontic or prosthodontic treatment, and no symptoms of temporomandibular joint disorders.

The treated patients received upper and lower full coverage Essix retainers as retention appliances with instructions to wear them full-time except during meals for 6 months and then at night only for the next 3 months. The retainers were formed from the action of heat from 0.75 mm (0.030 inches) copolyester Essix sheets (Dentsply Raintree Essix, New Orleans, Louisiana, USA) which is thermoformed to a thickness of 0.015 inches. The retainers were equilibrated and placed on the same day the fixed appliances were removed. The retainers extended to the second molars.

Occlusal records were taken using a method similar to that described by Razdolsky *et al.* (1989) The records included alginate impressions for study models to evaluate the occlusal contacts. Bite registration records were taken with a soft silicon-based impression material. (Zetaplus, Zhermack, Badia Polesine, Italy) The occlusal records were determined from treated patients at T0, T1, and T2. Occlusal records of the untreated normal sample were obtained once in centric occlusion when identified as appropriate for the study. The subjects were seated upright in a dental chair and the registration material was applied over the occlusal surfaces of the mandibular teeth. The patient was instructed to bite firmly in maximum intercuspation (centric occlusion). A second bite registration was made within 15 minutes to test reproducibility. If a subjective difference in the pattern of the contacts was observed, a further registration was obtained.

The interocclusal registration was viewed by holding it to the light box; perforations in the interocclusal registrations that let through light and very thin transparent sections without perforations were recorded as contacts.

The posterior contacts on the premolars and the molars were determined on the lower study models. The location of ideal posterior contacts were evaluated according to the method of Ramfjord and Ash (1971; Figure 1). Contacts on the cusp-marginal ridges and within 1 mm of that area were identified as 'ideally located contacts', while those in other areas were identified as 'non-ideal contacts'. First premolar contact areas were not taken into consideration in the untreated normal sample as these teeth had been extracted in the study group. All registrations were undertaken evaluated, and measured by the same orthodontist (BIA).

A Wilcoxon test was used to statistically evaluate the differences between T0, T1, and T2. Differences between the treated group and untreated normal sample were determined by the Mann–Whitney *U*-test.

The records of 10 patients at T0 were randomly selected to determine the method error. For each of the 10 patients, two similar occlusal registrations that were obtained at the clinical examination were used. There were no statistically significant differences ($P > 0.05$) in the mean number of contacts recorded using the two sets of registrations as determined by Wilcoxon test (Table 1).

Results

Table 2 shows the descriptive statistics and the significance of the differences between T0, T1, and T2 for the treated and untreated groups. Neither the posterior contacts nor the ideally located or non-ideal contacts showed a significant difference at T1.

No significant change was observed in the number of posterior tooth contacts at T1 whereas a significant increase was found at T2. An increase in posterior contacts was funded on the second premolar and second molar teeth. The

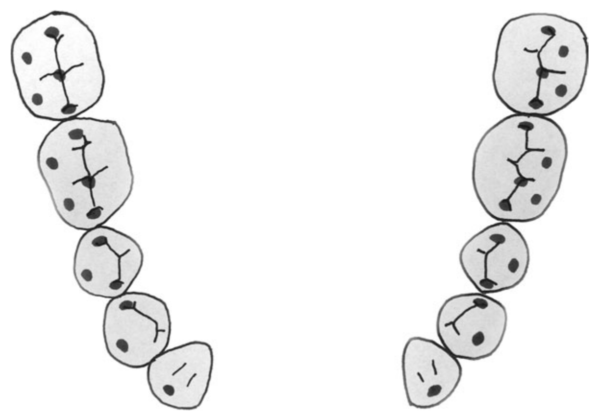

Figure 1 Location of 'ideally located contacts' modified from Ramfjord and Ash (1971).

Table 1 Descriptive statistics of two registrations of the study group at the beginning of retention and the main differences between the two registrations.

	Registration	$X \pm$ standard deviation	P
Posterior	1	21.70 ± 1.06	0.66
	2	21.60 ± 0.52	
Ideally located	1	10.80 ± 1.14	0.34
	2	10.70 ± 1.16	
Non-ideal	1	11.10 ± 0.74	0.16
	2	10.90 ± 0.88	
Premolar	1	4.90 ± 0.74	0.16
	2	4.70 ± 0.68	
First molar	1	8.40 ± 0.70	0.16
	2	8.60 ± 0.76	
Second molar	1	8.30 ± 0.68	1.00
	2	8.30 ± 0.68	

Table 2 Descriptive statistics and significant differences before (T0), after retention (T1), and 2.5 years after treatment (T2) and main differences between the normal (N) untreated sample and the study group.

	Group		Centric occlusion							
			X	Standard deviation	*P*			*P*		
					T0–T1	T1–T2	T0–T2	T0–N	T1–N	T2–N
Posterior	Study	T0	21.80	1.92	NS	**	*			
		T1	22.13	1.78						
		T2	27.67	1.86						
	Normal		23.00	1.53				NS	NS	NS
Ideal location	Study	T0	10.67	0.40	NS	*	*			
		T1	10.47	0.62						
		T2	12.00	0.92						
	Normal		15.73	1.01				**	**	**
Not ideal location	Study	T0	11.13	1.76	NS	*	*			
		T1	11.67	1.63						
		T2	15.67	1.51						
	Normal		7.27	1.18				NS	*	**
Premolar	Study	T0	4.93	0.47	NS	**	**			
		T1	5.13	0.65						
		T2	7.40	0.58						
	Normal		5.07	0.46				NS	NS	**
First molar	Study	T0	8.60	0.91	NS	NS	NS			
		T1	8.67	0.83						
		T2	10.27	0.83						
	Normal		8.47	0.69				NS	NS	NS
Second molar	Study	T0	8.20	0.91	NS	*	*			
		T1	8.33	0.91						
		T2	10.00	1.00						
	Normal		9.40	0.85				NS	NS	NS

*$P < 0.05$, **$P < 0.01$; NS, not-significant.

increase in ideally located and non-ideal contacts was found to be significant at T2 when compared with T0 and T1.

While the number of ideally located contacts on the posterior teeth at all three time points was lower when compared with normal values, non-ideal contacts at T1 and T2 were found more often when compared with normal values. Only the increased number of premolar contacts at T2 was more than the normal values.

Table 3 shows the changes in distribution and characteristics of posterior contacts in centric occlusion during T0–T1, T1–T2, and T0–T2. Ideally located contacts on the premolars increased significantly at T2 compared with T1, whereas non-ideal contacts on the premolars increased significantly at T2 compared with T0 and T1.

Discussion

Evaluation of occlusal contacts, which may be the most important predictor of occlusal stability, would help to explain any future relapse. Various studies have evaluated occlusal contact changes with conventional retainers; yet there is no research concerning occlusal contacts when Essix retainers are used. Therefore, in this study, the aim was to analyze occlusal contact changes in centric occlusion during the retention period in which full coverage thermoplastic appliances were used and also following long-term retention.

Clear thermoplastic appliances are aesthetic and comfortable and thus patient cooperation is better than with other retainers (Sheridan *et al.*, 1992). Therefore, these retainers are commonly used. An Essix retainer is thinner and stronger than other designs, but since it covers only the six anterior teeth, it still has a slight tendency to open the bite (Sheridan *et al.*, 1993). Wang (1997) advised that in extraction cases, thermoplastic retainers should be extended to the mesiobuccal grooves of the first molars. A full coverage, clear plastic type that can be worn full time is also preferable (Sheridan *et al.*, 1992). Consequently, in this study, full coverage Essix retainers ending at the second molars were used where extractions had been carried out.

There are different opinions concerning the retention schedule of these retainers. Sheridan *et al.* (1993) prescribed full-time wear of mandibular retainers and half-time wear of maxillary retainers for the first 4 weeks and both retainers only at night thereafter. Wang (1997) preferred the maxillary retainer to be worn all day and the mandibular retainer only at night for 2 months and then both retainers for 2 years or, if possible, indefinitely. In a recent study, Gill *et al.* (2007)

Table 3 Distribution of contacts on posterior teeth in centric occlusion in the study group at the beginning (T0), end of retention (T1), and in the long term (T2).

		Centric occlusion				
		X	Standard deviation	*P*		
				T0–T1	T1–T2	T0–T2
Premolar ideal location	T0	2.53	0.24	NS	*	NS
	T1	2.20	0.22			
	T2	2.93	0.35			
Premolar not ideal location	T0	2.40	0.47	NS	**	**
	T1	2.93	0.58			
	T2	4.47	0.54			
First molar ideal location	T0	4.00	0.24	NS	NS	NS
	T1	4.27	0.30			
	T2	4.60	0.31			
First molar not ideal location	T0	4.60	0.79	NS	NS	NS
	T1	4.40	0.76			
	T2	5.67	0.71			
Second molar ideal location	T0	4.13	0.32	NS	NS	NS
	T1	4.00	0.27			
	T2	4.40	0.41			
Second molar not ideal location	T0	4.13	0.81	NS	NS	NS
	T1	4.33	0.86			
	T2	5.60	0.86			

$^*P < 0.05$, $^{**}P < 0.01$; NS, non-significant.

compared part- and full-time Essix-type retainer wear with respect to dental alignment and occlusal changes. The retainers were either worn full time for 6 months or only at night. They concluded that night-time-only Essix retainer wear may be an acceptable retention regimen following the use of fixed appliances. In the present study, the patients were instructed to wear the retainers full time for 6 months and then at night for 3 months.

When upper and lower plastic appliances are worn simultaneously, because of the double thickness of plastic between the terminal molars (Sheridan *et al.*, 2001), the appliances in the present study were equilibrated to avoid any semblance of an efficient centric occlusion.

The total average number of posterior contacts was 22.13 at T1 and increased to 27.67 at T2. Posterior contacts did not increase significantly during T0–T1. This could be due to construction of the Essix retainers which covered the occlusal surfaces of the teeth. The significant increase at T2 was a consequence of the removal of the Essix retainers. This result shows the continued mobility of teeth even after 9 months of retention.

Retainers should be designed to eliminate occlusal interferences and to allow for continuing vertical settling (Alexander, 1993) Long-term studies have shown that a variety of occlusal changes occur after the active phase of orthodontic treatment. These changes may take place shortly after the removal of the active appliances, during the period of post-treatment 'settling', or over a period of years (Shapiro, 1974; Little *et al.*, 1981; Sadowsky and Sakols, 1982; Uhde *et al.*, 1983). It was also reported by Razdolsky *et al.* (1989) that relative vertical movements can continue up to 21 months after orthodontic therapy. If thermoplastic retainers are used, canine-to-canine Essix retainers, as introduced by Sheridan *et al.* (1993) or any other modification, can be designed to allow vertical settling.

McNamara and Henry (1971) reported a mean increase of posterior contacts from 17.4 to 19.7 at the end of a 1 year retention period, whereas Gazit and Lieberman (1985) found a mean increase of 11.2 to 17.4. In the study of Haydar *et al.* (1992), there was a slight increase in the number of contacts in the Hawley group to 22.40 and in the positioner group to 27.00 at the end of 3 months' retention. Dinçer *et al.* (2003) found a significant increase in posterior contacts from 11.45 to 19 with Hawley retainers after 9 months of retention. Sauget *et al.* (1997) also found a statistically significant increase in the number of total contacts after 3 months of retention with Hawley retainers. After a 3 month retention phase with conventional retainers, Durbin and Sadowsky (1986) found a 16 per cent increase in the number of posterior contacts. Razdolsky *et al.* (1989) counted a mean number of 36.6 contacts at the end of treatment and 58.2 contacts after 21 months. Başçiftçi *et al.* (2007) also found a slight increase with modified wrap-around Hawley retainers and Jensen plates with mandibular fixed retainers after a retention period of one year.

There were no differences in the number of posterior contacts in centric occlusion at any time point when compared with normal values. When distribution of contacts on posterior teeth were evaluated, the contacts on the second premolar and second molars increased significantly. Contrary to the present findings, Sultana *et al.* (2002) found no changes in the premolar regions and stated that no change in the premolar region after active treatment should be expected; they found a larger increase in the molar region, especially at the second molar after 1 year of retention.

In the present study, the number of ideally located contacts was less than normal values at T0, T1, and T2; however, the number of non-ideal contacts was greater than normal values at T1 and T2. Both the number of ideal and non-ideal contacts increased only at T2. Non-ideal contacts increased more than ideally located contacts. This may be the result of settling not being established by retainer guidance. Evaluation of the distribution of posterior contacts showed that the number of ideal and non-ideal contacts increased only for the second premolar teeth at T2. Dinçer *et al.* (2003) found that the number of ideal contacts significantly increased for all posterior teeth and non-ideal contacts significantly increased at the first and second molars at the end of retention.

An increased number of ideal contacts is important because the construction of ideal posterior occlusal guidance results in distributing the occlusal forces on the maximum number of inclined planes during interdigitation and provides maximum periodontal support (Alhgren and Posselt, 1968). An increase in the number of non-ideal contacts also suggests that settling should be carried out during the last phase of active treatment rather than in the retention period (Razdolsky *et al.*, 1989).

Conclusion

The expected increase of occlusal contacts was not observed at the end of the retention period with Essix thermoplastic retainers as these cover the occlusal surfaces of teeth. Both ideal and non-ideal posterior contacts increased in the long term while the number of non-ideal contacts was more than the ideal contacts.

Address for correspondence

Professor Müfide Dinçer
Faculty of Dentistry
Department of Orthodontics
Gazi University
Emek 06510
Ankara
Turkey
E-mail: mufidedincer@yahoo.com

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Maxillary expansion in the mixed dentition: rapid or semi-rapid?

Sabri Ilhan Ramoglu* and Zafer Sari**
Departments of Orthodontics, Faculties of Dentistry, *Erciyes University, Kayseri and **Selçuk University, Konya, Turkey

SUMMARY The purpose of this study was to investigate the effects of rapid maxillary expansion (RME) and semi-rapid maxillary expansion (SRME) in the mixed dentition period. The SRME group consisted of 18 patients (11 girls and 7 boys) with a mean age of 8.63 ± 1.09 years and the RME group 17 patients (11 girls and 6 boys) with a mean age of 8.78 ± 1.21 years. A splint type tooth- and tissue-borne modified bonded RME appliance was used, with the patients activating the screw two-quarter turns per day for the first week, followed by one-quarter turn every other day in the SRME group and two-quarter turns per day throughout treatment in the RME group. The average treatment time was 57.16 ± 21.52 and 21.23 ± 8.36 days for the SRME and RME groups, respectively. A Wilcoxon signed rank test was used to evaluate the treatment effects [pre-(T_0) – post-(T_1) treatment changes] for both the SRME and RME groups and a Mann–Whitney *U*-test to determine the differences between the two groups (T_0–T_1 changes SRME versus T_0–T_1 changes RME).

For both groups, the maxillary base, nasal cavity width and upper intercanine and intermolar distances were increased, and the upper molars tipped buccally. The only statistically significant ($P < 0.05$) difference between two groups was in inferior movement of posterior nasal spine (PNS) relative to the SN plane (SN⊥PNS). This measurement increased in both groups yet significantly more in the RME group. The results suggest that RME and SRME have similar effects on dentofacial structures both in the transverse, vertical, and sagittal planes.

Introduction

A crossbite is one of the most common transverse malocclusions in the posterior region of the dental arch (Ferrario *et al.*, 2003). The incidence of a posterior crossbite has been reported to be between 2.7 and 18.2 per cent in different populations (Kutin and Hawes, 1969; Thilander *et al.*, 1984; Da Silva Filho *et al.*, 1991; Sandikçioğlu and Hazar, 1997; Başçiftçi *et al.*, 2002; Tausche *et al.*, 2004). This entity may occur in the primary dentition and manifest itself as a constriction of the lateral dimension of the upper arch (Da Silva Filho *et al.*, 1991).

Different methods have been used to expand constricted maxillary arches. When evaluated on the basis of frequency of the activations, magnitude of the applied force, duration of the treatment, and patient age, different mechanics produce rapid, semi-rapid, or slow expansion (Sandikçioğlu and Hazar, 1997; Usumez and Uzel, 2008).

In rapid maxillary expansion (RME) protocols, a twice-daily activation schedule, which is most commonly proposed in the literature, was shown to produce residual loads during early treatment (Zimring and Isaacson, 1965). Işeri *et al.* (1998) reported that RME not only produced an expansion force at the intermaxillary suture but also caused high forces on various structures in the craniofacial complex. The retention of RME depends not only on bone formation in the intermaxillary suture but also on the creation of a stable relationship at the articulations of the maxilla and other bones of the facial skeleton (Isaacson and Ingram, 1964; Zimring and Isaacson, 1965). Therefore, relatively slower expansion is recommended to produce less tissue resistance in the nasomaxillary structures (Işeri *et al.*, 1998).

Both Geran *et al.* (2006) and Sari *et al.* (2003) used a regimen of one activation per day in young patients and reported success with this protocol. However, Sari *et al.* (2003) stated that this regimen is not superior to the classic regimen of two-quarter turns per day and suggested evaluation of slower rhythms for RME in the mixed dentition. Işeri *et al.* (1998) suggested a slow expansion protocol immediately after the separation of the intermaxillary suture by RME in order to produce less tissue resistance. İşeri and Özsoy (2004) used semi-rapid maxillary expansion (SRME) which is different to the SRME protocol described by Mew (1977, 1983, 1997). Mew (1983) and Sandikçioğlu and Hazar (1997) used an activation rhythm of 1 mm per week whereas İşeri and Özsoy (2004) used a schedule of 2 × 0.2 mm per day for the first 5–6 days and 3 × 0.2 mm per week for the rest of the expansion in older adolescents and adults.

While the effects of RME on adolescents and young adults are well documented, there is limited information on the outcome of SRME in mixed dentition subjects. Therefore, the purpose of this study was to evaluate the short-term effects of SRME on the vertical, sagittal, and transverse planes in mixed dentition patients.

Subjects and methods

The sample comprised 35 Caucasian patients, 22 girls and 13 boys who applied to Department of Orthodontics of Selçuk University for orthodontic treatment. The inclusion criteria dictated no sagittal skeletal problem, either a functional unilateral or bilateral posterior crossbite with transverse deficiency, the first permanent molars erupted and no more than one missing maxillary tooth in the right and left sides of the dentition. All parents signed an informed consent form.

The subjects were randomly divided into two groups of SRME and RME. The SRME group consisted of 18 patients, 11 girls and 7 boys, with a mean age of 8.63 ± 1.09 years and the RME group 17 patients, 11 girls and 6 boys, with a mean age of 8.78 ± 1.21 years.

Appliance and activation

A splint type tooth- and tissue-borne modified bonded RME appliance (Basciftci and Karaman, 2002; Basciftci *et al.*, 2002; Orhan *et al.*, 2003; Sari *et al.*, 2003; Usumez *et al.*, 2003) was used for both groups (Figure 1). The activation of the screw was two-quarter turns per day for the first week followed by one-quarter turn per day every other day for the SRME group. The mean treatment time was 57.16 ± 21.52 days. In the RME group, the schedule was two-quarter turns per day throughout treatment, and the mean treatment time was 21.23 ± 8.36 days.

Midpalatal suture opening was confirmed at the end of the first week on occlusal radiographs. Screw activation was ended when approximately 2 mm of overcorrection was achieved, and the screw was fixed by a ligature wire. The appliance was used as a fixed retainer for 14 days and then debonded. At the same appointment, a removable appliance was fabricated for retention.

Records and measurements

Lateral and frontal cephalometric radiographs and dental casts were taken before (T_0) and after (T_1) expansion. In order to determine the changes in molar inclination on frontal cephalometric radiographs, acrylic caps, which had partially embedded 0.7 mm thick and 10 mm long stainless steel wire positioned perpendicular to the occlusal surface, were individually constructed. The wire of the left cap was bent along on the edge to facilitate recognition of the left and right sides (Figure 2). The onlays were temporarily cemented with polycarboxylate luting cement on the first upper molars before exposure of the frontal cephalometric radiographs. The same caps were used for both the T_0 and T_1 records.

A total of 25 measurements, 18 on the lateral and three on frontal cephalometric radiographs, and four on dental casts, were assessed by one author (SIR). Lateral and frontal

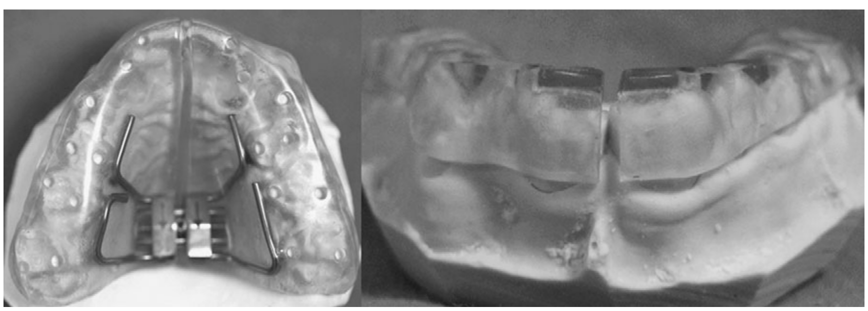

Figure 1 Modified acrylic bonded rapid maxillary expansion appliance.

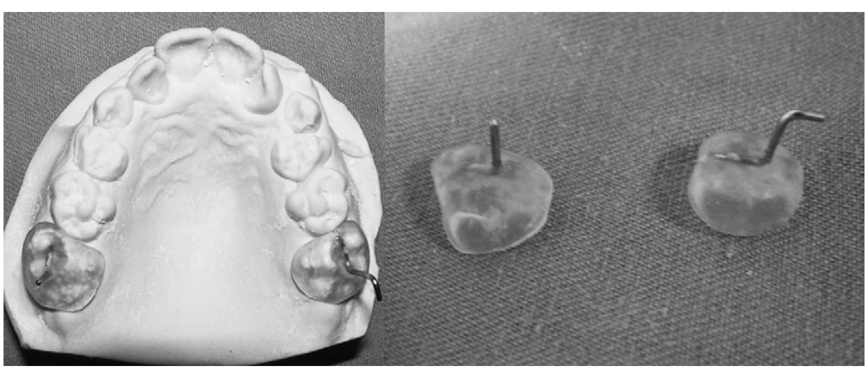

Figure 2 Acrylic caps constructed to determine buccolingual inclinations of the upper first molar.

cephalometric, and dental cast measurements are shown in Figures 3, 4 and 5, respectively.

Statistical analysis

Descriptive statistics, including the mean and standard deviation, were obtained for the data. To evaluate the T_0–T_1 changes for both the SRME and RME groups, a Wilcoxon signed-rank test and to determine the differences between the two groups (T_0–T_1 changes SRME versus T_0–T_1 changes RME), a Mann–Whitney *U*-test was used. The analyses were performed using the Statistical Package for Social Sciences (version 10.0.0, SPSS Inc., Chicago, Illinois, USA).

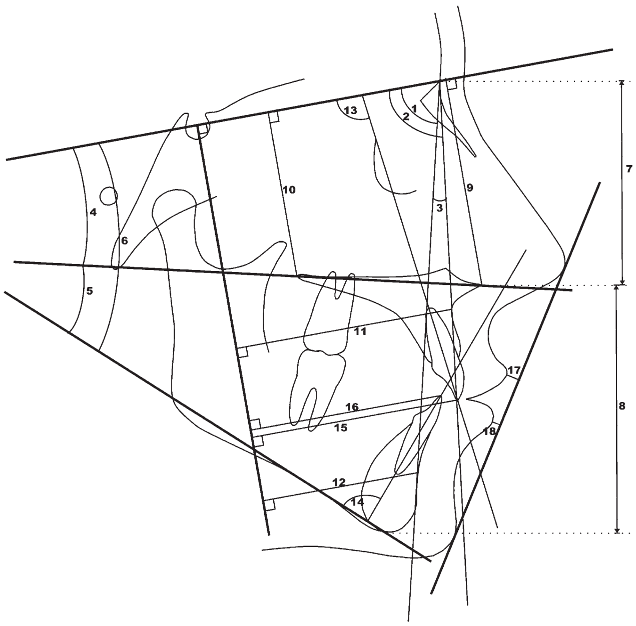

Figure 3 Lateral cephalograms—1: SNA (°), angle formed by the planes of sella-nasion and nasion-point A; 2: SNB (°), angle formed by the planes of sella-nasion and nasion-point B; 3: ANB (°), angle formed by the planes of nasion-point A and nasion-point B; 4: SN PP (°), angle formed by the sella-nasion plane and the palatal plane [anterior nasal spine (ANS)–posterior nasal spine (PNS)]; 5: MP PP (°), angle formed by the mandibular plane (gonion-menton) and the palatal plane; 6: SN^MP (°), angle formed by the sella-nasion plane and the mandibular plane; 7: N_ANS (mm), the distance between nasion and ANS; 8: ANS_Me (mm), the distance between ANS and menton; 9: SN⊥ANS (mm), the perpendicular distance of ANS to the sella-nasion plane; 10: SN⊥PNS (mm), the perpendicular distance of PNS to the sella-nasion plane; 11: SV⊥A (mm), the perpendicular distance of point A to the sella vertical plane (SV) was constructed through the sella, perpendicular to the sella-nasion plane; 12: SV⊥B (mm), the perpendicular distance of point B to the sella vertical plane constructed through the sella, perpendicular to the sella-nasion plane; 13: Isi SN (°), angle formed between the sella-nasion plane and Isi plane, a plane from the superior central incisor's incisal edge through its root; 14: Iii MP (°), angle formed between the mandibular plane and Iii plane, a plane from the inferior central incisor's incisal edge through its root; 15: SV⊥Isi (mm), the perpendicular distance of the incisal edge of superior central incisor to sella vertical plane; 16: SV⊥Iii (mm), the perpendicular distance of incisal edge of the inferior central incisor to sella vertical plane; 17: Ls_E (mm), the perpendicular distance of the most anterior point on the convexity of the superior lip to E plane that extends from the tip of the nose and the chin; 18: Li_E (mm), the perpendicular distance of the most anterior point on the convexity of the inferior lip to the E plane.

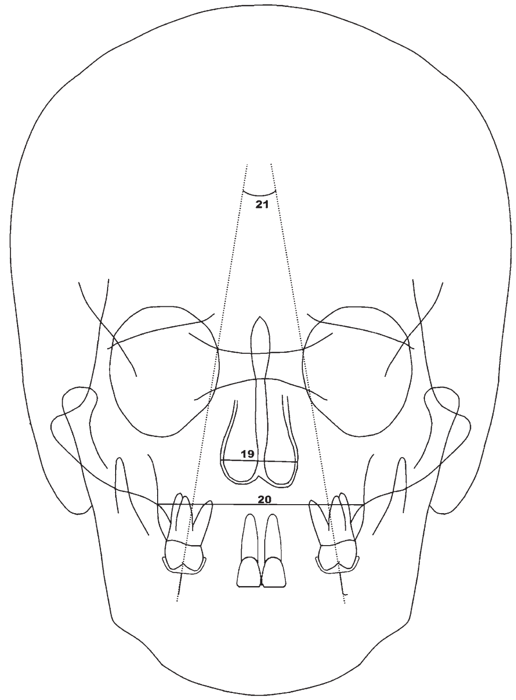

Figure 4 Frontal cephalograms—19: NC_CN (mm), nasal cavity width, the distance between left and right lateral piriform rims; 20: JL_JR (mm), maxillary skeletal width, the distance between left and right jugale points; 21: LAR LAL (°), the angle formed between the long axes of the right and left first permanent molars.

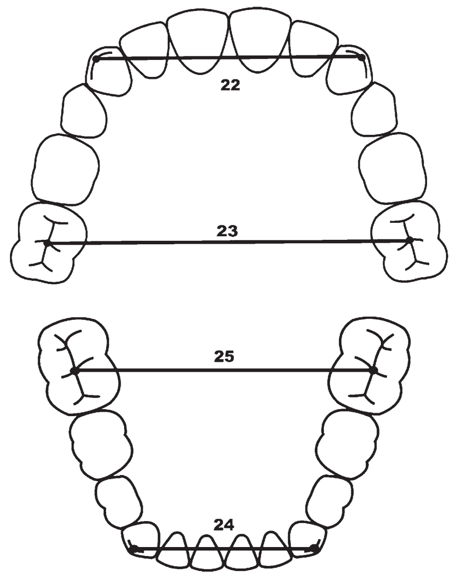

Figure 5 Dental casts—22: UC_UC (mm), the width between the upper canines; 23: UM_UM (mm), the width between the upper first molars; 24: LC_LC (mm), the width between the lower canines; 25: LM_LM (mm), the width between the lower first molars.

Method error

Approximately 1 month after the first measurements, 10 records from each group were randomly selected and remeasured by the same author. Intra-examiner measurement error was calculated with Dahlberg's formula ($\sqrt{\Sigma d^2/2n}$). The smallest measurement error was 0.11 mm for lower molar width and the largest 1.38 degrees at the lower incisor plane and mandibular plane angle.

Results

Treatment changes in the SRME group

In the SRME group, statistically significant increases were found in SNA, IiiP^MP, and MP^PP angles, SN⊥PNS distance ($P<0.05$), ANB angle, NC_CN, and LC_LC distances ($P<0.01$), LAR^LAL angle, JL_JR, upper canine (UC_UC), and upper molar (UM_UM) distances ($P<0.001$; Table 1).

Treatment changes in the RME group

In the RME group, statistically significant increases were found in ANS_Me distance ($P<0.05$), SN^MP and MP^PP angles, SN⊥PNS and LC_LC distances ($P<0.01$), LAR^LAL angle, NC_CN, JL_JR, UC_UC, and UM_UM distances ($P<0.001$), whereas a decrease was noted in SV⊥B distance ($P<0.05$; Table 2).

Comparison of the two groups

The only statistically significant difference between the two groups was in the amount of inferior movement of posterior nasal spine (PNS) point relative to the SN plane; SN⊥PNS distance showed a greater increase in the RME than in the SRME group ($P<0.05$; Table 3).

Discussion

To determine any possible alterations in the position of the maxilla in the sagittal plane, SV⊥A and SNA measurements were considered. A statistically significant increase of 0.55 degrees was found in SNA at the end of treatment in the SRME group ($P<0.05$). This finding was confirmed by the increase in ANB ($P<0.01$). Whereas SNB and SV⊥B showed no significant difference, the increase in SNA was related to anterior movement of point A. On the other hand, SNA remained stable in the RME group. It has been observed in previous studies (Sandikçioğlu and

Table 1 Changes with treatment in the semi-rapid maxillary expansion group ($n = 18$).

Variables	Pre-treatment		Post-treatment		Test	
	Mean	SD	Mean	SD	*P*-value	Significance
Lateral cephalogram						
1 SNA (°)	76.97	2.45	77.52	2.32	0.039	*
2 SNB (°)	74.22	3.14	74.19	3.17	0.776	NS
3 ANB (°)	2.75	1.88	3.33	1.63	0.009	**
4 SN^PP (°)	8.72	2.53	8.14	2.06	0.081	NS
5 MP^PP (°)	30.75	5.42	31.44	5.95	0.045	*
6 SN^MP (°)	39.47	5.51	39.61	6.19	0.537	NS
7 N_ANS (mm)	48.56	2.54	49.06	2.58	0.405	NS
8 ANS_Me (mm)	63.33	4.39	64.00	4.22	0.143	NS
9 SN⊥ANS (mm)	49.06	2.26	49.33	2.56	0.156	NS
10 SN⊥PNS (mm)	42.00	2.74	42.56	2.54	0.019	*
11 SV⊥A (mm)	55.86	4.12	55.69	4.15	0.605	NS
12 SV⊥B (mm)	42.36	6.93	42.19	6.85	0.470	NS
13 IsiP^SN (°)	100.36	7.56	100.44	7.32	0.887	NS
14 IiiP^MP (°)	90.08	7.43	91.42	6.78	0.017	*
15 SV⊥Isi (mm)	54.00	6.23	54.56	5.86	0.299	
16 SV⊥Iii (mm)	51.53	5.75	51.69	5.61	0.793	NS
17 Ls_E (mm)	2.33	2.61	2.22	2.09	0.954	NS
18 Li_E (mm)	0.58	2.66	0.33	2.70	0.412	NS
Frontal cephalogram						
19 NC_CN (mm)	28.86	3.07	30.56	2.37	0.001	**
20 JL_JR (mm)	62.89	2.60	64.81	2.68	0.000	***
21 LAR^LAL (°)	16.03	10.13	26.61	12.28	0.000	***
Dental casts						
22 UC_UC (mm)	29.22	3.47	34.36	4.07	0.000	***
23 UM_UM (mm)	42.76	4.33	48.47	4.07	0.000	***
24 LC_LC (mm)	27.51	4.81	27.91	4.91	0.009	**
25 LM_LM (mm)	43.45	4.74	43.43	4.68	0.795	NS

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

Table 2 Changes with treatment in the rapid maxillary expansion group ($n = 17$).

Variables	Pre-treatment		Post-treatment		Test	
	Mean	SD	Mean	SD	*P*-value	Significance
Lateral cephalogram						
1 SNA (°)	77.64	3.30	78.02	4.04	0.342	NS
2 SNB (°)	75.24	3.64	75.00	3.81	0.359	NS
3 ANB (°)	2.41	2.52	3.03	3.00	0.089	NS
4 SN^PP (°)	9.50	3.09	9.41	3.76	0.535	NS
5 MP^PP (°)	30.59	4.60	32.26	4.92	0.001	**
6 SN^MP (°)	40.08	6.00	41.67	5.59	0.003	**
7 N_ANS (mm)	49.29	3.94	49.56	4.72	0.588	NS
8 ANS_Me (mm)	62.38	3.47	63.67	4.00	0.038	*
9 SN⊥ANS (mm)	49.85	3.31	50.50	3.98	0.096	NS
10 SN⊥PNS (mm)	41.82	2.87	42.97	3.26	0.001	**
11 SV⊥A (mm)	53.82	3.48	53.79	4.60	0.804	NS
12 SV⊥B (mm)	41.41	6.81	40.09	7.39	0.034	*
13 IsiP^SN (°)	99.88	8.97	99.65	8.91	0.924	NS
14 IiiP^MP (°)	88.68	5.41	88.56	5.60	0.668	NS
15 SV⊥Isi (mm)	52.32	4.94	52.24	5.66	0.525	NS
16 SV⊥Iii (mm)	50.53	4.61	49.97	5.27	0.111	NS
17 Ls_E (mm)	2.82	2.65	2.24	2.93	0.109	NS
18 Li_E (mm)	0.50	2.33	0.06	2.12	0.179	NS
Frontal cephalogram						
19 NC_CN (mm)	29.21	2.31	30.88	2.74	0.000	***
20 JL_JR (mm)	62.26	3.89	64.71	4.02	0.000	***
21 LAR^LAL (°)	10.47	8.65	19.82	7.98	0.000	****
Dental casts						
22 UC_UC (mm)	27.72	2.65	32.50	2.46	0.000	***
23 UM_UM (mm)	42.03	4.18	47.14	4.31	0.000	***
24 LC_LC (mm)	25.89	2.36	26.27	2.25	0.001	**
25 LM_LM (mm)	38.76	3.37	38.89	3.47	0.075	NS

*$P < 0.05$; **$P < 0.001$; ***$P < 0.001$; NS, not significant.

Hazar, 1997; Akkaya *et al.*, 1999; Basciftci and Karaman, 2002; Sari *et al.*, 2003; Chung and Font, 2004) that SNA increases at the end of treatment. Chung and Font (2004) reported a statistically significant increase in SNA of 0.35 degrees but concluded that it may not be clinically significant. Da Silva Filho *et al.* (1991) also reported a similar increase in SNA of 0.50 degrees, which was insignificant in their study.

Another parameter used to determine anterior movement of the maxilla in the present study was SV⊥A, which did not show significant changes for either of the groups. This finding is similar to the results of Da Silva Filho *et al.* (1991) and Reed *et al.* (1999), whereas some authors (Sarver and Johnston 1989; Asanza *et al.*, 1997; Basciftci and Karaman, 2002; Sari *et al.*, 2003) reported movements of point A relative to the SV plane. In the present sample, point A moved forward in seven patients and backward in eight but did not move in three in the SRME group. In the RME group, it moved forward in five patients and backward in eight but did not move in four. Similar findings were also found for SNA. When the two groups were compared, no significant differences were observed for SV⊥A and SNA. Thus, RME and SRME have similar effects on the maxilla in the sagittal plane. However, individually the maxilla might show different movement characteristics.

In the SRME group, MP PP and SN⊥PNS showed a statistically significant increase ($P < 0.05$). An increase in SN⊥PNS measurement means inferior movement of PNS. SN⊥ANS remained stable, which can be described as a counter clockwise rotation of the palatal plane and may be a reason for the increase in MP^PP angle. As ANS_Me, SV⊥B, and SNB were stable, it may be concluded that this alteration did not affect the vertical and sagittal position of the mandible; the changes occurred only at the level of PNS. The same measurement, SN⊥PNS, showed a statistically significant increase in the RME group ($P < 0.01$) as well as SN^MP, MP^PP ($P < 0.01$), and ANS_Me ($P < 0.05$). A statistically significant decrease was also determined for SV⊥B ($P < 0.05$). These alterations of SN MP, MP PP, ANS_Me, and SV⊥B indicate inferior and posterior movement of the mandible in the RME group. However, when the two groups were compared, the only statistically significant difference was found for SN⊥PNS ($P < 0.05$), which indicates more inferior movement of PNS in the RME group. This data were supported by the increase

Table 3 Comparison of change with treatment in the semi-rapid maxillary expansion (SRME) versus the rapid maxillary expansion (RME) group.

Variables	SRME group (*n* = 18)		RME group (*n* = 17)		Test	
	Mean	SD	Mean	SD	*P*-value	Significance
Lateral cephalogram						
1 SNA (°)	0.56	1.02	0.38	1.77	0.987	NS
2 SNB (°)	−0.02	1.32	−0.23	1.48	0.665	NS
3 ANB (°)	0.58	0.75	0.61	1.42	0.814	NS
4 SN^PP (°)	−0.58	1.26	−0.08	1.93	0.739	NS
5 MP^PP (°)	0.69	1.76	1.67	1.53	0.135	NS
6 SN^MP (°)	0.14	2.08	1.59	1.72	0.057	NS
7 N_ANS (mm)	0.50	1.91	0.26	2.15	0.691	NS
8 ANS_Me (mm)	0.66	1.82	1.29	2.12	0.371	NS
9 SN┴ANS (mm)	0.28	1.15	0.65	1.54	0.414	NS
10 SN┴PNS (mm)	0.56	0.87	1.15	0.82	0.037	*
11 SV┴A (mm)	−0.17	1.33	−0.03	1.61	0.947	NS
12 SV┴B (mm)	−0.33	2.61	−1.32	2.33	0.313	NS
13 IsiP^SN (°)	0.08	2.70	−0.24	2.79	0.842	NS
14 IiiP^MP (°)	1.33	1.91	−0.12	2.40	0.842	NS
15 SV┴Isi (mm)	0.55	2.16	−0.02	1.30	0.506	NS
16 SV┴Iii (mm)	0.17	2.33	−0.56	1.42	0.506	NS
17 Ls_E (mm)	−0.11	1.68	−0.58	1.34	0.265	NS
18 Li_E (mm)	−0.25	1.25	−0.44	1.37	0.617	NS
Frontal cephalogram						
19 NC_CN (mm)	1.69	1.56	1.68	1.01	0.611	NS
20 JL_JR (mm)	1.92	1.11	2.38	1.44	0.378	NS
21 LAR^LAL (°)	10.61	6.08	9.35	3.91	0.644	NS
Dental casts						
22 UC_UC (mm)	5.13	1.47	4.77	1.53	0.621	NS
23 UM_UM (mm)	5.71	1.66	5.11	1.81	0.322	NS
24 Lc_LC (mm)	0.40	0.55	0.38	0.43	0.754	NS
25 LM_LM (mm)	−0.01	0.52	0.12	0.32	0.336	NS

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

in SN^MP and ANS_Me and the decrease in SV┴B in the RME group. This alteration in lower face height has been reported by several authors (Byrum, 1971; Da Silva Filho *et al.*, 1991; Sandikçioğlu and Hazar, 1997; Sari *et al.*, 2003; Chung and Font, 2004). Despite the fact that the difference between the two groups in the amount of inferior movement of PNS was as low as 0.59 mm, which is probably clinically insignificant, it might be taken into consideration in vertically growing patients. Inferior movement of PNS may also play a role in the increase of posterior nasal space airway; however, the clinical significance of this requires further investigation.

The upper incisors showed a stable position relative to SV┴Isi and IsiP^SN for both groups. This finding is in agreement with previous studies (Asanza *et al.*, 1997; Basciftci and Karaman, 2002; Sari *et al.*, 2003; Chung and Font, 2004). In the RME group, the lower incisors were stable when considered with IiiP^MP and SV┴Iii measurements. For the SRME group, SV┴Iii did not show a statistically significant difference, whereas IiiP^MP increased 1.34 degrees ($P<0.05$). When the method error values were considered, the largest error of 1.38 degrees was found for IiiP^MP measurement. As the recorded change for this parameter was very close to the method error value, this value was not taken into consideration. Furthermore, when the groups were compared, no statistically difference was noted for the position of the lower incisors.

The soft tissue variables, Ls_E and Li_E, were stable at T_1 in both groups. Similar findings were reported by Basciftci and Karaman (2002).

It was found that nasal cavity measurement increased significantly in both the RME ($P<0.001$) and SRME ($P<0.01$) groups. This finding is in agreement with previous investigations (Haas, 1965; Özgen *et al.*, 1994; Memikoglu and Iseri, 1999; Cross and McDonald, 2000; Akkaya *et al.*, 2002; Basciftci and Karaman, 2002; Basciftci *et al.*, 2002; Sari *et al.*, 2003; Chung and Font, 2004; Doruk *et al.*, 2004; İşeri and Özsoy, 2004). No difference was found between the two groups in the amount of this increase.

Increases in JL_JR distance, measured to evaluate the amount of expansion in the maxillary base, were statistically significant in both groups ($P<0.001$). This increase was also found in several previous studies (Memikoglu and Iseri, 1999; Cross and McDonald, 2000; Basciftci and Karaman, 2002; Sari *et al.*, 2003; Chung and Font, 2004; İşeri and Özsoy, 2004). When the amounts of the increases were compared, the two groups showed similar expansion rates.

Another parameter in the transverse plane is LAR^LAL. The changes in this parameter represent the amount of molar tipping in the buccolingual direction. This tipping is a result of a combination of alveolar and molar tipping (Haas, 1961; Bishara and Staley, 1987). In the present study, tipping occurred in both groups ($P < 0.001$) in agreement with previous studies (Hicks 1978; Asanza *et al.*, 1997; Basciftci and Karaman, 2002; Sari *et al.*, 2003; Davidovitch *et al.*, 2005, Garib *et al.*, 2005; Podesser *et al.*, 2007; Rungcharassaeng *et al.*, 2007). No difference was found between the RME and SRME groups.

According to the dental cast measurements, UM_UM and UC_UC width values increased in both groups as expected after maxillary expansion ($P < 0.001$). Increases in UM_UM (Haas, 1961; Küçükkeleş and Hamid Waheed, 1995; Sandikçioğlu and Hazar, 1997; Akkaya *et al.*, 1998; Memikoglu and Iseri, 1999; Reed *et al.*, 1999; Cross and McDonald, 2000; Basciftci and Karaman, 2002; Sari *et al.*, 2003; Chung and Font, 2004; İşeri and Özsoy, 2004; Garib *et al.*, 2005) and UC_UC (Sandikçioğlu and Hazar, 1997; Akkaya *et al.*, 1998; Memikoglu and Iseri, 1999; Basciftci and Karaman, 2002; Sari *et al.*, 2003) have been reported. However, no difference was found between the two groups in the present study in the amount of expansion.

Another parameter measured on the dental casts was lower molar (LM_LM) width; no significant changes were recorded in either of the groups. This is in accordance with the findings of Basciftci and Karaman (2002), but different from many other authors (Haas, 1961; Sandstrom *et al.*, 1988; Akkaya *et al.*, 1998; İşeri and Özsoy, 2004; Lima *et al.*, 2004). Haas (1980) stated that the more inferior position of the tongue and the increased clearance of buccinator muscles from the mandibular arch, as a result of the body of the appliance and the following maxillary expansion, lead to uprighting and buccal movement of the mandibular posterior teeth. However, the results of the current investigation conflict with this described mechanism. First, although the volume of the appliance used in the current study was larger than that of the Haas appliance, no expansion was observed in the lower arch. Second, despite the duration of the expansion period and the tongue being positioned inferiorly for a longer time period in the SRME group, no difference was observed between groups. While the disocclusion effect of the acrylic cap splint does not seem to be a valid reason for mandibular arch expansion, İşeri and Özsoy (2004) and Akkaya *et al.* (1998) reported an increase in LM_LM with a similar appliance. A possible explanation for the different results among studies may be differences in the age groups. The mean ages for the RME and SRME groups were 8.78 and 8.63 years, respectively, in the current study, 14.75 years in the study of İşeri and Özsoy (2004), and 11.96 and 12.31 years in the investigation of Akkaya *et al.* (1998). McNamara (2000) and Wendling *et al.* (2005) emphasized that the lower posterior teeth might erupt more lingually due to constriction of the maxillary arch. When treatment is undertaken at later ages, lingual eruption, in other words compensation of the mandibular teeth, may increase and after expansion of the maxilla, the amount of decompensation and buccal movement of the lower posterior teeth may increase. In addition to the previously described mechanism by Haas (1980), the amount of compensation in the lower arch may be responsible for the expansion of the mandibular posterior teeth. In this study, no changes were observed in LM_LM measurement while LC_LC measurement increased significantly in both groups ($P < 0.001$). However, the LC_LC measurement may not be considered reliable due to mobility of the primary canines used in the measurement at this developmental stage.

In the RME protocol, as the activation is faster than the SRME, shorter active treatment periods and chair side time is an advantage. Another advantage may be the shorter bonded appliance wear which negatively affects the oral hygiene.

Conclusion

The results suggest that the RME and SRME have a similar effect on dentofacial structures in the transverse, vertical, and sagittal planes. Whether the amount of relapse would be less with SRME due to a decrease in residual stresses in dentofacial structures should be evaluated further.

Address for correspondence

Dr Sabri Ilhan Ramoglu
Dişhekimliği Fakültesi
Erciyes Üniversitesi
Ortodonti A.D.
Melikgazi
Kampüs
Kayseri 38039
Turkey
E-mail: ilhanramoglu@yahoo.com

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Mandibular asymmetry in cleft lip and palate patients

Gokmen Kurt*, Mehmet Bayram**, Tancan Uysal* and Mete Ozer**
Departments of Orthodontics, *Universities of Erciyes, Kayseri and **Ondokuz Mayis, Samsun, Turkey

SUMMARY The aims of this study were to evaluate condylar, ramal, and condylar plus ramal mandibular vertical asymmetry in a group of cleft lip and palate (CLP) patients and compared with subjects with a 'normal' occlusion. Mandibular asymmetry index (condylar, ramal, and condylar plus ramal) and gonial angle measurements were examined on panoramic radiographs. The study groups comprised 20 unilateral cleft lip and palate (UCLP) patients (10 males and 10 females; mean age 13.03 ± 3.33 years), 20 bilateral cleft lip and palate (BCLP) patients (10 males and 10 females; mean age 13.73 ± 3.53 years), and a control group of 20 subjects (9 males and 11 females; mean age 14.35 ± 2.46 years) with a normal occlusion. Kruskal–Wallis one-way analysis of variance was used to determine statistically significant differences between the groups for condylar, ramal, and condylar plus ramal asymmetry index measurements at the 95 per cent confidence interval.

None of the investigated groups showed statistically significant gender differences for posterior vertical height measurements ($P > 0.05$). Asymmetry indices were similar, with no statistically significant differences found in any of the groups. However, gonial angle showed statistically significant differences ($P < 0.05$) in the UCLP group and condylar height (CH) in the BCLP patients ($P < 0.001$). Except for CH measurement in the BCLP group, CLP patients have symmetrical mandibles when compared with a normal occlusion sample.

Introduction

Asymmetry of the craniofacial complex can be recognized as differences in the size or relationship of the two sides of the face. This may be the result of discrepancies either in the form of individual bones or a malposition of one or more bones in the craniofacial complex. The asymmetry may also be limited to the overlying soft tissues (Sutton, 1968; Bishara *et al.*, 1994).

Cleft lip and palate (CLP) patients generally present anterior and posterior crossbites and mid-face deficiency with a tendency towards a Class III malocclusion (Shetye and Evans, 2006). In the literature, some authors reported significant mandibular asymmetries (Smahel and Brejcha, 1983; Laspos *et al.*, 1997), while others found no differences (Ishiguro *et al.*, 1976; Horswell and Levant, 1988) in CLP patients. Laspos *et al.* (1997) observed that individuals with a unilateral cleft lip and palate (UCLP) show asymmetry of the lower facial skeleton on postero-anterior (PA) radiographs. Smahel and Brejcha (1983) studied lateral and PA radiographs of 58 UCLP (32 complete CLP and 26 incomplete clefts of the palate) individuals and noted a shorter mandibular ramus in complete UCLP patients. Ishiguro *et al.* (1976) compared the morphological craniofacial patterns of 51 UCLP, 27 bilateral cleft lip and palate (BCLP), and 62 isolated cleft palate patients using PA radiographs but found no significant cleft group differences. Horswell and Levant (1988) who compared 16 UCLP subjects with published cephalometric standards did not find any significant differences in mandibular dimensions and morphology between the two groups.

Habets *et al.* (1988) described a method for measuring the vertical condylar and ramal heights for comparing the right and left sides of the mandible for evaluating condylar and ramal asymmetry. This method has been used to determine mandibular asymmetry in patients with temporomandibular disorders (TMD; Habets *et al.*, 1987, 1988; Miller *et al.*, 1996; Miller, 1997; Saglam and Sanli, 2004), Class II (Miller and Smidt, 1996), Class III malocclusions (Miller and Bodner, 1997), bilateral posterior crossbites (Kiki *et al.*, 2007), and different skeletal patterns (Saglam, 2003; Sezgin *et al.*, 2007; Kurt *et al.*, 2008; Uysal *et al.*, 2009).

In a recent study, Kurt *et al.* (2008) evaluated condylar and ramal mandibular asymmetry in a group of patients with Class II subdivision malocclusions using the method described by Habets *et al.* (1988). They showed that, except for condylar, ramal, and condylar plus ramal height measurements, Class II subdivision patients have a symmetrical condyles when compared with subjects with a normal occlusion.

In a review of the orthodontic literature, no published study was found that compared mandibular vertical asymmetry using the method of Habets *et al.* (1988) in a group of UCLP and BCLP patients compared with a normal occlusion sample. Therefore, the aim of this study was to evaluate condylar and ramal mandibular asymmetry in a group of patients with CLP in comparison with subjects with a normal occlusion.

Subjects and methods

Three groups were selected from the archives of the Department of Orthodontics, Faculty of Dentistry, Ondokuz Mayis University. All patients had undergone surgery using the Tennison and Millard techniques for cleft lip reconstruction and the Wardill–Kilner pushback technique for surgical construction of the cleft palate. The sample size and distributions of ages in the different groups are shown in Table 1. The research protocol was approved by the Regional Research Ethics Committee of the University of Erciyes.

Normal occlusion sample

Dental pantomograms (DPTs) were taken of 20 subjects (9 males and 11 females) for surgical indications with normal occlusion meeting the following criteria (Uysal, 2003):

1. Class I canine and molar relationship with minor or no crowding, normal growth and development, and well-aligned upper and lower dental arches;
2. All teeth present except third molars;
3. Good facial symmetry determined clinically;
4. No significant medical history; and
5. No history of trauma or any previous orthodontic or prosthodontic treatment, maxillofacial, or plastic surgery.

UCLP group

The following selection criteria were used in the UCLP group (10 males and 10 females):

1. Complete unilateral cleft lip, alveolus, and palate (5 right and 15 left side);
2. No systemic disease, no developmental or acquired craniofacial, or neuromuscular deformities;
3. No significant facial asymmetry;
4. No history of orthodontic treatment; and
5. No signs or symptoms of TMD.

Table 1 Mean and standard deviations (SD) of chronological ages for each group.

Groups	Gender	*n*	Age (years) Mean	SD
Normal occlusion	Male	9	13.44	2.65
	Female	11	15.09	2.12
	Total	20	14.35	2.46
Unilateral cleft lip and palate group	Male	10	13.35	3.57
	Female	10	12.70	3.23
	Total	20	13.03	3.33
Bilateral cleft lip and palate group	Male	10	14.95	3.34
	Female	10	12.50	3.45
	Total	20	13.73	3.53

BCLP group

The last four selection criteria (2–5) for UCLP patients were also valid for this group. Twenty subjects (10 males and 10 females) with complete bilateral cleft lip, alveolus, and palate were taken as the BCLP group.

The DPTs were exposed with Planmeca Proline CC, Helsinki, Finland, and processed (Dent-X 810, Elmsford, New York, USA) which had been previously standardized. All radiographs were taken in a standard manner by the same operator. The subjects were positioned with the lips at rest and the head orientated at the Frankfort horizontal plane (Azevedo *et al.*, 2006). The outlines of the condyle, the ascending ramus, and corpus of both sides were traced on acetate paper. On the tracing paper, a line (A-line) was drawn between the most lateral points of the condylar (O_1) and of the ascending ramus (O_2) image (Figure 1). To the A-line (the ramus tangent) from the most superior point of the condylar image, a perpendicular B-line was drawn. The vertical distance from this line on the ramus tangent to O_1 projected on the ramus tangent was measured. This distance was termed condylar height (CH) and that between the O_1 and O_2 ramus height. A C-line was constructed as a tangent on the mandibular corpus of each side and the angle between the A- and C-line was measured as the gonial angle (Figure 1). To measure condylar, ramal, and condylar plus ramal asymmetry, the following formula was used:

$$\text{Asymmetry index: } \left|\frac{CH_{right} - CH_{left}}{CH_{right} + CH_{left}}\right| \times 100.$$

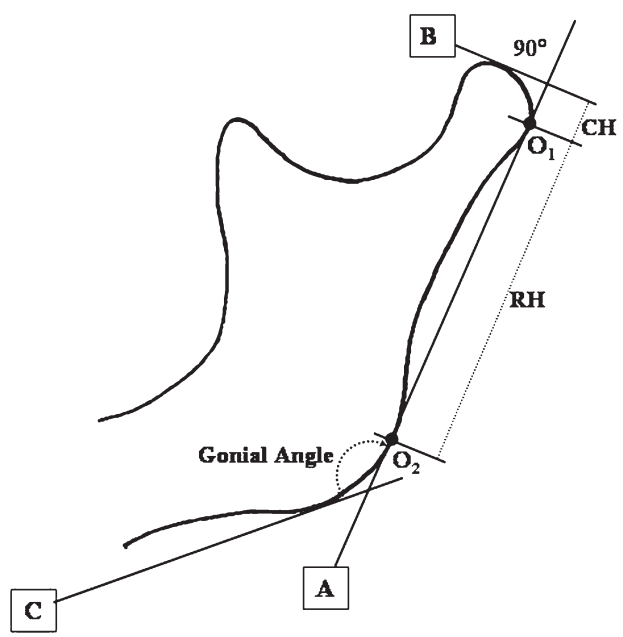

Figure 1 Measuring method according to Habets *et al.* (1988). O_1 and O_2, most lateral points of the image; A, ramus tangent; B, perpendicular line from A to the most superior part of the condylar image; C, corpus tangent; CH, condylar height; and RH, ramus height.

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences for Windows, version 10.1 (SPSS Inc., Chicago, Illinois, USA). Descriptive statistics were computed. The Kruskal–Wallis one-way analysis of variance was used to determine statistically significant differences between the groups for condylar, ramal, and condylar plus ramal asymmetry index measurements at a significance level of $P < 0.05$. A Mann–Whitney *U*-test was used to determine statistically significant differences between genders and sides for condylar, ramal, and condylar plus ramal height measurements.

A power analysis indicated that, a sample size of 60 subjects was required [20 normal occlusion, 9 male and 11 female (power: 68%); 20 unilateral, 10 male and 10 female (power: 72%); and 20 bilateral, 10 male and 10 female (power: 0.70%); CLP group].

Four weeks after the first measurements, 20 randomly selected DPTs were re-measured by the same author. A paired samples *t*-test was applied to the measurements. The difference between the first and second measurements of the 20 radiographs was insignificant. Correlation analysis yielded the highest *r* value, 0.991, for left gonial angle measurement and the lowest *r* value, 0.884, for left CH measurements. The method error was calculated using Dahlberg's formula. The values changed from 0.492 to 0.984 and were within acceptable limits.

Results

The descriptive mandibular asymmetry index for both male and female subjects were calculated separately in the normal occlusion and CLP patient groups to investigate the relationship between genders. Statistical testing revealed no significant differences between the mean values of the male and female subjects. Therefore, data for both genders were pooled for further analyses.

Statistical comparison of condylar, ramal, condylar plus ramal height, and gonial angle for the right and left sides in the normal occlusion and BCLP groups and for the cleft side and normal side in UCLP group are shown in Table 2.

There was no statistically significant difference in the normal occlusion group. Gonial angle exhibited a statistically significant difference ($P < 0.05$) in the UCLP group and CH ($P < 0.001$) in the BCLP group. Other measurements did not show any significant differences ($P > 0.05$; Table 2).

Descriptive statistics (mean, standard deviation, minimum, and maximum) and comparisons of the asymmetry indices between the normal occlusion, UCLP, and BCLP groups are shown in Table 3. Condylar asymmetry, ramal asymmetry, and condylar plus ramal asymmetry indices measurements did not exhibit any statistically significant difference. Thus, the use of further tests was not necessary for comparison of asymmetry indices among the investigated groups.

Discussion

DPTs have been used for the assessment of side-to-side height differences and measurement of condylar, ramal, and total heights to define side-to-side asymmetries (Habets *et al.*, 1987, 1988; Miller and Smidt, 1996; Miller *et al.* 1996; Miller, 1997; Miller and Bodner, 1997; Saglam, 2003; Saglam and Sanli, 2004; Kiki *et al.*, 2007; Sezgin *et al.*, 2007; Kurt *et al.*, 2008; Uysal *et al.*, 2009). A bilateral view of the mandible can be obtained with a DPT, and vertical measurements can be achieved (Wabeke *et al.*, 1995). A number of studies have been used DPTs to evaluate side-to-side differences (Habets *et al.*, 1987, 1988; Bezuur *et al.*, 1989). Kambylafkas *et al.* (2006) showed that DPTs can be used to asses vertical posterior mandibular asymmetries. Kyrkanides and Richter (2002) concluded that the degree of antegonial notching noted on DPTs can be used as an early indicator of developing mandibular and lower facial asymmetry in individuals with UCLP. These reports suggest that acceptable results can be achieved with DPTs and that they have a favourable cost–benefit relationship, and expose subjects to relatively low doses of radiation (Kambylafkas *et al.*, 2006).

The reproducibility of vertical and angular measurements on DPTs is acceptable if the patient's head is correctly positioned in the cephalostat (Yale, 1969; Larheim *et al.*, 1984; Kiki *et al.*, 2007). Habets *et al.* (1987) concluded that the head holder must be securely fixed to the DPT with the head well centred in the head holder of the DPT when a clinical film is to be evaluated. In this study, all films were taken under ideal conditions and inadequate and/or poor quality films were excluded.

Condylar, ramal, and condylar plus ramal height values were higher for the normal than the cleft side in the UCLP group, but the differences were statistically insignificant. Horswell and Levant (1988) who compared 16 UCLP subjects with published cephalometric standards did not find any significant differences in mandibular dimensions or morphology between the two groups. Gonial angle was higher on cleft side than on the normal side, and the difference was statistically significant ($P < 0.05$). This higher gonial angle value can be attributed to a compensation mechanism of the mandible on the cleft side for maintaining bilateral symmetry.

Comparison of right and left sides for condylar, ramal, condylar plus ramal height values, and gonial angle measurements in the BCLP group showed only a statistically significant difference for CH, indicating a symmetrical posterior vertical height of the mandible. The method described by Habets *et al.* (1988) has been used for evaluating condylar and ramal asymmetries in TMD patients (Habets *et al.*, 1987, 1988; Miller *et al.*, 1996; Miller, 1997; Saglam and Sanli, 2004) and in different malocclusions (Miller and Smidt, 1996; Miller and Bodner, 1997; Saglam, 2003; Kiki *et al.*, 2007; Sezgin *et al.*, 2007; Kurt *et al.*, 2008; Uysal

Table 2 Statistical comparison of height measurements and gonial angle for right and left sides in normal and bilateral cleft lip and palate (BCLP) groups and for cleft and normal sides in unilateral cleft lip and palate (UCLP) group.

	Normal group				Test	UCLP group				Test	BCLP group				Test
	Right side		Left side			Cleft side		Normal side			Right side		Left side		
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Condylar height	5.18	1.54	5.03	1.44	NS	6.25	1.54	6.95	1.97	NS	7.10	2.08	5.78	1.51	***
Ramus height	34.38	3.67	33.70	3.66	NS	45.63	5.72	45.83	6.37	NS	44.25	5.53	45.03	5.01	NS
Condylar plus ramal height	39.55	4.01	38.73	3.69	NS	51.88	5.94	52.78	6.66	NS	51.35	6.17	50.80	5.13	NS
Gonial angle	125.53	8.11	125.23	7.35	NS	128.48	5.23	127.4	5.72	*	133.78	8.65	133.25	8.28	NS

NS, not significant. *$P < 0.05$, ***$P < 0.001$.

Table 3 Statistical comparison of asymmetry index measurements among normal occlusion, unilateral cleft lip and palate (UCLP), and bilateral cleft lip and palate (BCLP) groups.

Variable	Normal group				UCLP group				BCLP group				Test
	Mean Difference	SD	Minimum	Maximum	Mean Difference	SD	Min	Max	Mean Difference	SD	Min	Max	
Condylar index	9.95	10.42	0.00	38.46	10.27	10.13	0.00	42.11	10.78	10.02	0.00	30.77	NS
Ramal index	2.91	2.29	0.00	7.44	3.02	3.11	0.00	12.56	2.82	3.08	0.00	14.29	NS
Condylar plus ramal index	2.26	1.26	0.65	5.03	2.62	2.84	0.00	9.73	2.85	2.07	0.50	9.27	NS

NS, not significant.

et al., 2009). According to Habets *et al.* (1987), a 3 per cent index ratio may result from a 1 cm change in head position while the DPT is being taken, and thus asymmetry index values (condylar, ramal, and condylar plus ramal asymmetry indices) greater than 3 per cent should be considered as mandibular posterior vertical asymmetry. In this study, for all three groups, condylar asymmetry index values were above 3 per cent, 9.95 ± 10.42, 10.27 ± 10.13, and 10.78 ± 10.02, for the normal, UCLP, and BCLP groups, respectively, indicating asymmetry, but the difference was not significant. Other studies evaluating condylar asymmetry with this method in different malocclusions and in TMD patients also found asymmetry values greater than 3 per cent both in study and control groups (Miller *et al.* 1996; Miller and Smidt, 1996; Miller and Bodner, 1997; Saglam and Sanli, 2004; Kurt *et al.*, 2008). These high values indicating asymmetry both in the treatment and control groups can be attributed to shape, angular, and positional differences between the right and left condyles without any pathology or without any related malocclusion (Yale, 1969). Cohlmia *et al.* (1996) found that the left condyle was positioned more anteriorly than the right condyle and Yale (1969) showed shape and angular differences of the condyles.

Ramal and condylar plus ramal index measurements used for evaluating posterior vertical dimensions of the mandible were similar among the three groups; the differences were statistically insignificant. No study exists that has evaluated mandibular asymmetry in CLP patients using the method of Habets *et al.* (1988). Laspos *et al.* (1997) found that the degree of mandibular asymmetry in UCLP appears not to be the major contributing factor to lower facial asymmetry in these individuals. Those authors attributed such asymmetry to possible cranial-base/temporal region anomalies.

Patients with no significant facial asymmetry were included in this study to evaluate possible, isolated asymmetry of the mandible in CLP individuals. No posterior vertical asymmetry (ramal and condylar plus ramal indices) was found in the mandibles of either the UCLP or BCLP individuals. Early detection of skeletal asymmetry in these patients gives an opportunity for interceptive therapy that can improve long-term treatment outcome. Diagnosis, treatment planning, and design of mechanics for the asymmetric patient requires the differentiation between problems of dental and skeletal origin (Kyrkanides and Richter, 2002).

Conclusion

1. No statistically significant gender differences in mandibular asymmetry were found among the normal occlusion sample or the UCLP and BCLP patient groups, as condylar asymmetry index values were significantly higher compared with the 3 per cent threshold value of Habets *et al.* (1987) in each of the three individual groups. Comparisons between groups were not statistically significant.
2. A statistically significant increase was found for gonial angle on the cleft side in the UCLP group.

Address for correspondence

Dr Tancan Uysal
Erciyes Üniversitesi
Dişhekimliği Fakültesi
Ortodonti A.D.
Melikgazi
Kampüs
Kayseri 38039
Turkey
E-mail: tancanuysal@yahoo.com

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A cephalometric intercentre comparison of patients with unilateral cleft lip and palate at 5 and 10 years of age

Filomena Del Guercio*, Maria Costanza Meazzini*, Giovanna Garattini**, Alberto Morabito***, Gunvor Semb**** and Roberto Brusati*
*Department of Maxillo-Facial Surgery, University of Milan, Regional Center for CLP, Departments of **Orthodontics and ***Biomedical Statistics, San Paolo Hospital, Milan, Italy and ****Oslo Cleft Team, Department of Plastic Surgery, National Hospital, Norway

SUMMARY The aim of this study was to evaluate any differences between the craniofacial growth of unilateral cleft lip and palate (UCLP) patients who underwent surgery in the Milan CLP centre with those from the Oslo CLP centre at 5 and 10 years of age.

The Milan sample comprised 88 UCLP patients (60 males, 28 females) at 5 years of age and 26 patients (17 males, 9 females) at 10 years of age all operated on by the same surgeon. The Oslo sample consisted of 48 UCLP patients (26 males, 22 females) aged 5 years and 29 patients (20 males, 9 females) aged 10 years treated by four different surgeons. Lateral cephalometric radiographs obtained for both samples were analysed and angular measurements and ratios were calculated both for the hard and soft tissues. Statistical analysis was undertaken with an unpaired *t*-test.

At 5 years of age, there were neither sagittal nor vertical hard tissue differences between the two groups. With regard to the soft tissues, only the naso-labial angle showed a statistically significant difference (Milan greater than Oslo by 5 degrees, $P < 0.01$). At 10 years of age, both SNA and ANB differences were larger in the Oslo group than in the Milan group, >2.6 degrees, $P < 0.01$ and >2.9 degrees, $P < 0.001$, respectively.

At 5 years of age, the Milan UCLP sample had the same maxillary protrusion as the Oslo group, while at 10 years of age, the Milan sample were slightly less protruded than the Oslo group.

Introduction

Numerous cephalometric studies (Ortiz-Monasterio *et al.*, 1966; Huddart, 1969; Da Silva Filho *et al.*, 1992; Capelozza Filho *et al.*, 1996) on cleft lip and palate (CLP) patients have shown that maxillary growth in operated CLP patients is often restricted three-dimensionally.

However, no consensus has been reached as to the cause of this growth inhibition. Surgical treatment is viewed as the variable most influencing craniofacial growth (Ross, 1987; Shaw *et al.*, 1992).

It is still controversial as to which type of surgical repair most negatively influences growth. Some authors (Bardach and Mooney, 1984; Kapuçu *et al.*, 1996; Capelozza Filho *et al.*, 1996; Huang *et al*., 2002) consider lip closure as the most important factor responsible for maxillary growth restriction, while others palatal surgery (Ross, 1987; Liao and Mars, 2005).

Secondary bone grafting is carried out usually before the eruption of the canines or, in some centres, before the eruption of the permanent maxillary lateral incisors (Eldeeb *et al.*, 1986; Bergland *et al.*, 1986; Lilya *et al.*, 2000). According to Semb (1988), secondary bone grafting after 8 years of age does not have any adverse influence on antero-posterior or vertical maxillary growth, while Enemark *et al.* (1987) and Daskalogiannakis and Ross (1997) report a negative influence on vertical growth when bone grafting is performed before 10–11 years of age.

The iatrogenic effect of surgical repair, on the other hand, has been shown to be strongly linked to the experience of the surgeons and their surgical skill (Shaw *et al.*, 1992).

Intercenter studies allow for comparison between different surgical protocols applied in different centres in order to define the protocol from which the best results in terms of growth, dental occlusion, and aesthetics can be obtained (Shaw *et al.*, 1992).

The results for the Oslo centre have been previously compared with other European centres and maxillary growth of the subjects has been shown to be among the best in Europe (Molsted *et al.*, 1992).

The Milan surgical protocol consists of lip, nose, and soft palate repair at 4–6 months of age (Brusati and Mannucci, 1992) and early secondary gingivoalveoloplasty (ESGAP) at 18–36 months of age during hard palate repair. Pre-surgical orthopaedics are performed in 60 per cent of patients. The Milan ESGAP seems to allow for excellent ossification (no necessity for secondary bone grafting), but at this time, it is not possible to determine its influence on maxillary growth (Meazzini *et al.*, 2007).

The Oslo CLP team use a different surgical protocol including lip closure (Millard procedure) at 3 months of age with hard palate repair by a one-layer vomer flap without any pre-surgical orthopaedics, and posterior palate closure at 18 months of age according to von Langenbeck (Semb, 1991). The alveolar cleft is repaired with a bone graft between 8 and 11 years of age (Bergland *et al.*, 1986).

The objective of this study was to determine whether there is any difference between the craniofacial growth of unilateral cleft lip and palate (UCLP) patients treated in the Milan CLP centre and those patients from the Oslo CLP centre at 5 and 10 years of age.

Subjects and methods

The Milan 5-year-old sample comprised 88 consecutively treated UCLP (60 males, 28 females) non-syndromic patients, with an average age of 5 years 1 month, all operated on by the same surgeon, and the 10-year-old sample 26 consecutively treated UCLP (17 males, 9 females) non-syndromic patients, with an average age of 9 years 10 months, all operated by the same surgeon. None of the subjects were omitted from the sample because of missing records or other reasons. All patients were Caucasian and of Italian origin.

The Oslo 5-year-old sample comprised 48 consecutively treated UCLP (26 males, 22 females) non-syndromic patients with an average age of 5 years 9 months and 29 consecutively treated UCLP (20 males, 9 females) non-syndromic patients, with an average age of 10 years treated by four different surgeons. All subjects were Caucasian of Norwegian origin.

Lateral cephalometric radiographs were obtained for both groups at 5 and 10 years of age. The radiographs (Figure 1) were traced by one trained operator (FDG).

The parameters evaluated on the lateral radiographs are listed in Table 1. Linear measurements were not compared as absolute values, as it was not possible to calculate the radiographic magnification obtained with different machines, since the technical parameters were not reported.

Statistical analysis

An unpaired *t*-test was used to determine any differences between the two samples. The same experienced operator retraced, after an interval of 1 month, 25 blindly selected radiographs to avoid bias linked to groups. Method error analysis was carried out using the formula of Dahlberg (1940). For all variables, the measurement error was less than 3 per cent of the total variance. Furthermore, systematic error was estimated with a one-sample *t*-test, while random error was evaluated through the coefficient of reliability as suggested by Houston (1983).

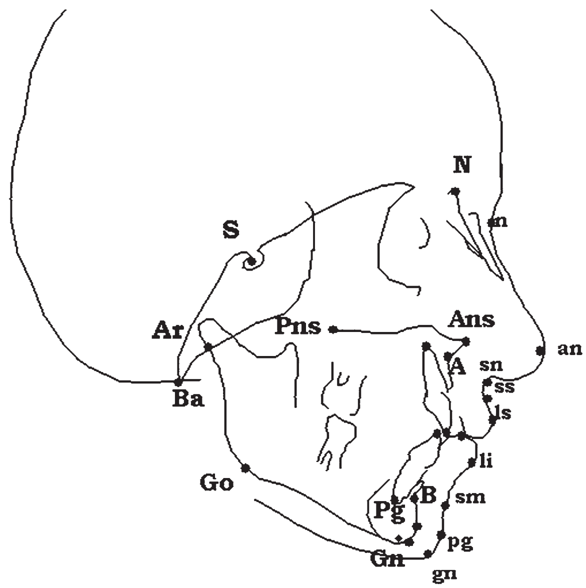

Figure 1 Skeletal and soft tissue landmarks measured on the lateral cephalometric radiographs. S (sella) midpoint of the fossa hypophysealis; Ba (basion) most postero-inferior point of the clivus; Ans (anterior nasal spine) most anterior point of antero-posterior profile of the upper jaw; Pns (posterior nasal spine) most posterior point of the bony palate; N (nasion) anterior point at the fronto-nasal suture; Point A deepest anterior point in the concavity of the anterior maxilla; Point B deepest anterior point in the concavity of the anterior mandible; Pg (pogonion) the most projecting point in the contour of the chin; Ar (articulare) intersection of a line along the posterior border of the mandible and the inferior border of the basilar occipital bone; Go (gonion) intersection between a line bisecting the posterior and inferior borders of the mandible and the contour of the chin; Gn (gnathion) point of intersection between the contour of the chin and a line bisecting the inferior border of the mandible and a line passing through N and Pg; n (nasion) most posterior point at the fronto-nasal suture level on the soft tissues; an (anterior nasalis) tip of the nose on the soft tissues; sn (subnasalis) point of intersection between the base of the nose and upper lip on the soft tissues; ss (subspinale) most posterior point in the anterior concavity of the upper lip on the soft tissues; sm (supramentale) most posterior point in the anterior concavity of the lower lip; pg (pogonion) most anterior point of the mandibular profile in the mental region on the soft tissues; (gnathion) most inferior point of the mandibular profile in the mental region on the soft tissues; ls (labiale superioris) most projecting point, on the frontal plane, of the upper lip; li (labiale inferioris) most projecting point, on the frontal plane, of the lower lip.

Results

Five years of age

Hard tissue variables. Sagittal dimensions. There was no significant difference in maxillary prominence, although in the sagittal jaw relationship, there was a statistically significant difference between the Milan and Oslo UCLP samples (Table 1). There was no significant difference in cranial base angulation ($P > 0.05$).

Vertical dimensions. There was no significant difference in palatal inclination. Craniomandibular, intermaxillary, and mandibular angles were significantly larger in the Milan UCLP sample ($P < 0.001$).

Soft tissue variables. There was no significant difference in the sagittal protrusion of the upper lip, while the sagittal

Table 1 Hard and soft tissues measurements at 5 and 10 years of age for the Milan and Oslo unilateral cleft lip and palate patients.

		Milan	Oslo	Mean difference
SNA	5 years	79.8 (4.1)	80.5 (3.9)	−0.7
	10 years	75.4 (3.7)**	78.0 (3.6)**	−2.6
S–N–Ans	5 years	84.1 (4.1)	83.7 (4.0)	0.4
	10 years	80.5 (3.8)	82.2 (3.9)	−1.7
S–N Pns–Ans	5 years	11.2 (4.6)	10.1 (3.6)	1.1
	10 years	11.8 (3.8)*	9.4 (4.1)*	2.4
SNB	5 years	74.6 (3.2)	74.4 (2.9)	0.2
	10 years	75.4 (3.4)	75.1 (3.6)	0.3
S–N–Pg	5 years	74.6 (3.2)	74.3 (3.0)	0.3
	10 years	76.4 (3.7)	76.0 (3.4)	0.4
S–N Go–Gn	5 years	38.4 (4.4)***	35.5 (4.3)***	2.9
	10 years	37.7 (4.4)	36.3 (3.9)	1.4
Ar Go–Gn	5 years	135.4 (4.8)***	129.4 (4.0)***	6.0
	10 years	132.7 (4.7)	131.5 (4.5)	1.2
ANB	5 years	5.2 (3.3)*	6.4 (2.9)*	−1.2
	10 years	−0.0 (3.1)***	2.9 (2.7)***	−2.9
Pns–Ans Go–Gn	5 years	27.5 (4.8)**	25.3 (4.5)**	2.2
	10 years	26.1 (5.0)	26.8 (5.2)	−0.7
N–A–Pg	5 years	170.9 (6.7)***	167.5 (5.7)***	3.4
	10 years	182.4 (7.0)***	176.0 (5.4)***	6.4
LFH/TFH	5 years	60.13%	60.13%	0.0%
	10 years	56.8%***	58.3%***	−1.5%
Ba–S–N	5 years	128.4 (4.9)	128.5 (5.5)	−0.1
	10 years	130.1 (5.1)	128.9 (5.0)	1.2
Ba–S–Pns	5 years	60.7(5.3)***	64.4(5.6)***	−3.7
	10 years	59.7 (5.0)	58.6 (4.6)	1.1
S–n–ss	5 years	85.0 (4.0)	84.9 (3.5)	0.1
	10 years	87.3 (4.2)	89.5 (3.1)	−2.2
S–n–sm	5 years	78.9 (3.4)	78.1 (2.6)	0.8
	10 years	81.2 (4.2)***	78.0 (2.5)***	3.2
ss–n–sm	5 years	6.0 (2.6)*	7.0 (2.0)*	−1.0
	10 years	3.6 (2.8)***	6.1 (2.2)***	−2.5
ss–n–pg	5 years	5.5 (2.8)	5.9 (2.3)	−0.4
	10 years	3.9 (1.8)***	5.6 (1.9)***	−1.7
n–sn–pg	5 years	167.1 (6.0)	167.8 (4.9)	−0.7
	10 years	171.2 (6.4)	167.9 (3.6)	3.3
A–N–ss	5 years	5.3 (3.3)	4.4 (3.3)	0.9
	10 years	12.3 (2.5)	12.3 (2.6)	0.0
an–sn–ls	5 years	127.7 (10.0)**	123.0 (10.5)**	4.7
	10 years	119.2 (10.6)	118.1 (12.7)	1.1

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

interlip relationship in the Milan group was significantly smaller than in the Oslo sample (Table 1). Naso-labial angle was larger in the Milan UCLP sample and the difference was statistically significant ($P < 0.01$).

Ten years of age

Hard tissue variables. Sagittal dimensions. There was a significant difference in maxillary prominence and in sagittal jaw relationship between the Milan and Oslo samples ($P < 0.01$; Table 1). The Oslo UCLP sample was more protruded than the Milan sample at the dentoalveolar level, although there was no difference in the protrusion of anterior nasal spine.

Vertical dimensions. There was no significant difference in any of the vertical dimensions.

Soft tissue variables. The sagittal relationship was significantly less favourable in the Milan UCLP sample compared with the Oslo UCLP sample ($P < 0.001$; Table 1).

Discussion

The results of the present study showed no differences in maxillary protrusion at 5 years of age between the two groups.

These data confirm cephalometrically the findings obtained using the 5-year yardstick by Flinn *et al.* (2006), where the 5-year-old dental arch relationship of patients from three different centres (Oslo, Norway; Milan, Italy; and Lancaster, Pennsylvania, USA) were compared. The results showed that between the three centres there were no statistically significant differences, even though the protocols differed.

In this study, the Milan sample showed a more divergent mandibular pattern and a more open gonial angle than the Oslo sample, demonstrating a different pattern of mandibular growth. Semb (1988) reported that after bone grafting there was a tendency towards posterior rotation of the mandible. Furthermore, Trotman *et al.* (1996) found that in patients who had undergone primary grafting, the mandibular growth pattern was different from the non-grafted group with a clockwise rotation of the mandible. ESGAP might therefore explain the difference in mandibular rotation. This apparent mandibular compensation which differentiated the Milan sample from the Oslo sample at 5 years of age was not significant at 10 years of age. A possible explanation might be that by 10 years of age, most of the Oslo sample had undergone secondary bone grafting.

The present results show that at 10 years of age, the Oslo sample was significantly more protruded at the maxillary dentoalveolar level than the Milan sample, although, there was no difference in protrusion of anterior nasal spine. Soft tissue differences confirmed a larger upper lip protrusion for the Oslo sample. At present, there is no explanation for this dentoalveolar growth difference at 10 years of age. The improved growth of the Oslo group compared with the Milan sample might be related to the different surgical protocols. Intrinsic racial differences might also be a confounding factor. Although there are cephalometric studies on the Norwegian population (El-Batouti *et al.*, 1994; Axelsson *et al.*, 2003), no data exist on craniofacial growth of Italians. There is a great variability in the Italian race due to Spanish and Austro-Hungarian domination in Northern Italy and Swedish domination in Southern Italy, but no studies have analysed this variability. Certainly, long-term data will be needed for a more definitive conclusion.

Conclusions

At 5 years of age, the Milan UCLP group appears to have the same maxillary protrusion as the Oslo sample, while at 10 years of age, the Milan UCLP sample appears to be slightly less protruded when compared with the Oslo group.

Address for correspondence

Filomena Del Guercio
Via Sartirana 1
Bollate
Milano 20021
Italy
E-mail: filomena.delguercio@libero.it

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Long-term stability of dentoalveolar and skeletal changes after activator–headgear treatment

Magnhild Lerstøl, Øystein Torget and Vaska Vandevska-Radunovic
Department of Orthodontics, Faculty of Dentistry, University of Oslo, Norway

SUMMARY The aim of this study was to analyze the long-term stability of combined activator–headgear treatment on skeletal and dental structures in Class II patients. The material comprised 26 subjects, 10 girls and 16 boys. All had a molar Class II relationship, overjet ≥6 mm, and overbite ≥5 mm. They were treated in one practice with combined activator and headgear appliances. Lateral cephalometric radiographs and dental study casts were taken before treatment (T0, mean age 11.9 years), at the end of activator–headgear treatment (T1, mean age 15.9 years), and 12–15 years out of retention (T2, mean age 28.6 years). Nineteen cephalometric and nine dental cast variables were evaluated using a paired sample *t*-test between T0–T1, T1–T2, and T0–T2.

At T1, the majority of the cephalometric measurements showed statistically significant changes. ANB was significantly reduced by 2.3 degrees due to a significant increase in SNB, but only small changes were observed in SNA. The interincisal angle increased as a result of significant retroclination of both maxillary and mandibular incisors. All patients achieved a Class I molar relationship and a significant reduction in overjet and overbite. At T2, the results showed only slight relapse from T1. However, the relapse did not compromise the significant improvement in almost all the cephalometric and dental variables. Combined activator–headgear treatment improved the skeletal and dental conditions and the results remained stable in the long term.

Introduction

Various removable and fixed functional appliances are used in the treatment of Class II division 1 malocclusions. Activators and modified activators with headgear are some of the oldest systems that are still frequently used (Andresen, 1936; Rakosi, 1997a,b; Proffit, 2000). A clinically evident improvement of Class II malocclusions is repeatedly demonstrated, but the nature of changes due to activator treatment has been controversial. Some investigators report mainly dentoalveolar (Jakobsson, 1967; Wieslander and Lagerström, 1979; Cura *et al.*, 1996), others mainly skeletal (Cozza *et al.*, 2004) changes, while some claim that the improvement of the sagittal occlusal relationship is due equally to skeletal and dental changes (Pancherz, 1984; Marşan, 2007). Regardless of the nature of the changes, the greatest challenge and major goal is to treat the malocclusion to correct function and aesthetics and to ensure that the treatment results remain stable.

While the short-term effects of Class II treatment have been widely investigated, long-term stability of skeletal and dental alterations has received less attention. It seems likely that relapse tendencies are inevitable, but their extent and clinical significance are variable (Herzberg, 1973; Wieslander and Lagerström, 1979; Fidler *et al.*, 1995; Janson *et al.*, 2004). Relapse of overbite and overjet, retroclination of the mandibular incisors, and worsening of the sagittal molar relationship are most often mentioned, but they do not seem to compromise an otherwise successful correction of a Class II division 1 malocclusion (Fidler *et al.*, 1995; Elms *et al.*, 1996).

Apart from one study that evaluated the stability of treatment results with only a headgear–activator 5 years post-retention (Lehman *et al.*, 1988), all other long-term investigations have evaluated Class II division 1 subjects treated with a combination of functional and/or headgear and fixed appliances. For a better understanding of the long-term benefits of any functional appliance, including the headgear–activator, it is important to have long observation periods and a treatment method limited to only one appliance. Therefore, the aim of this study was to investigate the long-term stability of the skeletal and dental changes in Class II division 1 patients treated only with a headgear–activator.

Subjects and methods

The subjects were 26 Class II malocclusion patients, 10 girls and 16 boys, with mean age of 11.9 years (±1.2). They were treated by a single orthodontist (ØT) in his private practice. The start records were collected in the period between 1983 and 1987. To be included in the study, the patients had to fulfil the following criteria: (1) treated only with a modified activator and Kloehn headgear; (2) have a Class II molar relationship; (3) an overjet of at least 6 mm and/or an overbite of at least 5 mm; and (4) to have full records at the end of treatment. Patients requiring fixed appliances (e.g. because of anterior crowding exceeding 4 mm, agenesis, or previous extractions) after the initial functional appliance treatment were excluded.

A complete file search of the practice included a total of 497 patients that had their start records collected during the 5 year period. Fifty cases were found to fulfil the inclusion criteria. Of those, 26 patients consented to participate. The other 24 patients had either moved abroad or to other parts of the country (nine patients), could not take time off work (six patients), or were not interested (two patients). One patient was pregnant and did not wish to undergo radiographic evaluation, and six patients could not be contacted.

Appliance design

The activator was a loose fitting appliance, where all the maxillary teeth as well as the mandibular incisors were covered by acrylic (Figure 1). The working bite was taken with the mandible set forward in an edge-to-edge relationship and bite raising of approximately 1 mm. For patients where the initial overjet was 9 mm or more, the working bite was taken behind an edge-to-edge relationship and a second activator was provided during treatment. Trimming was performed to guide eruption facets for the lower premolars and molars, and if necessary, to allow retroclination of proclined upper incisors. Bands were cemented on the upper first molars, and a Kloehn headgear with a cervical pull was adjusted. The adjustment included expansion of the inner bow by about 2 mm. The recommendations for use were 12–14 hours a day during active treatment. Active treatment was considered finished when the first molars were in Class I occlusion and the overjet and overbite were at least 4 mm or less. After active treatment, the bands were removed and the activator was used for retention. Five of the patients were provided with a new activator for retention. The retention phase consisted of approximately 2 years nightly use of the activator, first every night, then every second and third night until the activator was used approximately once a week. Treatment and retention lasted approximately 4 years (±1.1), while the post-retention period was 13.9 years (±1.6).

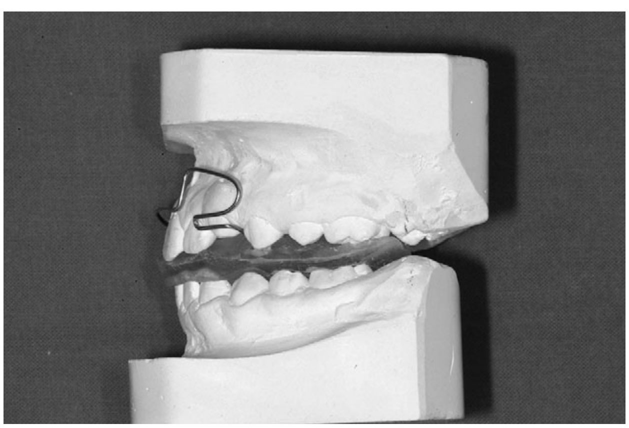

Figure 1 The activator appliance without the Kloehn headgear mounted on study casts.

Records, including lateral cephalograms and study casts, were taken at the start of treatment (T0), mean age 11.9 ± 1.2 years; after the end of active retention (T1), mean age 15.9 ± 1.1 years; and post-retention (T2), mean age 28.6 ± 1.6 years.

Cephalometric analysis

All the analyses were undertaken by one author (ML). The tracings were performed on acetate paper and then scanned on Adobe Photoshop. Corrections were made for linear enlargement, and the tracings were analyzed using FACAD® (Ilexis AB, Linköping, Sweden). Definitions relating to the angular and linear measurements are given below:

Angular measurements (in degrees);
ML/nsL, angle of the mandibular plane (go-gn) and nasion-sella line (s-n);
ML/NL, angle of the mandibular plane (go-gn) and nasal line (pm-sp);
ILs/Ili, posterior angle of the upper and lower incisor long axis;
ILi/ML, supero-posterior angle of the lower incisor long axis and mandibular plane (go-gn);
ILi/nB, supero-anterior angle of the lower incisor long axis and n-B;
ILs/nsL, infero-posterior angle of the upper incisor long axis and the nasion-sella line;
ILs/nA, supero-posterior angle of the upper incisor long axis and n-A.
Nasolabial angle, angle formed by a line drawn tangentially to the base of the nose and a line tangential to the upper lip.
Linear measurements (in millimetres);
Ii⊥Apg, distance from ii to A-pg;
Ii⊥nB, distance from ii to n-B;
Is⊥Apg, distance from is to A-pg;
Is⊥nA, distance from is to n-A;
PLi-EL, distance from PLi (prolabium inferior) to PRN-PG (Ricketts E line);
PLs-EL, distance from PLs (prolabium superior) to PRN-PG (Ricketts E line).

Study cast analysis

The molar relationship was measured as the distance between the mesiobuccal tip of the maxillary first molar and the buccal groove of the mandibular first molar, and the canine relationship as the distance from the cusp tip of the maxillary canine to the distal contact point of the mandibular canine. Overjet was measured as the distance parallel to the occlusal plane from the buccal surface of the most proclined upper incisor to the buccal surface on the corresponding lower incisor, and overbite as the distance from the incisal tip of the upper first right incisor to the incisal tip of the lower first right incisor.

Arch width. The intercanine distance was measured as the width between 33 and 43, from cusp tip to cusp tip. When the lower canines were unerupted, the distance was not measured. The maxillary intermolar distance was measured between the mesiopalatal cusps of 16 and 26 and the mandibular intermolar distance between the lingual fossae of 36 and 46. Space analysis gave the degree of space discrepancy. The total mesiodistal dimensions of the upper and lower six anterior teeth was calculated and subtracted from the arch length between the distal surfaces of the canines. All measurements were in millimetres.

Study error

Ten cephalograms and 20 study casts were randomly selected and re-measured after an interval of 3 months. The combined study error (SE) was calculated using the formula proposed by Dahlberg (1940):

$$SE = \sum d^2 / 2n,$$

where d is the difference between two registrations and n is the number of double registrations. The SE for measurements on study casts ranged from 0.6 to 1.5 mm with a mean of 0.9 mm and on the cephalograms from 0.7 to 2.8 degrees with a mean of 1.7 degrees for the angular and 0.6 mm (0.2–0.8) for the linear measurements.

Statistical analysis

The means and standard deviations were calculated for all the measured cephalometric and study models variables. A paired sample *t*-test was used to evaluate the mean changes between T0–T1, T1–T2, and T0–T2. A level of $P<0.05$ was considered to indicate a statistically significant difference.

Results

Cephalometric analysis

Treatment changes T0–T1. Nearly all craniofacial variables showed statistically significant changes, except for SNA. SNB and SNPg increased during treatment, while ANB decreased (Table 1, Figure 2a). A statistically significant decrease was observed for NSBa, the mandibular plane angle (ML/nsL), and the intermaxillary angle (ML/NL; Table 1, Figure 2b). The lower and upper incisors became more retroclined and retruded, which led to an increased interincisal angle. All these changes were statistically significant (Table 1, Figure 2c). The upper and lower lip became significantly retrusive, while the nasolabial angle became more obtuse, but this change was not significant (Table 1, Figure 2d,e).

Table 1 Treatment changes of selected cephalometric variables after active treatment (T0–T1), post-retention (T1–T2), and between pre-treatment and post-retention (T0–T2).

Variables	T0–T1		T1–T2		T0–T2	
	Mean	SD	Mean	SD	Mean	SD
SNA (°)	−0.3	1.3	0.5	1.4	0.2	1.5
SNA (°)	2.0**	1.6	1.0*	1.8	2.9	1.7
ANB (°)	−2.3**	1.7	−0.5	1.4	−2.6	1.4
SNPg (°)	2.1**	1.6	1.3*	1.7	3.4	1.8
ML/nsL (°)	−1.2*	2.1	−2.1**	2.5	−3.3	2.7
ML/NL (°)	−1.3*	2.1	−1.4*	2.4	−2.6	2.7
NSBa (°)	−1.1*	2.3	−1.7	2.6	−1.1	2.0
ILs/ILI (°)	6.4**	6.7	4.1*	6.8	10.5**	5.6
ILi/ML (°)	−2.7**	3.3	−1.3	4.0	−4.0**	4.5
ILi/nB (°)	−1.9*	2.6	−2.4*	4.1	−4.5**	4.1
Ii⊥Apg (mm)	0.8*	1.5	−0.6*	1.2	−0.2	3.8
Ii⊥nB (mm)	−0.2	1.1	−0.8*	1.2	−0.2	1.1
ILs/nsL (°)	−2.5	6.0	0.8	5.9	−3.3*	5.3
ILs/nA (°)	−2.2*	6.1	1.2	4.6	−3.4*	5.1
Is⊥Apg (mm)	−2.5**	2.0	0.8	1.5	−3.4**	1.5
Is⊥nA (mm)	−0.3	3.2	0.5	3.1	−0.7*	1.9
Nasolabial angle	2.5	9.8	−3.8*	5.6	−1.2	10.0
PLi-EL (mm)	−2.5**	1.9	−3.0**	1.8	−5.2**	2.3
PLs-EL (mm)	−3.5**	2.2	−27**	1.4	−6.4**	2.2

SD, standard deviation. *$P\leq0.05$, **$P\leq0.001$.

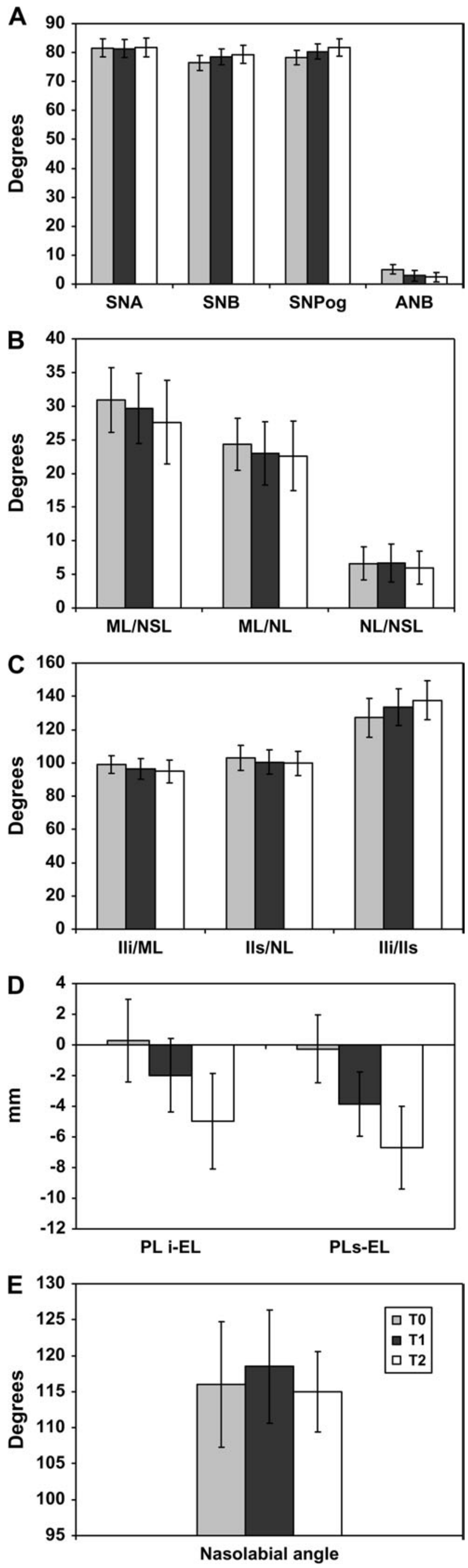

Figure 2 Mean values and standard deviations of mandibular and maxillary prognathism (A), mandibular (ML/nsL) and maxillary (NL/nsL) jaw inclination (B), incisor inclination (C), linear distance from lips to E line (D), and nasolabial angle (E) at treatment start (T0), treatment end (T1), and post-retention (T2).

Post-treatment changes T1–T2. SNB and SNPg continued to increase significantly after the end of retention. Despite this, there was a slight decrease in ANB, but the change was not significant (Table 1, Figure 2A). No significant changes were found for NSBa. During the post-treatment period, both ML/nsL and ML/NL decreased significantly (Table 1, Figure 2B).

The lower incisors became more retroclined and retruded (Table 1, Figure 2C). The distances from Ii to APg and Ii to NB were significantly reduced. The upper incisors showed a tendency for further retroclination. The distance from Is to APg was significantly reduced, resulting in more uprighted upper incisors. The interincisal angle continued to increase significantly after treatment, but with large individual variations (Table 1, Figure 2C).

Further significant retrusion of the lips was noticed, while the nasolabial angle significantly decreased (Table 1, Figure 2D,E).

Study cast analysis

Treatment changes T0–T1. Overjet and overbite were significantly reduced. The combined molar relationship on both sides significantly improved towards a Class I occlusion as did the canine relationship on both sides (Table 2, Figure 3A). The transverse dimensions showed an overall enlargement. The distance between the maxillary molars significantly increased during treatment. The mandibular intermolar distance also demonstrated a significant increase, but to a lesser extent. Intercanine distance decreased, but this was not significant (Table 2, Figure 3B). There was a slight, but significant increase in space in the upper anterior segment during treatment. The space conditions in the lower jaw remained almost the same, with a small tendency for reduction, but this was not significant (Table 2, Figure 3C).

Post-treatment changes T1–T2. Overjet remained stable, with only a slight, non-significant increase. Overbite, however, significantly increased. The molar relationship on both sides showed minor relapse and the canine relationship showed a tendency for further improvement. These changes were, however, not significant (Table 2, Figure 3A). The transverse dimensions reduced. Upper and lower intermolar width in both arches significantly decreased, as did intercanine distance (Table 2, Figure 3B).

A reduction in space occurred in both jaws. This was more pronounced in the lower anterior segment, and the changes were significant (Table 2, Figure 3C).

Discussion

The present investigation was based on a selected group of patients treated in a single practice, by an experienced orthodontist with only an activator–headgear appliance. Cephalometric and study cast analyses showed an overall

Table 2 Treatment changes (mm) of the variables measured on the study models post-treatment (T0–T1), post-retention (T1–T2), and between pre-treatment and post-retention (T0–T2).

Variables	T0–T1		T1–T2		T0–T2	
	Mean	SD	Mean	SD	Mean	SD
Overjet	−4.4**	1.7	0.1	1.7	−4.3**	1.7
Overbite	−2.3**	1.0	0.3*	0.7	−2.0**	1.2
Molar relationship	3.6**	1.2	−0.3	0.7	3.3**	1.2
Canine relationship	4.0**	1.1	0.1	0.8	−4.3**	1.1
16–26	2.2**	1.6	−0.8*	1.1	1.4**	1.4
33–43	0.04	0.8	−0.9*	1.1	−0.9**	1.1
36–46	1.0**	1.0	−0.5*	1.0	0.5	1.3
Space conditions upper anterior segment	0.7**	1.7	−0.4*	0.8	0.3	1.6
Space conditions lower anterior segment	−0.04	1.3	−1.6**	1.1	−1.6**	1.4

SD, standard deviation. *$P \leq 0.05$, **$P \leq 0.001$.

satisfactory treatment response. At T1, all patients achieved a Class I molar relationship and significant reduction of overjet and overbite. The treatment results showed slight relapse at T2, but it did not compromise the clinically significant improvement for almost all skeletal and dental variables.

The main focus of this investigation was long-term, post-retention stability and not the effectiveness of the appliance *per se*. However, assessment of the treatment changes was important. Firstly, the effectiveness of the activator–headgear appliance treatment had to be evaluated and secondly, the treatment results were necessary as a reference point for the study of stability or relapse during T2. In general, the observed skeletal and dental changes were in accordance with previous studies (Lehman *et al.*, 1988; Lagerström *et al.*, 1990; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002; Marşan, 2007). A significant reduction of the relative prognathism (ANB) was due to a significant increase in SNB and SNPg and an insignificant reduction of SNA. The inclination of the mandible decreased (ML/nsL) resulting in a decreased intermaxillary angle (ML/NL). Similar effects have been reported in almost all investigations that included activator, activator–headgear, and Herbst appliances (Wieslander, 1993; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002; Phan *et al.*, 2006). The time elapsed between T0 and T1 was 4 years and the mean age of the patients was approximately 16 years at T1. During this period, a substantial amount of growth had taken place, explaining changes such as augmentation of SNB by 2 degrees. Increases in SNA and SNB have also been shown in untreated Class II and Class I adolescents, with mandibular forward growth exceeding that of the maxilla (You *et al.*, 2001; Thilander *et al.*, 2005; Stahl *et al.*, 2008). Despite similar craniofacial growth in the two groups, no self-correction could be observed in the untreated Class II individuals (You *et al.*, 2001; Stahl *et al.*, 2008).

The interincisor angle significantly increased at T1, as both upper and lower incisors showed significant retroclination. Retroclination of the upper incisors is

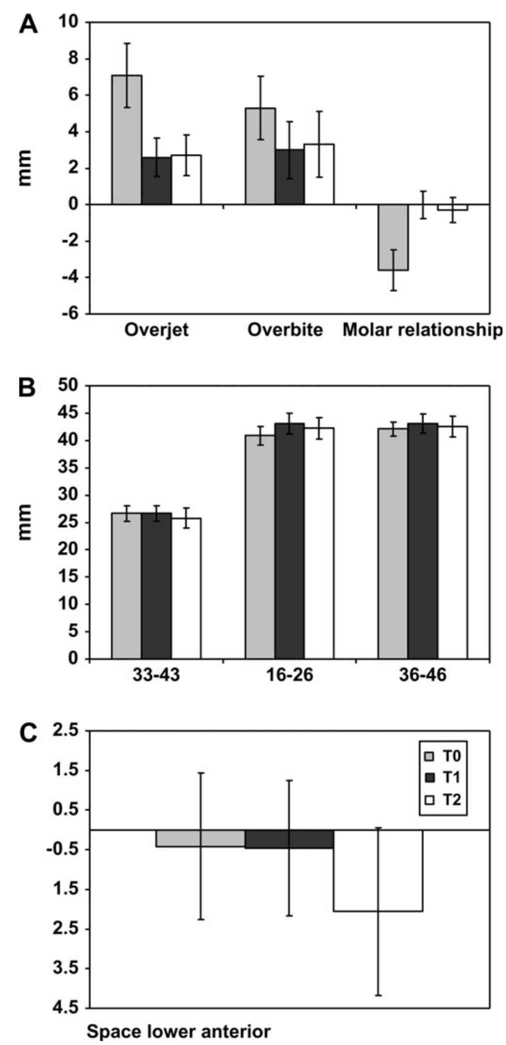

Figure 3 Mean values and standard deviations of dental overjet, overbite, and molar relationship (A), mandibular intercanine (33–43) and intermolar (36–46), and maxillary intermolar distance (16–26) (B), and available space in the lower anterior segment (C) at treatment start (T0), treatment end (T1), and post-retention (T2). Negative reading indicates a distal relationship.

commonly reported (Lehman *et al.*, 1988; Lagerström *et al.*, 1990; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002), but treatment changes in the inclination of the lower incisors are somewhat contradictory. Lehman *et al.* (1988) and Altenburger and Ingervall (1998) observed proclination during activator–headgear treatment, while Lagerström *et al.* (1990) and Bendeus *et al.* (2002) reported retroclination. The differences may have been due to appliance design, whether the incisors were capped with acrylic, trimming of the appliance, and patient compliance.

The treatment effects of functional appliances, whether skeletal or dental, are almost exclusively evaluated on lateral cephalograms. In this manner, the changes can only be assessed in the sagittal and vertical, but not in the transversal plane. On the other hand, precise identification of mesial and distal molar surfaces cannot be carried out bilaterally, although asymmetric, unilateral improvement can sometimes be observed. In order to overcome these shortcomings, plaster study models were included. Their analysis provided a reliable, bilateral evaluation of the sagittal changes in both canine and molar relationships, as well as overjet, overbite, transverse changes, and crowding. In agreement with previous findings, molar and canine relationship, as well as overjet and overbite significantly improved after treatment. In addition, a significant increase in intermolar distance was observed in both jaws, while the intercanine distance was stable. Retroclination of the lower incisors lead to minor, insignificant crowding in the lower anterior segment. Despite retroclination of the maxillary incisors, an increase in space conditions was observed. Possible distal movement of the teeth in the lateral segments may explain the overall gain in space and hence the increase in the incisor region. It is important to note that the transverse dimension and space measurements, although significant, were very small and considering the large measurement error should be interpreted with caution.

No matter how successful orthodontic treatment, if the results fail to remain stable, any favourable aesthetics and function will be compromised. Therefore, stability of treatment is of prime concern for patients and orthodontists alike. The results achieved during treatment in this study were stable and showed only small changes at T2. The overjet, overbite, and molar relationship relapsed, with overbite being the only variable showing a significant increase. However, all changes remained significant when compared with T0. The reduction in intermolar and mandibular intercanine distance was small, but significant, and so was the maxillary and mandibular anterior space, as crowding increased. Increased anterior crowding can be regarded as a result of the normal physiological processes of dental maturation and ageing as tooth alignment deterioration and mandibular intercanine distance reduction are also reported in individuals without previous orthodontic treatment (Humerfelt and Slagsvold, 1972; Bishara *et al.*, 1997; Bondevik, 1998, 2007). Furthermore, none of the patients were provided with bonded retainers.

A major factor contributing to the stability of treatment results is the growth pattern of the patients (Ormiston *et al.*, 2005). It has been reported that patients showing satisfactory response to activator–headgear treatment often display favourable growth (DeVincenzo, 1991; Elms *et al.*, 1996; Rakosi, 1997b; Janson *et al.*, 2004), while unfavourable growth can compromise even excellent treatment results (Herzberg, 1973). The majority of the patients in the present sample displayed further anterior mandibular growth as seen in the continued increase of SNB and SNPg. The mandibular and intermaxillary angles continued to decrease post-retention and these changes were significant. Overall, none of the skeletal variables showed relapse and continued to change in the same direction as during active treatment. The dental variables showed a slightly different pattern. The interincisal angle continued to increase after T1, mainly due to further uprighting of the mandibular incisors. The upper incisors, however, slightly proclined, but this change was not significant.

Studies on longitudinal growth changes in the adult craniofacial complex show that soft tissue changes in nose, lips, and chin occur as much after 25 years of age as between 18 and 25 years (Formby *et al.*, 1994). This supports the findings of the present study as the soft tissue variables showed greater changes than the skeletal ones. The lips became more retrusive and the nasiolabial angle significantly decreased post-retention. Such changes are most probably due to natural continued growth of the nose and chin, which has been shown to occur in both males and females (Nanda *et al.*, 1990).

Several other factors influencing the stability of orthodontically treated dentitions have been identified. Nanda *et al.* (1993) mentioned good occlusion and cuspal interdigitation, a constant intercanine width, and no proclination of the lower incisors as some of the most important factors for long-term stability. In this study, a satisfactory occlusion and intercuspation at the end of treatment was achieved; the intercanine distance was almost unchanged and the lower incisors showed slight retrusion. Despite this, the intercanine distance decreased and the lower incisors retruded even more after the end of retention, both changes being significant. Although these alterations did not compromise the good clinical result, it is questionable if the above-mentioned recommendations are sufficient to provide a stable post-treatment result.

Forces deriving from the surrounding orofacial tissues are also believed to promote stability of post-treatment results (Melrose and Millett, 1998). If dental changes are in harmony with the tongue and facial muscles, the result is more prone to be stable (Nanda *et al.*, 1993). Treatment with a functional appliance and a prolonged retention period as in the present study may have helped the soft tissues adapt to occlusal changes. The teeth were given sufficient time to adjust to the new position and function since the retention protocol included the same appliance as during treatment. Considering the good long-term outcome in these patients, it is probable that in addition to a favourable growth pattern, correct diagnosis, treatment, and retention protocol in motivated patients should be regarded as contributing factors to stable long-term treatment results.

Prediction of relapse and/or stability after orthodontic treatment seems to be difficult as the dentition constantly changes throughout life, with or without orthodontic treatment (Uhde *et al.*, 1983; Bishara *et al.*, 1997; Bondevik, 1998, 2007). Orthodontists need to differentiate post-treatment changes attributed to dental instability from those due to growth and ageing. Therefore, understanding of the physiological dental tissue alterations is important because of its influence on the occlusion after the end of orthodontic treatment and retention. Comparison of the study group with an untreated sample with the same malocclusion would have given useful information to differentiate these incidents. However, adults with an untreated Class II division 1 malocclusion are almost impossible to find. Besides these obvious limitations, it has to be emphasized that the main goal of this investigation was the long-term stability of combined activator and headgear treatment and not the effectiveness of the appliance versus growth. The only study that evaluated long-term changes of untreated adult patients with Class II division 1 malocclusion was published by Feldmann *et al.* (1999). Comparison of the skeletal changes with that investigation was not possible as no cephalograms were taken. Despite improvement of the sagittal and vertical occlusal variables from adolescence to adulthood, all individuals still presented features characteristic of Class II division 1 deep overbite patients. These findings are in contrast with the occlusal characteristics demonstrated in the present patient group, as all of them maintained the Class I sagittal and vertical occlusal traits. However, most of the untreated individuals developed mild dental crowding in both jaws (Feldmann *et al.*, 1999), which corresponds to the present findings and supports the natural developmental concept rather than instability or relapse.

Conclusions

The selected patient group treated with only a headgear–activator appliance and following a carefully planned retention protocol showed improved skeletal and dental conditions which remained stable 10–15 years post-retention. The post-retention changes in occlusion and dental alignment are in accordance with previously reported changes due to ageing in untreated patients. Nevertheless, taking into account the limitations deriving from the fact that no control group of untreated Class II adults was available, these results have to be interpreted with caution. Further research is needed to differentiate between changes due to natural ageing and those due to relapse after orthodontic treatment.

Address for correspondence

Magnhild Lerstøl
Department of Orthodontics
Faculty of Dentistry
University of Oslo
P.O. Box 1109
Blindern
N-0317 Oslo
Norway
E-mail: magnhild.lerstol@odont.uio.no

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Cervical vertebrae anomalies in orthodontic patients: a growth-based superimpositional approach

Despina D. Koletsis and Demetrios J. Halazonetis
Orthodontic Department, School of Dentistry, University of Athens, Greece

SUMMARY The purpose of this study was to propose a growth-based structural superimposition method for assessment of cervical vertebral fusion and evaluate variations and abnormalities of the upper cervical vertebrae. Standardized lateral cephalograms of 156 patients (69 males and 87 females, age range 6–20 years), representing a skeletally heterogeneous orthodontic population, were used. Primary criterion for sample selection was the existence of at least two lateral cephalograms, one taken before orthodontic treatment, which depicted the first four cervical vertebrae. The abnormalities of the vertebrae were estimated by visual assessment and structural superimposition. Lateral cephalometric analysis was conducted in order to correlate vertebral anomalies to skeletal pattern. Descriptive statistics were calculated for all variables and interobserver agreement was evaluated using the kappa statistic.

Four patients (2.6 per cent) were found to have secondary ossicles in close relationship to the first cervical vertebra, while in 7.4 per cent, the vertebral arteries of the atlas were surrounded by a complete ring-shaped osseous structure. Three cephalograms showed atlas posterior arch dehiscence. After visual examination, 14 patients were provisionally identified as presenting fusion between the second and third cervical vertebrae. However, growth-based superimposition of the radiographs disclosed that no patient showed actual fusion, even though the lateral cephalometric analysis revealed sufficient extreme skeletal patterns, which have been previously related to vertebral fusion.

The findings of this study demonstrated a low percentage of atlas anomalies. It was not possible to correlate skeletal pattern to fusion of cervical vertebrae because no fusions were found. Subjective visual examination of a single cephalogram may result in false-positive findings of fusion and growth-based superimposition is recommended.

Introduction

Recently, there has been increased interest in the study of anomalies of the cervical vertebrae in the orthodontic literature, probably stemming from the demonstrated association between such anomalies and craniofacial syndromes (Gray *et al.*, 1964; Gunderson *et al.*, 1967; Brinker *et al.*, 1997; Guille and Sherk, 2002; Tracy *et al.*, 2004; Kaplan *et al.*, 2005), non-syndromic congenital anomalies, such as clefts (Ross and Lindsay, 1965; Sandham, 1986; Horswell, 1991; Uğar and Semb, 2000; Giannakari, 2004; Rajion *et al.*, 2006), and also conventional orthodontic malocclusions (Sonnesen and Kjær, 2007a,b, 2008a,b). Interstudy differences in the prevalence of these anomalies are large and difficult to explain; they could be attributed to true population differences or to methodological errors, arising from the choice of plain visual assessment as the method of evaluation. It is doubtful if this approach can be significantly improved because, besides being subjective and possibly unreliable, it is based on a single radiograph that has inherently limited information. However, integrating additional images, preferably at different postures or growth stages, could provide increased diagnostic confidence.

In orthodontics, the main concern is with the detection of the congenital subgroup of spine malformations, mainly fusions at the level of C2–C3 and atlas dehiscences, but in orthopaedics, where problems of the spine have been studied more extensively and in depth, fusions are even induced in order to correct spine deformities such as scoliosis (Mercado *et al.*, 2007). The specificity and sensitivity of various diagnostic methods to evaluate the success of such fusions is an active area of research. In addition to subjective observation of a single radiograph, more sophisticated methods have been investigated, including flexion–extension radiograph pairs (Taylor *et al.*, 2007), computed tomography (Brodsky *et al.*, 1991; Rajion *et al.*, 2006; Carreon *et al.*, 2007), and computer-aided quantitative motion analysis (Taylor *et al.*, 2007; Fassett *et al.*, 2008). Such procedures are not indicated for routine orthodontic patients because congenital fusions of the cervical spine are low in frequency and do not present with significant clinical manifestations that require intervention (Klimo *et al.*, 2007). However, since incidental findings may be observed (Soni *et al.*, 2008), it would be beneficial to be able to arrive at a definitive diagnosis, based on the diagnostic records already available from orthodontic treatment.

The aims of the present study were (1) to propose a growth-based superimpositional approach for assessing cervical vertebral fusions, (2) to apply this method for recording the type and prevalence of upper cervical vertebrae anomalies in a skeletally heterogeneous orthodontic population, and (3) to assess any correlation between cervical spine anomalies and craniofacial skeletal pattern.

Materials

The sample consisted of standardized lateral cephalograms of 156 patients (69 males and 87 females), consecutively treated either in the Orthodontic Department, School of Dentistry, University of Athens, or in a private orthodontic practice. The lateral radiographs were selected irrespective of gender and type of malocclusion. Inclusion criteria were (1) age between 6 and 20 years, (2) at least two lateral cephalograms (one at the beginning of orthodontic treatment), and (3) radiographs of good quality, showing the first four cervical vertebrae and a reference ruler on the cephalostat, for exact measurement of the magnification factor. Exclusion criteria were previous orthodontic treatment and syndromes and other developmental deformities.

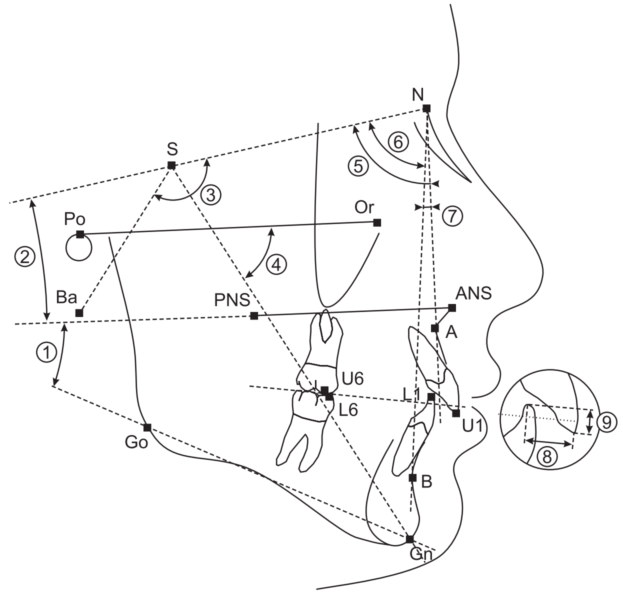

Figure 1 Points and measurements used for the cephalometric analysis. Porion (Po), orbitale (Or), sella (S), nasion (N), anterior nasal spine (ANS), posterior nasal spine (PNS), point A (A), point B (B), gnathion (Gn), gonion (Go), basion (Ba), upper incisor tip (U1), lower incisor tip (L1), lower molar mesial cusp (L6), and upper molar mesial cusp (U6).

Methods

All lateral radiographs were scanned at 150 dpi and saved as JPEG files.

Lateral cephalometric analysis

The initial radiographs were digitized by one author (DK) with Viewbox 3 software (dHal Software, Kifissia, Greece). A comprehensive cephalometric analysis was performed but only 15 skeletal and dental points were used in this investigation (Figure 1).

Nine variables which represented vertical and sagittal craniofacial dimensions were calculated. These were the angles ANS–PNS to Go–Gn, S–N to ANS–PNS, cranial base angle (N–S–Ba), Po–Or to S–Gn, SNA, SNB, ANB, and the linear measurements overjet and overbite.

To assess repeatability and measurement error, 20 radiographs were randomly selected, re-digitized, and re-measured by the same investigator, after a period of at least 1 week. Systematic error was assessed by paired *t*-tests (alpha = 5 per cent) and random error was evaluated according to Houston (1983). No systematic error was detected. Random error ranged from 0.28 to 0.86 degrees for angular measurements and from 0.52 to 0.57 mm for linear measurements. The reliability coefficient ranged from 92.5 to 99.0 per cent.

Cervical spine morphology

The radiographs were visually assessed by both authors separately and the prevalence of posterior cervical artery canal morphology, atlas dehiscence, accessory ossicles, and fusions were noted.

The first cervical vertebra was classified into four types according to the morphology of the posterior margin of the lateral articular processes, as described by Farman *et al.* (1979) and Farman and Escobar (1982): type 1, posterior margins of the atlas processes almost perpendicular to the posterior arch; type 2, superior arch of the processes form a short posterior lip; type 3, superior arch of the processes extends posteriorly but does not fuse with the posterior arch; and type 4, vertebral arteries surrounded by a complete ring-shaped structure.

A posterior arch dehiscence (rachischisis) of the atlas was recorded when a uniform radio-opacity without an internal cortical outline was observed at the distal margin of the posterior arch, signifying failure of fusion (Farman *et al.*, 1979; Farman and Escobar, 1982; Sandham, 1986; Jones, 1998).

Accessory ossicles were identified as independent radio-opaque structures in close relationship to the cervical units (Farman *et al.*, 1979; Farman and Escobar, 1982).

Fusions between the cervical vertebrae were identified as osseous continuities, without complete separation at the intervertebral disc or at the articular surfaces (Farman *et al.*, 1979; Farman and Escobar, 1982; Sandham, 1986).

Interobserver agreement was evaluated by comparing the individual results. Evaluations for atlas dehiscence were identical between the investigators. Assessment of the type of articular process of the atlas showed agreement in 70 per cent of the cases. When there was disagreement, it was only between neighbouring categories. The calculated weighted kappa statistic was 0.65 (Altman, 1991).

There was no agreement for fusions; one investigator identifying 14 fusion cases between the posterior arches or articular surfaces of C2 and C3, whereas the other examiner none. For further investigation, the disputed cases were traced and superimposed.

Structural superimposition

Tracing of C2 and C3 was performed according to the recommendations of Vastardis and Evans (1996), except for the area of disputed fusion which was left untraced. Three structural superimpositions of the tracings were carried out using a best-fit criterion, taking into account normal vertebral growth with enlargement occurring at the body–disc interface by physeal ossification (Dickson and Deacon, 1987): (1) superimposition of C2, (2) superimposition of C3, and (3) superimposition of the intervertebral disc space between C2 and C3. To avoid tracing errors, similar superimpositions were conducted using the original digital image files. These were processed by imaging software (Adobe Photoshop CS3, Adobe Systems Inc., San Jose, California, USA), first by automatic contrast adjustment and then by enhancement of the outlines of the osseous structures (glowing edges filter, colourizing with contrasting colours, and superimposition using a 'difference' blending mode).

If an osseous fusion between two vertebrae exists, then two consequences are expected: (1) the relative spatial relationship between the vertebrae should remain unchanged, even under extension or flexion of the spine and (2) growth of the vertebrae should result in characteristic features, not observed under normal circumstances. Growth of the vertebrae proceeds by endochondral ossification of the physeal plates that lie between the vertebral body and the intervertebral discs (Dickson and Deacon, 1987). The growth process is similar to that occurring in long bones, with the significant difference that there is no epiphysis beyond the physeal plates, which will fuse with the vertebral body. Thus, it is not possible to determine the age of growth cessation by radiographically observing the time of epiphyseal fusion. Studies of spinal elongation (Stokes and Windisch, 2006) have shown that increases in intervertebral disc height effectively cease after 10 years, but vertebral bodies continue growing even after 20 years of age. Thus, fusion of vertebrae at the posterior processes or at the articular surfaces during a period of active growth should result in progressive diminution of the intervertebral disc space and decreased overall spine length.

Results

Lateral cephalometric analysis and craniofacial dimensions

Descriptive statistics of the cephalometric measurements are shown in Table 1.

Cervical spine morphology

The percentage of each of the four types of morphology of the posterior margin of the lateral articular processes (Farman *et al.*, 1979; Farman and Escobar, 1982) was as follows: type 1, 33.0; type 2, 51.0; type 3, 8.7; and type 4, 7.4 (average values of the two investigators).

A midline dehiscence of the posterior arches of the atlas was observed in three cases (1.9 per cent). In all three, a uniform radio-opacity of the distal margins of the divided arch was observed, while in one patient, this was associated with a thin, boomerang-shaped profile of the vertebra (Figure 2).

Formation of accessory ossicles in the area between the atlas posterior arch and the base of the skull was observed in four patients (2.6 per cent).

Fourteen patients (9 per cent) were at first identified by one investigator as presenting fusion between the C2 and C3. All revealed a uniform radio-opacity in the area between the inferior articular surface of C2 and the superior articular

Table 1 Cephalometric analysis results. All measurements in degrees except where otherwise noted.

	Mean	Standard deviation	Range
Vertical			
ANS–PNS/Go–Gn	28.4	5.85	12.0 to 50.0
S–N/ANS–PNS	7.0	3.47	−0.2 to 18.3
S–N/Go–Gn	33.9	5.52	18.0 to 51.1
Po–Or/S–Gn	59.4	3.90	51.7 to 70.7
Sagittal			
SNA	80.0	3.84	70.4 to 89.7
SNB	76.3	3.91	66.1 to 88.7
ANB	3.7	3.21	−9.2 to 10.3
Cranial base			
N–S–Ba	131.4	7.80	60.1 to 144.4
Incisor relationship			
Overjet (mm)	5.2	3.23	−3.7 to 12.4
Overbite (mm)	2.4	2.39	−6.6 to 8.8

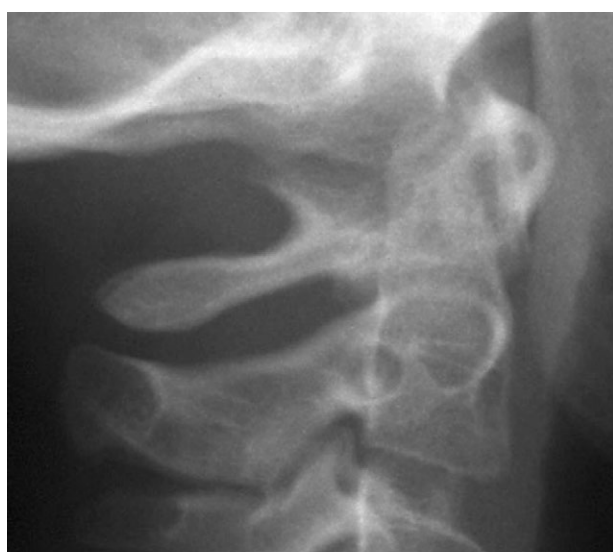

Figure 2 Patient no. 33. Atlas dehiscence.

surface of C3 on at least one of the radiographs. However, after tracing and superimposition of each of the 14 pairs of radiographs, no actual fusion was found. In all cases of suspected fusion, it was not possible to satisfactorily superimpose the complete C2–C3 structure (Figure 3). Separate superimpositions at C2 or C3 showed increased overall distancing between the two vertebrae with age, presumably an effect of unimpeded growth. The height of the intervertebral disc space remained relatively unchanged.

Relationship between facial morphology and fusion anomalies

Due to no fusions in the sample, it was not possible to arrive at any correlations between craniofacial morphology and fusion anomalies. However, since such relationships have been reported in the literature (Sonnesen and Kjær, 2007a,b, 2008a,b), a valid concern could be raised that perhaps the present sample did not encompass sufficiently 'extreme' facial types to produce a detectable number of fusions. Thus, the cephalometric results were used to calculate the expected fusions, based on the percentages reported by Sonnesen and Kjær (2007a,b, 2008a,b). The skeletal Class II category included 22 patients who had an ANB angle larger than 1 standard deviation (SD) from the average, whereas the skeletal Class III category included five patients. In the skeletal deep bite category, 24 patients were identified as having a S–N to Go–Gn angle more than 1 SD below the average; the corresponding number in the skeletal open bite category was 22. However, because of overlap with the Class II and Class III categories, these numbers were reduced to 20 and 13, respectively. Thus, by multiplying with the appropriate frequencies, the calculated total number of expected fusions was 43.

Discussion

The prevalence of cervical vertebrae anomalies has been reported in numerous studies in the literature but with a wide variation in results (Table 2). Explanations for this could include true interpopulation diversity, differences in methodological reliability, subjectivity, and lack of interobserver calibration.

Regarding fusions, two groups of studies are found, one reporting low prevalence, ranging from 0 to 4 per cent (Brown *et al.*, 1964; Ross and Lindsay, 1965; Sandham, 1986; Uğar and Semb, 2000; Giannakari, 2004; Rajion *et al.*, 2006), and the recent studies of Sonnesen and Kjær (2007a,b, 2008a,b) that quote values above 14 per cent,

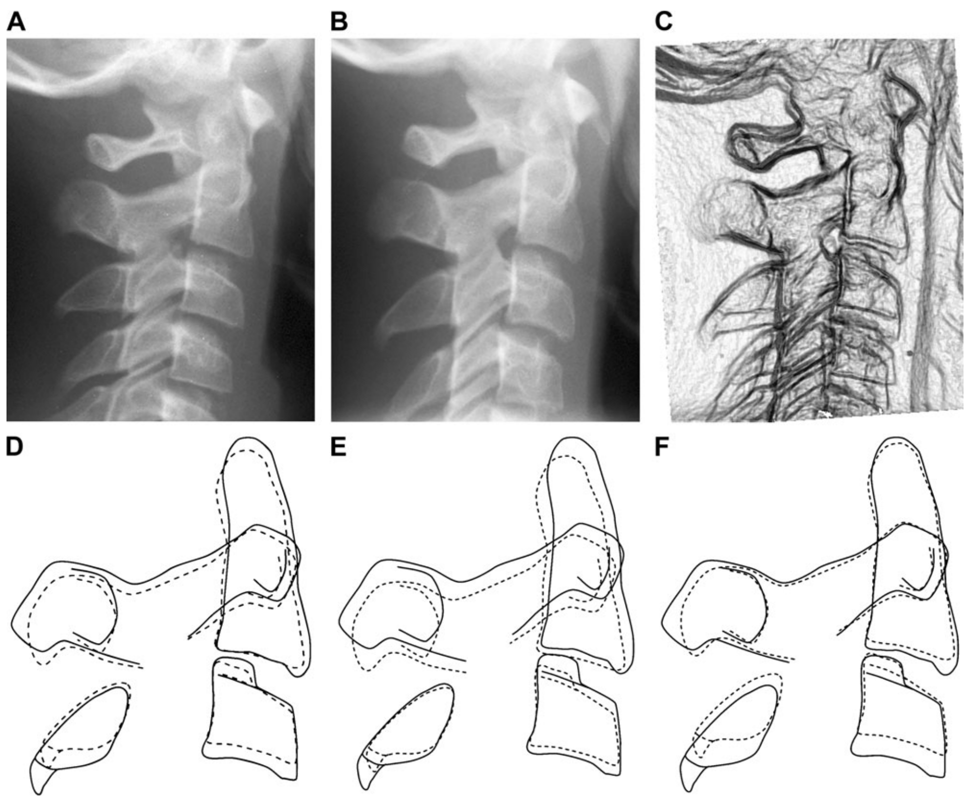

Figure 3 Patient no. 9 (male). (A) Initial radiograph at 13 years of age, (B) final radiograph 2 years later, (C) superimposition of the images at C2 after enhancement and colourization (see text; here reproduced in grey scale), and (D–F) tracing superimpositions at each of three areas: intervertebral disc space, C3, and C2, respectively. Note constant height of disc space and relative downward displacement of C3 when superimposing on C2 (C and F).

Table 2 Prevalence of cervical vertebrae anomalies as reported in the literature.

Authors	Year	Sample size	Accessory ossicles (%)	Vertebral artery type (%)	Atlas dehiscence (%)	Vertebral fusion (%)	Unspecified (%)
Brown *et al.*	1964	1400				0.71	
Ross and Lindsay	1965	800				0.75	
Farman *et al.*	1979	220	1.4	Type 1: 12.7 Type 2: 60.5 Type 3: 18.6 Type 4: 8.1	3.6		
Sandham	1986	120			0.8	0	
Horswell	1991	100					7
Uğar and Semb	2000	264			5	4.1	
Giannakari	2004	50	0		0	0	
Rajion *et al.*	2006	12			0	0	
Sonnesen and Kjær (skeletal deep bite group)	2007a	41			9.8	41.5	
Sonnesen and Kjær (skeletal Class III group)	2007b	57			12.3	61.4	
Sonnesen and Kjær (skeletal Class II group)	2008a	34			5.9	52.9	
Sonnesen and Kjær (skeletal open bite group)	2008b	38			13.2	42.1	
Sonnesen and Kjær (normal group)	2007a,b and 2008a,b	21			4.8	14.3	
Present study		156	2.6	Type 1: 33.0 Type 2: 51.0 Type 3: 8.7 Type 4: 7.4	1.9	0	

exceeding 60 per cent for skeletal Class III individuals (Table 2). The present results are in agreement with the first group, even though cephalometric analysis showed that the sample included a sufficient number of extreme skeletal patterns. On this basis, approximately 43 fusions could have been expected, a number significantly larger than even the 14 provisionally identified.

Most investigations in the orthodontic literature have used subjective visual examination of cephalometric radiographs. However, the criterion of absence of a continuous radiolucent area between the articular or spinous processes may not be valid because spine inclination, flexion or extension, and morphological variations could result in superposition of structures giving an analogous appearance. The gold standard for assessing fusions and other anomalies is direct observation on autopsy material or during surgical exploration (Brown *et al.*, 1964; Templeton and Brown, 1964; Brodsky *et al.*, 1991). No study could be identified that specifically assessed the sensitivity and specificity of cephalometric radiography in the cervical region, but studies evaluating post-surgical fusions in the lumbar region have shown low agreement between pre-operative radiographs and surgical results (Brodsky *et al.*, 1991; Blumenthal and Gill, 1993; Kant *et al.*, 1995).

Flexion–extension radiograph pairs are used extensively in the orthopaedic literature for evaluating post-surgical results of induced fusion (Brodsky *et al.*, 1991; Taylor *et al.*, 2007; Fassett *et al.*, 2008). Changes in intervertebral angulation can be assessed either by observation or by manual and computer-aided measurements (Taylor *et al.*, 2007; Fassett *et al.*, 2008). Subjective evaluation has low interobserver agreement, possibly due to lack of consensus criteria; quantitative measurements improve the results. However, flexion–extension pairs result in extra radiation dosage to the patient and this is not recommended for routine screening, considering that most fusions at the C2–C3 level remain asymptomatic and do not require any intervention (Klimo *et al.*, 2007). Even if two cephalometric radiographs, that happen to show significant differences in spine angulation, are available, measurements between the vertebrae are not expected to provide conclusive answers because the difference in angulation that can be achieved in a cephalostat is much smaller than that obtained from flexion–extension pairs taken in extreme spine angulation. In the present sample, the maximum spine angulation between C2 and C6 was approximately 20 degrees, whereas in diagnostic flexion–extension pairs, the values range from 31 to 80 degrees (Reitman *et al.*, 2004). Considering that the angulation at C2–C3 represents 15 per cent of the total (Reitman *et al.*, 2004), the maximum expected angulation between C2 and C3 in cephalometric radiography would be approximately 3 degrees, which may be difficult to measure. Furthermore, the presence of fusion does not imply zero angulation between the vertebrae because bone is inherently elastic and can exhibit deflection under stress (Bono *et al.*, 2007). There is

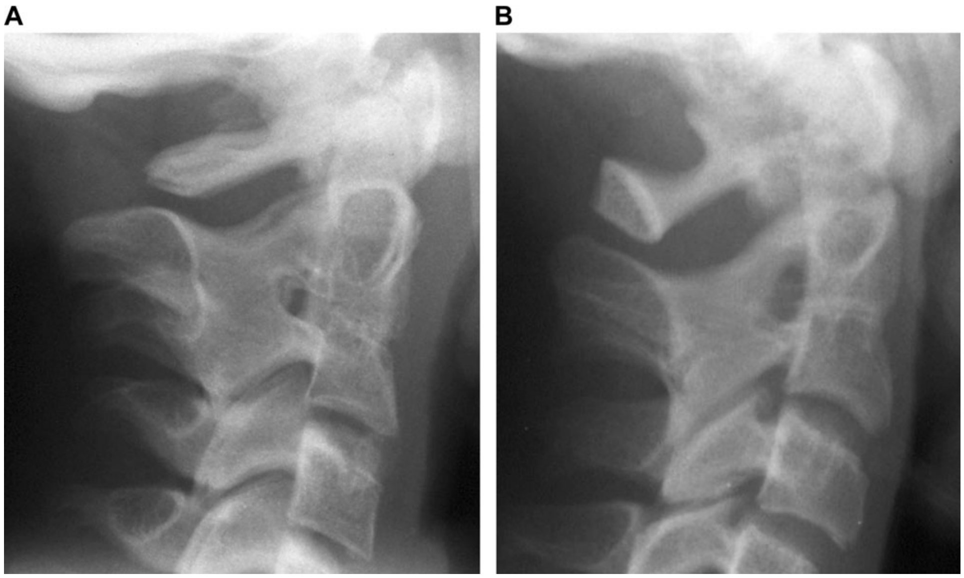

Figure 4 Obliteration of intervertebral disc space between C2 and C3 due to fusion of the articular processes. These patients were not part of the sample.

no consensus regarding the cut-off point signifying fusion but most investigators accept the value of 1.5 degrees (Taylor *et al.*, 2007; Fassett *et al.*, 2008). These factors make it unlikely that fusions could be detected with the small angular deviations seen between cephalometric radiographs.

A pre- and post-treatment orthodontic cephalogram are usually taken routinely during a period when there is active growth. Growth of the vertebrae occurs at the superior and inferior surfaces of the body in a similar manner to the epiphyseal plates of long bones (Dickson and Deacon, 1987). The intervertebral disc has been found to increase in size up to the age of approximately 10 years and remain constant thereafter, whereas the vertebral bodies increase in height beyond 20 years of age (Stokes and Windisch, 2006). In the presence of fusion, continuation of growth at the physeal plates is expected, thereby reducing or even obliterating the disc space (Brown *et al.*, 1964; Ritsilä and Alhopuro, 1975; Figure 4).

The present structural superimposition method is based on the intervening growth between the two successive cephalograms. The observed increase in vertebral body height confirms active growth, whereas separation of the vertebrae and the constant disc space confirm absence of fusion. In cases of suspected fusion at the initial examination, the time delay of 1 or 2 years is not a significant limitation, unless other signs point to syndromic conditions.

Conclusions

Assessment of fusions from a single cephalometric radiograph is highly subjective. A growth-based superimpositional method is proposed, that does not require extra radiation, beyond that used for routine orthodontic records.

Address for correspondence

Despina Koletsis
10 Rodon Street
Zografou 15772
Athens
Greece
E-mail: d.koletsi@gmail.com

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Quality of life in patients with severe malocclusion before treatment

Jaana Rusanen*, Satu Lahti**,***, Mimmi Tolvanen** and Pertti Pirttiniemi*,***
Departments of *Oral Development and Orthodontics, and **Community Dentistry, Institute of Dentistry, University of Oulu and ***Oral and Maxillofacial Department, Oulu University Hospital, Finland

SUMMARY The aim of this study was to determine the occurrence of oral health impacts among patients with severe malocclusions and dentofacial deformities before treatment. A further aim was to evaluate the effect of gender or the type of malocclusion on the oral impacts.

The study comprised 151 adult patients who were referred for orthodontic or surgical-orthodontic treatment to the Oral and Maxillofacial Department, Oulu University Hospital, Finland during the years 2001–2004. The study group consisted of 92 females and 59 males with a mean age of 35.5 years [standard deviation (SD) 11.5 years, range 16–64 years]. A self-completed Oral Health Impact Profile (OHIP)-14 questionnaire was used to measure oral impacts during a 1 month reference period. The prevalence, extent, and severity scores were calculated from the OHIP-14. Malocclusions were registered at clinical examination. The prevalence and mean extent and severity scores were compared among malocclusion groups and between genders. Statistical significance was evaluated with Mann–Whitney, Kruskall–Wallis, Chi-squared, and Fisher's exact tests.

The prevalence of oral impacts perceived fairly or very often was 70.2 per cent. The mean severity and extent scores were 17.2 (SD 10.5, range 0–45) and 2.5 (SD 2.6, range 0–10), respectively. Physical pain as well as psychological discomfort and disability were the most commonly perceived oral impacts. Being self-conscious, feeling tense, having difficulties in relaxing, and being somewhat irritable with other people were more common in females than in males. No differences were observed in oral impacts among the malocclusion groups.

Compared with a 'normal' population, patients with severe malocclusions report high levels of oral impacts. Females reported oral impacts more often than males.

Introduction

In dental research, more emphasis has traditionally been placed on clinician-driven outcome measures than on subjective patient-based measures, such as perceived functional status or psychological and social well-being (de Oliveira and Sheiham, 2003). The presence of malocclusion among other oral conditions represents only one dimension of the complex nature of oral health, and its clinical assessments have shown only a weak relationship with the perceived oral health of an individual (Locker 1988, 1992; Dini *et al.*, 2003). While clinician-driven assessment is in some respects relevant, patient-based assessment provides more substantive information concerning the impacts of oral disorders because patients are considered to be the best persons to judge their own oral health-related quality of life (OHRQoL; Cunningham and Hunt, 2001; de Oliveira and Sheiham, 2003).

Patients with severe malocclusions or dentofacial deformities may report various oral health impacts that affect their well-being in many ways. A combination of orthodontics and orthognathic surgery is, in many cases, a contemporary modality to treat these patients (Mayo *et al.*, 1991). Patients who seek orthognathic surgery often hope for a remarkable improvement in their physical well-being and quality of life. Problems in the facial region in general, such as those of chewing, speaking, and periodontal disease, are common physical complaints in patients with severe malocclusions (Scott *et al.*, 1999). Improvement in aesthetics is a significant motivating factor to undergo orthodontic or orthognathic treatment, and some of these patients report concerns with body image and a low self-esteem or self-concept (Scott *et al.*, 1999). Temporomandibular joint problems and external motivation (such as the need to please others) are also common reasons to seek orthognathic treatment as well as a need to gain aesthetic or functional improvement (Cunningham *et al.*, 1995).

According to the review by Cunningham and Hunt (2001), only limited data are available on orthodontic patients' OHRQoL, and changes in quality of life have more often been studied in relation to orthognathic surgery than orthodontic treatment. One reason for this might be that patients undergoing orthognathic surgery have more severe problems and are thus more likely to benefit psychologically from improved facial and dental appearance and have a possible increase in self-confidence compared with patients treated only by orthodontics (Kiyak *et al.*, 1982, 1984; Cunningham *et al.*, 2000). O'Brien *et al.* (1998) stated that the majority of oral health measures developed in dentistry are not applicable to orthodontic patients because most indications for orthodontic treatment are asymptomatic and related to aesthetics, as opposed to features such as pain or discomfort. For this reason, it is important to use self-report instruments to determine the patients' own views and feelings along with clinical outcome indicators (Cunningham and Hunt, 2001). These instruments should measure several dimensions of oral health as described by Locker (1988). Of the several measures of OHRQoL (Locker and Allen, 2007), one of the most commonly used is the Oral Health Impact Profile (OHIP) or its short form OHIP-14. The measure was based on the International Classification of Impairments, Disabilities, and Handicaps model of disease and its consequences (Locker, 1988). OHIP intends to assess the social impact of oral disorders, i.e. the dysfunction, discomfort, and disability caused by these conditions (Locker and Allen, 2007). It includes seven sub-scales: functional limitation, physical pain, physiological discomfort, physical disability, psychological disability, social disability, and handicap (Slade and Spencer, 1994). These aspects represent the hierarchy of impacts that can affect a patients' daily life and motivate them to seek orthodontic or orthognathic treatment.

The purpose of this study was to determine the occurrence of oral health impacts among patients with severe skeletal malocclusions who required orthodontic and/or orthognathic surgery. A further aim was to determine the effect of gender or type of malocclusion on oral impacts.

Subjects and methods

The study was approved by the Ethics Committee of the Northern Ostrobothnia Hospital District.

This was a secondary analysis of a data collected for a longitudinal study. The original study group comprised 249 adult patients, all of whom had severe, diagnosed skeletal malocclusions with considerable functional disorders and who were awaiting orthodontic or surgical-orthodontic treatment at the Oral and Maxillofacial Department at Oulu University Hospital. From these, 170 patients agreed to participate in this study, which included a questionnaire survey and clinical examination. The study was performed during the years 2001—2004, and the final study group comprised 92 (61 per cent) females and 59 (39 per cent) males. The mean age of the participants was 35.5 years (SD 11.5 years, range 16–64 years).

Data were collected using a standardized, self-completed questionnaire that included a Finnish translation of the OHIP-14 measure with a 1 month reference period and questions on age and gender. In the OHIP questionnaire, subjects were asked, for example, the following: 'Have you found it uncomfortable to eat any foods because of problems with your teeth, mouth, or dentures?' Five ordinal response categories were coded with the following values: 0, 'never'; 1, 'hardly ever'; 2, 'occasionally'; 3, 'fairly often'; and 4,'very often'. The Finnish OHIP-14 has been found to be valid and reliable (Sutinen *et al.*, 2007; Lahti *et al.*, 2008).

The subjects were invited to a clinical examination and the questionnaire was given to them to fill in at home. A self-addressed envelope was provided for return of the questionnaire. The clinical examinations were conducted by one author (JR) who had undergone training in stomatognathic examinations before measurements. Overbite was defined as a vertical overlap of the right central incisor (mm) and overjet as a horizontal overlap of the right central incisor (mm). The bite was considered to be open when there was no occlusal contact (less than 0 mm), and a deep bite was diagnosed when the overbite was 4 mm or more. A reverse overjet was registered when the overjet was less than 0 mm (negative) and an increased overjet when the overjet was 4 mm or more. A posterior crossbite was registered when a canine or one or more upper premolars or molars occluded more palatally than the lower teeth (transverse discrepancy) and a scissor bite when a canine, premolar, or molar occluded entirely buccal to the lower arch teeth. A lateral open bite was registered when there was no occlusal contact of one or more upper and lower premolars or molars unilaterally or bilaterally. Sagittal (antero-posterior) molar relationship was graded using Angle's classification of the first permanent molars bilaterally. When the molar relationship was cusp to cusp, it was classified as an Angle Class II malocclusion. The oral measurements were performed using articulating paper (lateral scissor bite, crossbite, and open bite) and a periodontal probe (overjet and overbite).

Three variables were calculated from the OHIP-14. 'Prevalence' described the percentage of the participants reporting one or more items 'fairly often' or 'very often'. The 'severity' score (potential range 0–56) was calculated by summing ordinal values for the 14 items. Higher scores indicated poorer oral health and disability. The 'extent' score (potential range 0–14) was calculated by summing the number of items reported 'fairly often' or 'very often'. Those participants who had three or more missing OHIP items or three 'don't know' responses were omitted from analysis, and for participants with one or two missing OHIP items, the values were replaced with the sample mean for the group. Adequate clinical and questionnaire data were available for 151 subjects who were included in the analyses.

Distribution of the prevalence scores and the mean levels of the extent and severity scores between malocclusion groups and between genders were calculated. As the distributions of the extent and severity scores were not normally distributed, the statistical significances of the differences between the groups were evaluated using the non-parametric Mann–Whitney and Kruskall–Wallis tests. Chi-squared and Fisher's exact tests were used to evaluate the statistical significance of the differences in prevalence between the groups. Statistical analyses were performed using the Statistical Package for Social Sciences for Windows version 16.0 (SPSS Inc., Chicago, Illinois, USA).

Results

The prevalence of oral impacts in this study was 70.2 per cent. The mean severity score was 17.2 (SD 10.5, range 0–45) and the mean extent score 2.5 (SD 2.6, range 0–10). Distribution of the patients according to their malocclusions is presented in Table 1. Of the patients, 3.3 per cent (five) were using removable dentures.

The percentage distributions of OHIP-14 items reported occasionally, fairly often, or very often among participants are shown in Figure 1. Because of problems with their teeth, mouth, or dentures during the previous month, 67.6 per cent of the participants had felt pain or discomfort occasionally 36.4 per cent, fairly often 19.9 per cent, or very often 11.3 per cent. Over two-thirds (69.5 per cent) had found it uncomfortable to eat. Being self-conscious with their teeth, mouth, or dentures was reported by 69.5 per cent of the participants and more than a half (57.6 per cent) had occasionally (27.8 per cent), fairly often (15.2 per cent), or very often (14.6 per cent) felt tense. Nearly half of the participants (49 per cent) had felt that life in general was less satisfying, and 47 per cent had found it difficult to relax. Despite very severe impacts on their oral health, only 5.3 per cent of the subjects with a severe malocclusion or dentofacial deformity had been totally unable to function.

Table 1 Distribution of the patients according to their malocclusions.

Malocclusion	Gender					
	All		Female		Male	
	n	%	*n*	%	*n*	%
Class II	67	44	47	51	20	34
Class III	25	17	11	12	14	24
Lateral crossbite	53	35	30	33	23	39
Lateral scissor bite	41	27	26	28	15	24
Lateral open bite	35	23	18	20	17	29
Open bite	15	10	11	12	4	7
Deep bite (>4 mm)	81	54	47	51	34	58

Females tended to report oral impacts (fairly often and very often responses) related to the teeth, mouth, or dentures more often than males (Table 2). The differences were statistically significant in the psychological and social dimensions of OHIP-14, i.e. females reported being self-conscious, feeling tense, difficulties in relaxing, and being a bit irritable with other people significantly more often than males.

When comparing prevalence rates among participants with different malocclusions, statistically significant differences were found in the lateral crossbite, open bite, reverse overjet, and Class II malocclusion groups. Participants with a lateral crossbite had more often been a bit embarrassed because of problems related to their teeth, mouth, or dentures ($P = 0.039$) when compared with patients with transverse normal dimensions of the lateral teeth. Subjects with an open bite reported discomfort more often

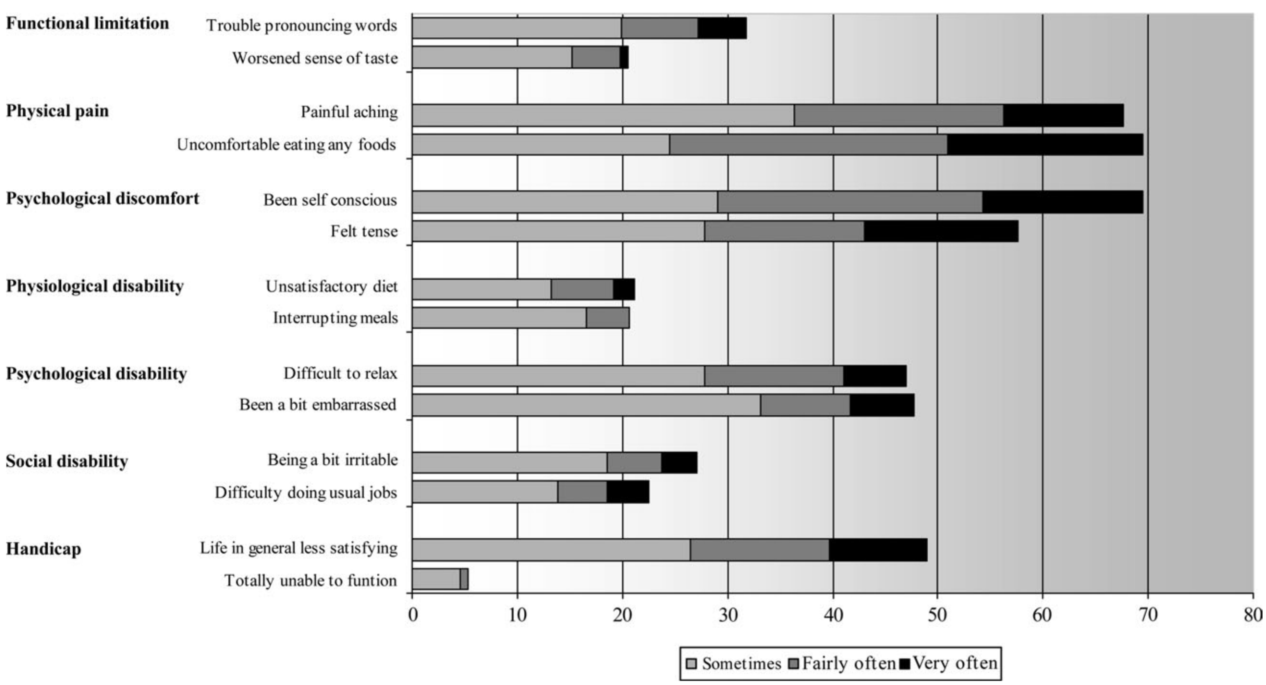

Figure 1 Percentage distribution of occasionally, fairly often, or very often responses to each Oral Health Impact Profile-14 items among patients with severe malocclusions before orthodontic or orthognathic treatment.

Table 2 Percentage of 'fairly often' or 'very often' Oral Health Impact Profile-14 responses and the mean extent and severity scores among males and females.

DHIP items	Gender			
	All	Males	Females	*P*
Trouble pronouncing words	12	10	13	0.595
Worsened sense of taste	5	3	7	0.483
Painful aching	31	22	37	0.053
Uncomfortable eating any foods	45	39	49	0.231
Being self-conscious	40	25	50	0.003
Felt tense	30	10	42	0.000
Unsatisfactory diet	8	3	11	0.128
Interrupting meals	4	0	7	0.082
Difficult to relax	19	5	28	0.000
Been a bit embarrassed	15	9	19	0.089
Been a bit irritable	9	0	14	0.003
Difficulty doing usual jobs	9	5	11	0.216
Life in general less satisfying	23	19	25	0.362
Totally unable to function	1	0	1	1.000
Extent score	2.5	1.5	3.1	<0.001
Severity score	17.2	13.5	19.6	<0.001

P values between males and females for the item-wise values from chi-square tests and for the mean extent and severity scores from Mann–Whitney tests.

when eating any foods ($P = 0.020$) than those with a normal vertical overlap or deep bite. Patients with a reverse overjet reported being slightly more embarrassed ($P = 0.022$) and irritable with other people ($P = 0.025$) more often when compared with those with a positive overjet. Class II malocclusion subjects were less self-conscious in relation to their teeth, mouth, or dentures ($P = 0.043$) and had an unsatisfactory diet less often ($P = 0.044$) compared with those with a Class III or other malocclusion. There were no statistically significant differences in the OHIP-14 severity and extent scores between different malocclusion groups.

Discussion

Patients with skeletal malocclusions were found to have high levels of subjective oral impacts in all malocclusion groups. The total prevalence of reported oral impacts was greater than 70 per cent. This prevalence is seven times higher when compared with the results of the National Health 2000 survey among adult Finns aged 30 years and older (Lahti *et al.*, 2008), and even higher when compared with 30 to 44 year olds. Differences in the severity and extent scores were also greater when compared with those reported in a nationally representative study among Finns (Lahti *et al.*, 2008). The the severity score was four times higher and the extent score eight times higher in the present study. The severity scores were over two to four times higher and the extent scores five to seven times higher compared with those of dentate adults in the United Kingdom and Australia (Slade *et al.*, 2005). Of the patients in this study, 3.3 per cent were using removable dentures. Among adults Finns, the difference in the severity scores between subjects wearing and not wearing removable dentures was 6.43 and 2.83, respectively (Lahti *et al.*, 2008). Thus, the use of dentures did not have a major contribution to the high severity reported by the patients in this investigation. In a recent study (Lee *et al.*, 2007), the mean severity OHIP-14 score of 152 Chinese patients with dentofacial deformities was 15.0, which is in agreement with the scores found in the present investigation. Despite the different reference periods used in Finland (1 month) and in the United Kingdom and Australia (12 months; Slade *et al.*, 2005), the mean severity and extent scores of OHIP-14 may be compared with a reasonable degree of confidence (Sutinen *et al.*, 2007).

However, there are some oral conditions that seem to have almost equally high oral impacts as severe malocclusions. For example, patients' OHRQoL is significantly aggravated by a dry mouth and xerostomia (Locker 2003; Thomson *et al.*, 2006). In a study by Ikebe *et al.* (2007), elderly Japanese dry mouth and xerostomia patients had an almost similar severity score (16.8, SD 8.3) as the malocclusion patients in this study. It seems that a severe malocclusion usually impairs a patient's quality of life more than other oral conditions in the general population. For example, it was found that patients' quality of life was impaired by removable and full dentures but not to the same extent as by malocclusions (Lahti *et al.*, 2008). Interestingly, malocclusion patients felt uncomfortable eating at least twice as often compared with those with dentures, and they suffered psychological disability related to their oral conditions nearly four times more often (Lahti *et al.*, 2008). Painful biting was also more than three times more common in malocclusion patients compared with those with dentures.

All 14 OHIP items showed higher scores in malocclusion patients, and the profile of the item-wise responses was different from adult Finns (Lahti *et al.*, 2008). Reported physical pain and psychological discomfort occurred four times more often among patients with a severe malocclusion than among adult Finns. Psychological disability, such as difficulty relaxing, was reported nearly 10 times more often and being a bit embarrassed over seven times more often in malocclusion patients compared with Finnish adults. The participants of this study reported social disability, such as being a bit irritable or having difficulty doing their usual work, eight times more often and felt life in general to be less satisfying seven times more often than adult Finns. This may be a consequence of the multifactorial nature of the malocclusions and may possibly be the reason to seek treatment.

All participants in this study had been diagnosed with severe skeletal malocclusions with considerable functional disorders. Among the malocclusion groups, differences in oral health impacts were found in the lateral crossbite, open bite, reverse overjet, and Class II malocclusion groups. For example, patients with an open bite reported more often that they found it uncomfortable to eat, which could be explained by difficulty in biting. Patients with a reverse overjet felt more often a bit embarrassed and being a bit irritable with other people, possibly due to their facial appearance. Interestingly, participants with a Class II malocclusion were, in this study, found to be less often self-conscious in relation to their teeth, mouth, or dentures and had less often had an unsatisfactory diet compared with those with a Class III or other malocclusion. In this study, a number of subjects had combinations of different malocclusions. It is not always clear to resolve which of those malocclusions caused subjective oral impacts.

Females reported severe oral impacts more often when compared with males. This is in agreement with the study of McGrath and Bedi (2000) on gender variations in the social and psychological impacts of oral health. They found that compared with males, oral health had a greater impact on the quality of life of females, both positively and negatively. Those authors also stated that females perceived oral health as enhancing their quality of life, in particular their appearance, moods, and general well-being. On the other hand, in the Finnish National Health 2000 survey (Lahti *et al.*, 2008), there were only minor differences between females and males, a finding that differs from the results of the present study. The severity score of males was slightly higher (4.2 versus 13.5) than that of females (3.9 versus 19.6).

There are many reasons to seek orthodontic treatment. Aesthetic improvement of appearance is a significant motivating factor to undergo orthodontic or orthognathic treatment and is often related to the social well-being of the patient (Heldt *et al.*, 1982). de Oliveira and Sheiham (2003) estimated that 80 per cent of orthodontic patients seek orthodontic treatment due to aesthetic rather than health-related or functional concerns, and Mayo *et al.* (1991) estimated that dental function was as significant as aesthetics, while temporomandibular disorders was an additional reason. Scott *et al.* (1999) stated that disorders such as severe pain and psychological, physiological, or social disabilities are compelling reasons to seek treatment. In this study, physical pain as well as psychological discomfort and disability were the most common oral impacts in malocclusion patients before treatment. In most cases, there was more than one reason to seek orthodontic treatment. However, the main aim when seeking treatment is to restore physiological, physical, social health, and well-being.

As this was a secondary analysis of a data collected for a longitudinal study, no power calculations were performed. Some significances in the differences between malocclusions may have been higher if the study group was larger. The OHIP-14 measure used was previously found to be reliable and valid (Sutinen *et al.*, 2007), but intra-examiner reliability was not assessed. However, all clinical measurements were performed by one trained author using same instrumentation.

Conclusions

Patients with severe malocclusion or dentofacial deformities reported significantly higher levels of oral health impacts than the general population, and it seems that severe malocclusion impairs patients' quality of life more than many other oral conditions. Females tend to suffer more from oral impacts than males, but there were no specific malocclusions that caused discomfort or pain affecting a patient's well-being more often compared with others.

Address for correspondence

Dr Jaana Rusanen
Department of Oral Development and Orthodontics
Institute of Dentistry
University of Oulu
P.O.Box 5281
FIN-90014 University of Oulu
Finland
E-mail: jaana.rusanen@oulu.fi

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Prevalence of orthodontic treatment need in southern Italian schoolchildren

Letizia Perillo*, Caterina Masucci**, Fabrizia Ferro*, Davide Apicella* and Tiziano Baccetti**
Departments of Orthodontics, *University of Naples (Second University) and **University of Florence, Italy

SUMMARY The present survey was performed to determine orthodontic treatment need in a large sample (*n* = 703) of 12-year-old schoolchildren from the southern part of Italy. The sample comprised 331 males (47 per cent) and 372 females (53 per cent), all orthodontically untreated. Two examiners, who had been previously trained in the use of occlusal indices, screened all the schoolchildren. The prevalence rates for the Dental Health Component (DHC) of the Index of Orthodontic Treatment Need (IOTN) as well as for occlusal features (Angle Class, overjet, overbite, crowding, posterior crossbite) were calculated for the total sample. The IOTN grades were statistically compared in the two genders using the chi-square test.

The findings indicated that this southern Italian school population showed a rather low prevalence rate for objective need for treatment (grades 4 and 5; 27.3 per cent of the total sample). This prevalence rate is generally lower than those reported in northern and central European countries (Sweden, Germany, and UK) but slightly greater than those in France. No significant differences in the DHC grades of the IOTN were found between genders. Among the occlusal features diagnosed in the subjects examined, a high prevalence rate was found for crowding (45.9 per cent). Moreover, posterior crossbites and Class III malocclusions, which would presumably have benefited from early orthodontic intervention, were still present in 14.2 and 4.3 per cent of the students, respectively.

Introduction

During the last three decades, a notable increase in orthodontic treatment demand has occurred as a consequence of the high perception rate of malocclusions, along with a greater attention to aesthetics. However, disagreement still exists regarding the definition of 'normal occlusion', while objective methods to define orthodontic treatment need are necessary.

Several studies have attempted to provide epidemiological reports of the prevalence of malocclusions in different ethnic groups (Brunelle *et al.*, 1996; Tschill *et al.*, 1997; Thilander *et al.*, 2001). With this aim, some authors (Brunelle *et al.*, 1996; Tschill *et al.*, 1997) have chosen measures of single occlusal traits (Björk *et al.*, 1964) as well as Angle's classification (Angle 1907). Recently, orthodontic treatment need has been expressed by a series of indices including the Dental Aesthetic Index (Baca-Garcia *et al.*, 2004), the Treatment Priority Index (Uğur *et al.*, 1998), the Index of Complexity Outcome and Need (Liepa *et al.*, 2003), and the Index of Orthodontic Treatment Need (IOTN; Brook and Shaw, 1989). The IOTN is based on a Dental Health Component (DHC) and an Aesthetic Component; it has been described extensively (Brook and Shaw, 1989). With regard to previous methods, the IOTN is objective, synthetic, and allows for comparisons between different population groups (Shaw *et al.*, 1991; Cooper *et al.*, 2000).

Whereas northern and central European populations, such as Swedes (Josefsson *et al.*, 2007), Britains (Chestnutt *et al.*, 2006), Germans (Tausche *et al.*, 2004), and French (Souames *et al.*, 2006), have been the object of a great number of surveys, there are very few investigations that have evaluated the prevalence of malocclusions (Ciuffolo *et al.*, 2005) and orthodontic treatment need (Nobile *et al.*, 2007) in southern European ethnic groups.

The purpose of the present epidemiologic study was to evaluate the orthodontic features of 12-year-old schoolchildren in southern Italy by means of the IOTN, with the aim of obtaining information for public health planning for orthodontic screening and prevention and of providing data that could be compared with the findings of other European surveys.

Subjects and methods

Study population

The study target population consisted of schoolchildren attending the second year of secondary school (corresponding to the eighth grade) of state-funded schools in Naples (Southern Italy). Forty-eight schools (13 000 pupils) were randomly selected according to a cluster sampling design from an initial pool of 79 schools that had been previously identified by the school district to avoid possible biases ensuing from social heterogeneity. Classes within schools were sampled systematically. All students belonging to the sampled classes were examined, both to improve study feasibility and so as not to discriminate among pupils in the same class. Written consent to the examination was obtained from the children and their parents.

Final sample

Sample size was calculated assuming a 50 per cent prevalence ratio for any characteristics to be estimated, and a precision of the estimate of ±3 with a 95 per cent confidence interval (sampling from finite population, nQuery Advisor, v. 4.0, Statistical Solution Ltd, Cork, Ireland). This assumption leads to the highest sample size with the given precision. Nine hundred and eighty-seven students were randomly selected according to a cluster sampling design.

All selected children present at the schools on the day of the examination (888 subjects) participated in the study. Students who had already finished their orthodontic treatment and those who were undergoing treatment at the time of the study were excluded. Therefore, the sample for final analysis comprised only orthodontically untreated subjects.

Clinical examination

The students were examined at the schools, in a quiet classroom without external interference, under natural or artificial illumination. The examination lasted approximately 15 minutes per child, following the World Health Organisation (1985) guidelines. The assessment of dental occlusion was carried out using latex gloves, dental mouth mirrors, and millimetric rulers. No radiographs, study casts, or previous written records were used. Personal data and information about orthodontic treatment were obtained directly from the students. The clinical examination was carried out by two examiners (LP and FF), who had previously undergone calibration to standardize their procedures.

Orthodontic variables

Molar relationship. The relationship between the upper and lower first permanent molars was determined according to Angle's classification. Patients with subdivision malocclusions were included in the Class II or Class III groups on the basis of the predominant occlusal characteristic, or according to the relationship between the canines.

Overjet and Overbite. Values between 0 and 4 mm were considered normal.

Posterior crossbite. A posterior crossbite was diagnosed when there was a crossover of at least one tooth in the posterior segments of the dental arches. A posterior crossbite could be unilateral (right or left) or bilateral.

Scissor bite. A scissor bite was considered to be present when the palatal cusps of the upper molars were positioned buccally in relation to the buccal cusps of the lower molars.

Crowding and diastemas. These were recorded for the anterior as well as for the posterior segments. A midline diastema was considered to be present when there was a space of at least 2 mm between the maxillary central incisors.

Orthodontic treatment need

The need for orthodontic treatment was assessed by means of the DHC of the IOTN (Brook and Shaw, 1989). The DHC of the IOTN has five grades: grades 4 and 5 represent high priority for treatment, grade 3 borderline need, and grades 1 and 2 no or little need for treatment (Table 1).

Statistical methods

Descriptive statistics were calculated for the prevalence ratio (and confidence intervals) of orthodontic variables and IOTN DHC grades. The significance of differences for IOTN DHC grades between genders was assessed by means of chi-square tests ($P < 0.05$). All statistical analyses were performed using S-Plus (S-Plus 8 Enterprise Developer, Insightful, Seattle, Washington, USA).

Results

A total of 888 students (mean age 12.2 years with a standard deviation of 0.6 years) from 44 secondary schools in Naples were examined. One hundred and eighty-five students were excluded because either they had received orthodontic treatment (65) or were currently undergoing orthodontic treatment (120). The final sample comprised 703 subjects (331 males, 47 per cent, and 372 females, 53 per cent).

Table 2 shows the distribution of the sample according to the DHC of the IOTN. An objective treatment need was recorded in 27.3 per cent of the schoolchildren (grades 5 and 4); 36.7 per cent were assigned to borderline need (grade 3) and 35.8 per cent to little/no need of orthodontic treatment (grades 1 and 2). No statistical difference with regard to DHC grades was found between genders ($P = 0.43$; Table 3).

The prevalence of each occlusal trait in the total sample is reported in Table 4. The highest prevalence was found for a Class I malocclusion (59.5 per cent), which was followed by crowding (45.9 per cent). Class II and Class III prevalence rates were 36.3 and 4.2 per cent, respectively. An overjet greater than 4 mm was present in 144 subjects (16.2 per cent), while 0.6 per cent had a negative overjet. Open bite prevalence was 0.7 per cent, and a deep bite was recorded in 179 subjects (20.2 per cent). For the variables in the transverse plane, a crossbite was present in 14.2 per cent, with a unilateral crossbite (11.2 per cent) more frequent than a bilateral crossbite (2.9 per cent).

Discussion

The orthodontic features of single populations have been the object of several investigations in different European countries

Table 1 Grades of the Dental Health Component of the Index of Orthodontic Treatment Need. (Reproduced from Brook P H, Shaw WC 1989 The development of an index of treatment priority. European Journal of Orthodontics 11: 309–320, with permission of Oxford University Press).

Grade 5—Very great
Defects of cleft lip and/or palate.
Increased overjet greater than 9 mm.
Reverse overjet greater than 3.5 mm with reported masticatory or speech difficulties.
Impeded eruption of teeth (with the exception of third molars) due to crowding, displacement, the presence of supernumerary teeth, retained primary teeth, and any other pathological cause.
Extensive hypodontia with restorative implication (more than one tooth missing in any quadrant) requiring pre-restorative orthodontics.
Grade 4—Great
Increased overjet greater than 6 mm but less than or equal to 9 mm.
Reverse overjet greater than 3.5 mm with no reported masticatory or speech difficulties.
Reverse overjet greater than 1 mm but less than or equal to 3.5 mm with reported masticatory or speech difficulties.
Anterior or posterior crossbites with greater than 2 mm displacement between retruded contact position and intercuspal position.
Posterior lingual crossbites with no occlusal contact in one or both buccal segments.
Severe displacement or teeth greater than 4 mm.
Extreme lateral or anterior open bite greater than 4 mm.
Increased and complete overbite causing notable indentation on the palate or labial gingivae.
Patient referred by colleague for collaborative care, e.g. periodontal, restorative, or TMJ considerations.
Less extensive hypodontia requiring pre-restorative orthodontics or orthodontic space closure to obviate the need for a prosthesis (not more than one tooth missing in any quadrant).
Grade 3—Moderate
Increased overjet greater than 3.5 mm but less than or equal to 6 mm with incompetent lips at rest.
Reverse overjet greater than 1 mm but less than or equal to 3.5 mm.
Increased and complete overbite with gingival contact but without indentations or signs of trauma.
Anterior or posterior crossbites with less than or equal to 2 mm but greater than 1 mm displacement between retruded contact position and intercuspal position.
Moderate lateral or anterior open bite greater than 2 mm but less than or equal to 4 mm.
Moderate displacement of teeth greater than 2 mm but less than or equal to 4 mm.
Grade 2—Little
Increased overjet greater than 3.5 mm but less than or equal to 6 mm with competent lips at rest.
Reverse overjet greater than 0 mm but less than or equal to 1 mm.
Increased overbite greater than 3.5 mm with no gingival contact.
Anterior or posterior crossbites with less than or equal to 1 mm displacement between retruded contact position and intercuspal position.
Small lateral or anterior open bites greater than 1 mm but less than or equal to 2 mm.
Pre-normal or post-normal occlusions with no other anomalies.
Mild displacement of teeth greater than 1 mm but less than or equal to 2 mm.
Grade 1—None
Other variation in occlusion including displacement less than or equal to 1 mm.

Table 2 Prevalence of the grades of the Dental Health Component of the Index of Orthodontic Treatment Need as assessed in the total sample (n = 703).

Grade	*n*	%	95% Confidence interval*
1	49	6.9	4.8–8.2
2	203	28.9	26–32.0
3	258	36.7	33.7–40.2
4	173	24.6	22.1–27.8
5	20	2.7	1.7–3.9

*Exact binomial test.

Table 3 Prevalence of the grades of the Dental Health Component of the Index of Orthodontic Treatment Need in the total sample (n = 703) divided according to gender. No statistical difference with regard to DHC grades was found between genders (P = 0.43).

Grades	Females (n = 372)	Males (n = 331)
1	28 (4.0%)	21 (2.9%)
2	114 (15.9%)	89 (13.0%)
3	138 (19.7%)	120 (17.0%)
4	83 (11.**6%)**	90 (13.0%)
5	9 (1.2%)	11 (1.5%)

with the purpose of recording the prevalence of malocclusions and of evaluating orthodontic treatment need. While data are widely available with regard to northern and central European populations, there is a lack of surveys that have analysed the oral health status of southern Europeans.

In the present study, the DHC of the IOTN was used to record the orthodontic treatment need of the population by means of an objective and synthetic method (Shaw *et al.*, 1991; Cooper *et al.*, 2000). According to the index, 27.3 per cent of the whole sample, that included 703 schoolchildren, was classified as being in need of orthodontic treatment (grades 5 and 4). This prevalence rate is useful for comparison with that reported by the vast majority of European surveys on similar samples of orthodontically untreated subjects. The results show that the percentage is relatively greater than those reported by Souames *et al.* (2006)

Table 4 Prevalence of occlusal variables in the total sample (*n* = 703).

Occlusal variables	*n*	%	95% Confidence interval*
Sagittal variables			
Class I	418	59.5	56.1–62.7
Class I—incisal relationship 1	402	57.2	53.8–60.5
Class I—incisal relationship 2	14	1.9	1.1–3.0
Class I—incisal relationship 3	2	0.3	0.1–0.9
Class II	255	36.3	33.1–39.5
Class II division 1	92	13.1	10.9–15.4
Class II division 1 subdivision	145	20.6	17.9–23.4
Class II division 2	18	2.6	1.6–3.9
Class II division 2 subdivision	0	0	
Class III	30	4.3	3.0–5.8
Class III subdivision	12	1.7	0.09–2.8
Overjet >4 mm	114	16.2	13.8–18.8
Overjet 0–4 mm	585	83.2	80.6–85.6
Overjet <0 mm	4	0.6	0.2–1.3
Vertical variables			
Overjet >4 mm	142	20.2	17.6–22.9
Overbite 0–4 mm	556	79.2	76.3–81.8
Overbite <0 mm	5	0.7	0.2–1.4
Transverse variables			
Crossbite	100	14.2	11.9–16.7
Unilateral right	40	5.7	4.3–7.5
Unilateral left	39	5.5	4.1–7.2
Bilateral	21	2.9	1.9–4.3
Scissor bite	22	3.5	2.1–4.5
Crowding and diastemas			
Crowding	323	45.9	42.6–49.2
Upper arch—anterior	92	13.1	10.9–15.4
Upper arch—diffuse	28	4.1	2.8–5.6
Lower arch—anterior	264	37.5	34.3–40.8
Lower arch—diffuse	27	3.8	2.6–5.3
Diastemas	161	22.9	20.2–25.9
Upper arch—midline	68	9.9	7.8–11.8
Upper arch—diffuse	58	8.2	6.5–10.2
Lower arch—midline	15	2.1	1.2–3.3
Lower arch—diffuse	46	6.5	4.9–8.4

*Exact binomial test.

of schoolchildren aged 9–12 years from the Department of Val d'Oise, France (21.3 per cent). On the contrary, the majority of the British studies conducted on similar target populations found a higher prevalence rate for objective orthodontic treatment need in previously untreated subjects: 32.7 per cent (Brook and Shaw, 1989), 33 per cent (Burden and Holmes, 1994) in 11- to 12-year-old school populations in Manchester and Sheffield, and approximately 35 per cent in more recent British reports (Chestnutt *et al.*, 2006). Finally, in a Swedish sample of 12- to 13-year-old students, objective orthodontic treatment need was found in 39.5 per cent of the examined subjects (Josefsson *et al.*, 2007). The findings of the present study, therefore, indicate that a substantial need for orthodontic intervention was present at a similar level to French children but generally lower than northern European populations (United Kingdom and Sweden).

With regard to the occlusal findings, the highest prevalence was for crowding, which affected more than 45 per cent of the subjects, mostly within a Class I malocclusion. Over one-third (36.3 per cent) of the examined population had a Class II malocclusion. These findings serve as reference data for the epidemiology of malocclusions at an age which is frequently considered as the optimal time for treatment of many of these dentoskeletal disharmonies (Malmgren *et al.*, 1987; Gianelly, 1995; Baccetti *et al.*, 2000; McNamara and Brudon, 2001). However, the Swedish population (Josefsson *et al.*, 2007) exhibited a higher percentage of Class II malocclusions (48.8 per cent). Posterior crossbites were present in 14.2 per cent of the subjects and Class III malocclusions in 4.3 per cent. The prevalence rates for these occlusal disharmonies appear to be very high especially when early treatment in the primary or early mixed dentition has been recommended for these types of malocclusions (Thilander *et al.*, 1984; McNamara and Brudon, 2001; Franchi *et al.*, 2004).

The present study examined the occlusal conditions of orthodontically untreated schoolchildren in southern Italy. During examination of the initial total sample of subjects participating in the survey (*n* = 888), it was found that 185 students (21 per cent) had been previously treated or were currently undergoing orthodontic treatment. This prevalence rate is less than that reported in studies conducted in Sweden (Josefsson *et al.*, 2005) and Germany (Bissar *et al.*, 2007; 28 per cent and 48 per cent, respectively). It should be noted that the age of the subjects examined corresponded to the phase of change from the mixed to the permanent dentition during the circumpubertal period, a physiological stage when the majority of orthodontic treatment approaches are recommended (Malmgren *et al.*, 1987; Gianelly, 1995; Baccetti *et al.*, 2000; McNamara and Brudon, 2001). The results of the present study are thus similar to the findings of Nobile *et al.* (2007) in a sample of 546 students who were 12 years old in Calabria, southern Italy (15.9 per cent). Therefore, it appears that in the late mixed or early permanent phases of the dentition, in Southern Italy only one subject in five is an orthodontic patient, a prevalence rate which is lower than northern or central European countries (Sweden and Germany).

It appears that there is a reasonable balance between a definite orthodontic treatment need and the actual implementation of orthodontic treatment in some of the European countries considered. For instance, the increased need for orthodontic treatment in the Swedish population corresponds to a rather high prevalence of orthodontic therapies (Josefsson *et al.*, 2005), and a similar correlation can be derived from the southern Italian data, where a rather low prevalence rate of orthodontic treatment is associated with a rather low prevalence of treatment need. On the other hand, different countries may present with discrepancies in this relationship: in the UK a very low percentage (8 per cent) of subjects exhibited an orthodontic treatment need at the age of 12 years in contrast with a high prevalence rate of treatment need (35 per cent; Chestnutt *et al.*, 2006). It should be taken into account, however, that the current survey found a high prevalence (37 per cent) of schoolchildren assigned to grade 3 of the DHC of the IOTN. These subjects, with borderline malocclusions, such as increased overjet (ranging from 3.5 to 6 mm), reverse overjet (from −1 to −3.5 mm), and anterior or posterior crossbites, can be regarded also as potential orthodontic patients since these types of dentoskeletal disharmonies can be treated favourably in growing patients. The results of investigations in those European countries where the prevalence rate for subjects undergoing orthodontic treatment is higher may show a lower percentage of grade 3 subjects: for instance, 26.1 per cent in the Swedish population (Josefsson *et al.*, 2007) at an average age of 11–12 years and 25.5 per cent in a German sample (Tausche *et al.*, 2004) at the age of 6–8 years.

Conclusions

The DHC of the IOTN proved to be an easy-to-use and reliable method to describe the need for orthodontic treatment in a southern Italian population. The findings in 703 schoolchildren who were 12 years old from the area of Naples, Italy, indicated that this population shows a rather low prevalence rate for objective orthodontic treatment need (grades 4 and 5). This prevalence rate is generally lower than those reported in northern and central European countries (Sweden, Germany, and UK), but slightly greater than in France. Among the occlusal problems diagnosed in the subjects examined, high prevalence rates were found for posterior crossbites and Class III malocclusions, which would presumably have benefited from early orthodontic intervention.

Address for correspondence

Tiziano Baccetti
Department of Orthodontics
Università degli Studi di Firenze
Via del Ponte di Mezzo, 46-48
50127 Firenze
Italy
E-mail: t.baccetti@odonto.unifi.it

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An evaluation of clinicians' choices when selecting archwires

Clare McNamara*, Karen J. Drage**, Jonathan R. Sandy* and Anthony J. Ireland***
Orthodontic Departments, *Bristol Dental Hospital, **Derriford Hospital, Plymouth and ***Royal United Hospital Bath, UK

SUMMARY The aim of this research was to determine the choices made by clinicians with respect to archwires and arch form during the initial and latter stages of orthodontic treatment with fixed appliances.

A questionnaire-based study was carried out at Bristol Dental Hospital between November 2005 and March 2006. Questionnaires were distributed within the dental hospital and at local meetings in order to obtain a mixed sample of hospital and practice-based orthodontists. The clinicians asked to complete the questionnaire were consultant orthodontists ($n = 37$), specialist practitioners ($n = 36$), senior specialist registrars in orthodontics ($n = 10$), and dentists with a special interest in orthodontics ($n = 17$). The questionnaire consisted of two parts: the first was concerned with the initial alignment phase of treatment and the second with the space-closing phase of treatment in premolar extraction cases. The choice of archwires, significance of arch form, and intra-arch dimensions considered important at both stages were assessed. The clinicians were also asked about their usual practice with regard to adaptation of working archwires and the use of study models and symmetry charts.

One hundred questionnaires were returned, giving a response rate of 92.6 per cent. The majority of clinicians felt that preservation of the pre-treatment arch form was essential in the latter but not in the early stages of treatment. In particular, conservation of the original intercanine width was considered important. However, there was no uniformity in how arch form should be preserved. Some respondents used study models and symmetry charts as an aid, but even then they were used in different ways. There was no uniformity in the landmarks used when adapting stainless steel archwires to arch form. Therefore, even when clinicians do adapt their archwires carefully with the intention of preserving arch form, are they choosing the correct arch form?

Introduction

Following a course of orthodontic treatment, teeth have an inherent tendency to relapse towards their pre-treatment positions. Even when the aim of orthodontic treatment is only to move teeth within the neutral zone of the soft tissues, relapse may occur. Firstly, the gingival and periodontal tissues affected by tooth movement require time to re-organize following completion of treatment. Within the periodontal ligament (PDL), the collagenous fibres may take between 4 and 6 months to re-organize, while the elastic supracrestal fibres of the gingiva can take as long as 7–8 months (Reitan, 1969). Secondly, continued facial growth may also influence the long-term results of orthodontic treatment. A longitudinal study of adults has demonstrated that skeletal growth continues, albeit at a very slow rate, throughout adult life (Behrents, 1985) in the sagittal, vertical, and transverse dimensions, with a great deal of individual variation.

Finally, relapse may also occur when the teeth are placed in inherently unstable positions outside the soft tissue envelope. There is evidence to suggest that the most reliable way of maximizing post-treatment stability is to maintain the original, pre-treatment arch form in which the teeth are presumed to be in a stable position (Felton *et al.*, 1987; Little, 1990; de la Cruz *et al.*, 1995).

Arch form describes the position and relationship of the teeth to one another in all three dimensions. It can be considered to be a result of the underlying skeletal morphology, the surrounding soft tissues, and any additional environmental effects. The soft tissue influence is thought to arise as a result of the resting pressure of the lips, cheeks, and tongue, along with forces from within the PDL (Mills, 1968). The latter, in particular, are thought to play a role in stabilizing the teeth once they have attained their final position within the arch (Proffit, 1978).

Many attempts have been made to find a universal arch form that would fit every individual and their malocclusion. These include the Bonwill-Hawley arch, catenary curve, and trifocal ellipse (Hawley, 1905; McConnail and Scher, 1949; Currier, 1969; Brader, 1972). Indeed, a variety of arch forms are available. However, it is generally acknowledged that no single arch form is characteristic of a specific malocclusion and so customization of archwires is always required (Felton *et al.*, 1987). At each stage during orthodontic treatment, there is the potential for alteration of the arch form, which may have an effect on long-term stability. Studies have shown that maintenance of intercanine width, intermolar width, and arch length contributes greatly to a stable post-treatment result (Glenn *et al.*, 1987; Little, 1990). A meta-analysis by Burke *et al.* (1998) also supported the view that preservation of the original mandibular intercanine width is important for post-treatment stability, as in almost all instances, it has a tendency to return to its pre-treatment value.

The aim of the present study was therefore to assess clinicians' views with regard to the choice of archwire and arch form and eventually to compare this with their theoretical practice when adjusting working archwires.

Materials and methods

Ethical approval to survey the clinicians was requested from the Royal United Hospital Bath, local research ethics committee and a letter was subsequently received to the effect that no ethical committee approval was required.

The study comprised a questionnaire survey of clinicians carried out between November 2005 and March 2006. In order to ensure a good response rate, the questionnaire was personally handed to 108 clinicians and a follow-up telephone call was made to those not returning the questionnaire within 4 weeks. The clinicians asked to complete the questionnaire included consultant orthodontists (n = 37), specialist practitioners (n = 36), senior specialist registrars in orthodontics (n = 10), and dentists with a special interest in orthodontics (n = 17).

The questionnaire was divided into two parts. The first part was designed to determine clinical practice during initial alignment with particular regard to:

1. Archwire material choices, dimensions, and trade name of the routinely used wires, if known.
2. Which arch form was used and whether this was considered important during initial alignment.
3. If a particular arch form was used, what intra-arch dimensions, if any, were considered important in choosing this arch form?

The second part of the questionnaire was concerned with the archwires and arch forms used during the space-closing phase of treatment. The scenario given was a Class I incisor relationship, premolar extraction case. The questions considered the following:

1. The archwire material and dimensions used.
2. Whether study models were used for the adaptation of archwires to the original arch form.
3. If study models were used, then what landmarks on the study models were considered important?
4. The use of symmetry charts with regard to adaptation of archwires.

Statistical analysis

No formal statistical analysis was carried out as it was considered that this would not be helpful in view of the large number of variables and possible presence of confounders.

Results

The questionnaire was returned by 100 clinicians giving an excellent response rate of 92.6 per cent. The responses to the two parts of the questionnaire were as follows.

Questionnaire part 1—initial alignment

Ninety-nine per cent of respondents used a 0.022 inch slot system for labially placed pre-adjusted edgewise fixed appliances. All but one (99 per cent) used nickel–titanium (NiTi) as their initial aligning archwire. A straight length of 0.014 inch multistranded stainless steel was routinely placed by one clinician.

Clinicians were then asked the type and trade name of their preferred NiTi archwire. Twenty-three clinicians stated that they used classic type (martensitic stable), 34 super-elastic (austenitic active), and 34 heat-activated (martensitic active) NiTi at the start of treatment. Nine stated that they did not know what type of NiTi they used. The clinicians were then asked the trade name of the archwire routinely used. Of the clinicians who stated the type of NiTi they used, 32 per cent did not know the trade name of the archwire. Of those who did know, few knew the actual name of the archwire, but did know the manufacturer. Therefore, the percentage of clinicians who did not know the actual name of the archwire they used could potentially be much higher than 32 per cent. In one case, Timolium® was cited as a classic NiTi archwire, whereas it is in fact a nickel-free titanium alloy archwire.

The arch form of the initial NiTi archwire was considered important by 16 per cent of clinicians and arch width by 23 per cent. When asked what dimensions within the arch clinicians considered important during initial alignment, a variety of responses were observed (Table 1). The most common combination took into account the upper and lower intercanine and first molar widths. All but one respondent felt that the lower intercanine width was an important dimension to consider during initial alignment.

Of those clinicians who returned their questionnaires, 83 per cent felt that the arch form of the initial NiTi was not important and 77 per cent felt that the arch width was not important. Of the clinicians using a pre-formed NiTi archwire at bond up, 53 per cent appeared to use a particular arch form and again, an array of arch forms were used, with the most common known arch form being the catenary curve (Figure 1). Nearly 50 per cent of respondents did not know which arch form they used, perhaps because it was not thought to be necessary at this time. Other named arch forms used included Euroform (n = 10), Damon (n = 6), and European Progressive (n = 1).

Questionnaire part 2—selection of archwires and arch form for space closure

Once again 99 per cent of respondents stated that they used stainless steel as a preferred archwire material for closure

Table 1 Arch width dimensions considered important by 23 per cent of clinicians in initial alignment.

Arch dimensions	Number of clinicians
Lower canine width only	5
Lower canine and molar widths	4
Upper and lower canine widths	1
Upper and lower canine and first molar widths	9
Upper and lower canine, first molar, and second molar widths	1
Upper and lower premolar and first molar widths	1
Upper and lower canine, premolar, first molar, and second molar widths	2

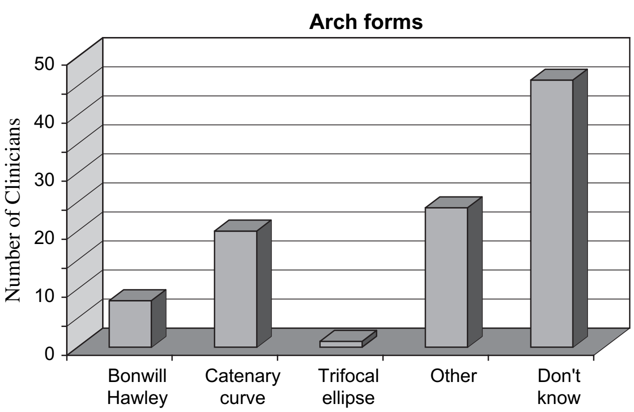

Figure 1 Arch forms used in initial alignment.

Table 2 Landmarks used for working archwire adaptation (n = 83).

Landmarks chosen	Combinations of teeth chosen	Number of clinicians
Actual teeth	Incisal edge/canine cusp tip	1
	Incisal edge/canine cusp tip/first molar cusps	5
	Incisal edge/canine cusp tip/premolar cusps/first molar cusps	7
	Canine cusp tip	3
	Canine cusp tip/premolar cusps	1
	Canine cusp tip/premolar cusps/first molar cusps	1
	Canine cusp tip/first molar cusps	2
	Premolar cusps	1
Imagined bracket position	Incisor/canine	1
	Incisor/canine/first molar	8
	Incisor/canine/premolar	2
	Incisor/canine/premolar/first molar	4
	Incisor/canine/premolar cusps/first molar/second molar	18
	Incisor/premolar/first molar	1
	Incisor/first molar	1
	Canine	5
	Canine/first molar	17
	First molar	2
Other	WALA ridge	2
	Buccal faces of teeth	1

of premolar extraction spaces. The wire cross-sectional dimension varied, but the majority of clinicians used 0.019 × 0.025 inch stainless steel in both the upper and lower arches. One clinician performed space closure using 0.018 × 0.025 inch NiTi archwires.

When selecting a working archwire, 28 per cent of the clinicians stated that they always used study models when doing so, 16 per cent said they often but not always used them, 39 per cent occasionally, and 17 per cent never used study models when selecting working wires.

Of those using study models (n = 83), 57 used the lower model to choose the lower arch form, while interestingly 26 used the upper models to select the lower arch form. When choosing the upper arch form, there was greater variety as to what model was used. Twenty clinicians used the lower study model only, 18 the upper study model only, and 40 a combination of both.

When adapting an archwire to a study model, several different combinations of teeth were used: incisor, canines, premolars, or molars. While 21 (25.3 per cent) of the respondents used the actual teeth as landmarks for archwire adaptation, 59 (71.1 per cent) used the imagined bracket position as the landmark. Within this, different combinations of teeth were chosen to act as the landmarks (Table 2). Of the remainder, two used the WALA (Will Andrews Larry Andrews) ridge and one the buccal faces of the teeth. The most popular combination was the imagined bracket position of the incisor/canine/premolar/first molar and second molar teeth. All but five respondents included the canines, with some combination of canines and first molars in the majority of cases. However, there was a large variety in the landmarks and positions on these landmarks used to identify arch form, with no particular pattern predominating.

The current survey also highlighted that a large number of respondents (46 per cent) never used symmetry charts when selecting and adapting working archwires. Only 10 per cent stated that they always used them, with 14 per cent often and 28 per cent occasionally using them. The question was not answered by two respondents. One symmetry chart trade name predominated, namely Euroarch. Others were used to a lesser extent and included Euroform, MBT™, and 3M (Figure 2). The most common use of the symmetry chart was to check for archwire symmetry alone or in combination with the checking of arch size. Symmetry charts were used to determine arch size, form, and symmetry in different combinations (Table 3).

Of those using a symmetry chart for arch size (n = 24), 83.3 per cent stated that they used it on the lower study model to choose the lower arch form. Following this, the upper archwire was then coordinated to the lower archwire.

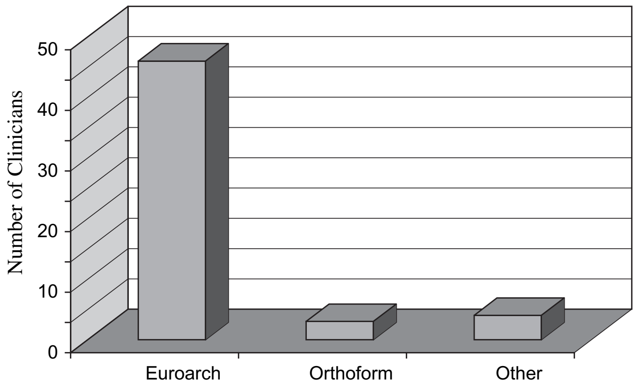

Figure 2 Symmetry charts used by the clinicians during treatment.

Table 3 The reasons stated for the use of symmetry charts (used by 54% of clinicians).

To check for	Number of clinicians
Arch size	2
Arch symmetry	23
Arch form	2
Size and symmetry	11
Form and symmetry	5
Form and size	2
Size, symmetry, and form	9

Of those using a symmetry chart to select arch form (*n* = 18), two used it on its own just to check for symmetry, with the majority again using it on the lower study model to choose the lower arch form and then coordinating the upper archwire to this chosen lower arch form.

Discussion

The questionnaire used in the present research was designed in order to determine clinicians' theoretical views concerning arch form, both in the early stages of treatment, when light flexible wires would be expected to be used, and during space closure when stiffer, larger dimension wires might be expected to be employed.

From this study, the majority of clinicians were found to be using NiTi archwires in the initial stages of treatment. This corresponds with the findings of a previous US survey (Keim *et al.*, 2002) in which the percentage of clinicians using NiTi archwires during alignment increased from 75.8 per cent in 1996 to 80.2 per cent in 2002. With the introduction of both super-elastic and, more recently, thermo-elastic NiTi archwires, the clinician is able to make use of larger dimension rectangular wires from the initial levelling and aligning phase of treatment (Miura *et al.*, 1990). It is possible that the use of such large archwires early on in treatment may contribute to the development of an arch form in the early stages of treatment, over which the clinician may have little or no control.

NiTi archwires are available in a number of different shapes and sizes and, therefore, for the clinician to have some control of arch form, it would mean having to stock a large inventory of archwires. It is not really until the stainless steel phase of treatment that the clinician can truly adapt the archwire to each patient. In this questionnaire, arch form was not considered important by the majority of clinicians (83 per cent) at the initial stage of treatment, becoming more important in the later archwires used in treatment.

Interestingly, many clinicians did not know the name of the manufacturer, or indeed the trade name, of the wires they used. Although a number of practitioners (53 per cent) used a specific arch form, with the catenary curve being the most popular, few considered arch form to be significant during initial alignment. This questionnaire identified the large number of different arch forms that are in use, which perhaps shows a general lack of agreement between clinicians as to what is the most appropriate one to use (Figure 1).

Even though the overall arch form was not considered to be important, the majority of clinicians still felt that lower intercanine width dimension was an important consideration and should be taken into account when choosing an aligning archwire (Table 1). This is an interesting finding when considering the NiTi archwires actually available on the market. A study carried out using NiTi archwires from different manufacturers, which varied in shape and size (Braun *et al.,* 1999), found that the average mandibular intercanine width exceeded the natural intercanine width by 5.95 mm. Maintaining this shape throughout treatment will result in alteration of the original arch form and the problems that have been associated with this, e.g. increased incidence of relapse. On the other hand, if the clinician wishes to regain the patient's initial arch form, then significant 'round tripping' of the teeth will be required. From these findings, it might appear reasonable to design NiTi archwires with a reduced intercanine width. Although producing a customized NiTi archwire would be impractical, due to natural variation in arch form with race and gender (Burris and Harris, 2000), it could be argued that a reduction in intercanine width of currently available arch forms would at least more closely correspond to most patients' arch forms.

From the current questionnaire on the initial alignment phase of treatment, it would seem that the majority of operators feel that it is not important what arch form is used. Indeed, it has been suggested that bending only a very simple arch form in light stainless steel or even using just a straight piece of stainless steel for initial alignment would be sufficient (Mills, 1987).

In the second part of this study, the questionnaire concentrated on the choice of archwire and the importance of arch form during the space-closing phase of fixed appliance treatment. From the results, there appears to be general agreement as to the choice of archwire for space closure, with an almost universal use of 0.019 × 0.025 inch stainless steel wire in a 0.022 inch bracket slot. The use of the 0.022 inch bracket slot certainly differs considerably from the results of the survey of American orthodontists (Keim *et al.*, 2002), where by contrast, only just over half (54 per cent) of respondents used a 0.022 inch slot.

When choosing an arch form, the percentage of clinicians routinely using study models was quite low, at just 28 per cent. Of those who did use them, the majority used only the lower model to select both upper and lower arch forms. This does seem the most reasonable approach as it is the lower intercanine width which is prone to relapse if expanded. A meta-analysis by Burke *et al.* (1998) suggested that this measurement returns to its pre-treatment dimension following the end of retention. Conversely, some expansion of the upper intercanine and intermolar widths has proved to be stable in the longer term (Sadowsky, 1994). The use of just the lower model was not universal, with some respondents using both upper and lower models, while others used only the upper model to select arch form.

Using only the upper model for adjustment of the upper archwire may not be the most appropriate approach. For instance, if the upper archwire is adjusted without reference to the lower archwire, the two arches may not be coordinated. Also, in the case of some malocclusions, the upper study model will not accurately represent the actual arch form. For example, in a patient with a Class II division 2 incisor relationship, retroclination of the upper incisors and a scissor bite on the first premolars will give an incorrect impression of both arch length and arch form. The first approach, using the lower study model, seems more logical as the upper arch will then be coordinated with the lower arch for a correct transverse occlusal result.

The questionnaire also highlighted differences between clinicians concerning the teeth and landmarks used to identify the arch form and which will then be used to adapt the archwires during treatment (Table 2). Most clinicians considered mandibular intercanine width important, and indeed the majority used a combination of teeth, including the canines and molars. However, the differences once again highlight a general lack of agreement between the clinicians surveyed. Previously, it has been recommended taking into account incisor, canine, and molar position when choosing the arch form (Cozzani, 2000). Even when focussing on particular teeth, when deciding on the arch form in the present study, some respondents used the cusp tips as landmarks, others the buccal surfaces, and others still the imagined bracket positions. No single landmark choice predominated (Table 2). If there are so many combinations of teeth and landmarks in use, then there must also be several different opinions as to where on the dental arch the arch form actually lies. Therefore, in the case of clinicians who painstakingly adjust each archwire using pre-treatment models, where is the arch form? In particular, where is it on a pre-treatment model with malaligned teeth? This lack of consistency with regard to arch form selection was an interesting finding.

Approximately half of those questioned in the present research used symmetry charts during treatment. Again, there was no uniformity in how they were used. Although symmetry charts were most often used in combination with the lower study model when choosing the arch shape (83 per cent), a minority of clinicians (2 per cent) made their archwires conform to the symmetry chart without reference to study models or the patient. In these cases, a particular size was chosen for all non-extraction cases and a second size for all extraction cases. Such an approach will not allow an accurate adaptation to the majority of patients' pre-treatment arch forms.

Additional comments written on two of the completed questionnaires raised other issues, when it came to the use of pre-treatment models for adaptation of archwires to the arch form. The comments suggested that in an ideal world, the clinicians in question would have used study models routinely. However, the study models were stored off site, due to lack of space, and as a result were not readily available for each appointment. The intimation is that little if any consideration was being given to pre-treatment arch form. The use of digital models would reduce storage problems and perhaps make virtual models more readily available at the patient appointment. Certainly, a comparison of measurements on digital and cast study models, with regard to tooth size and overjet, found that digital measurements were slightly smaller than those from plaster study models. The differences ranged from 0.16 to 0.49 mm but were not thought to be clinically relevant (Santoro *et al.*, 2003). Digital models do allow a static view from any direction (Joffe, 2004), but how easy it would be to accurately adjust an arch form to a virtual study model remains unresolved.

Conclusions

1. The majority of clinicians felt that preservation of the pre-treatment arch form was essential in the latter stages of treatment. In particular, conservation of the original intercanine width was considered important. However, it was not considered important in the early stages of treatment when NiTi archwires were used for initial alignment.
2. There was no uniformity in how arch form was preserved. Some clinicians used study models and symmetry charts as an aid, but even then they were used in different ways. There was also no consistency in the landmarks that were used when adapting stainless steel archwires to the arch form. Therefore, even when clinicians do carefully adapt their archwires, with the intention of preserving arch form, are they choosing the correct arch size and arch form?

Address for correspondence
Clare McNamara
Orthodontic Department
Bristol Dental Hospital
Lower Maudlin Street
Bristol BS1 2LY
UK
E-mail: clare.mcnamara@glos.nhs.uk

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Chondroitin sulphate (WF6 epitope) levels in peri-miniscrew implant crevicular fluid during orthodontic loading

Imjai Intachai*, Suttichai Krisanaprakornkit**, Prachya Kongtawelert***, Siriwan Ong-chai***, Boonsiva Buranastidporn*, Eduardo Yugo Suzuki* and Dhirawat Jotikasthira*

Departments of *Orthodontics, **Odontology and Oral Pathology, Faculty of Dentistry, and ***Department of Biochemistry, Thailand Excellence Center for Tissue Engineering, Chiang Mai University, Thailand

SUMMARY The aim of this study was to monitor changes in chondroitin sulphate (CS; WF6 epitope) levels in peri-miniscrew implant crevicular fluid (PMICF) during orthodontic loading.

Ten patients (seven males and three females; aged 22.0 ± 3.4 years), who required orthodontic treatment with extraction of all four premolar teeth, participated in the study. Twenty miniscrew implants (used as orthodontic anchorage) were placed, two in each patient, buccally and bilaterally in the alveolar bone between the roots of the maxillary posterior teeth. Sentalloy closed-coil springs (50 g) were used to load the miniscrew implants and to move the maxillary canines distally. During the unloaded period, PMICF samples were collected on days 1, 3, 5, and 7 after miniscrew implant placement and on days 14, 21, 28, and 35 during the loaded period. Clinical mobility assessments of the miniscrew implants were recorded at each visit. The competitive enzyme-linked immunosorbent assay with monoclonal antibody WF6 was used to detect CS (WF6 epitope) levels in the PMICF samples. The differences between the CS (WF6 epitope) levels during the unloaded and loaded periods were determined by a Mann–Whitney *U*-test.

During the loaded period, two miniscrew implants were considered to have failed. The CS (WF6 epitope) levels during the unloaded period ranged from 0.00 to 758.03 ng/ml and those during the loaded period from 0.00 to 1025.11 ng/ml. Medians of CS (WF6 epitope) levels, around ‘immobile’ miniscrew implants, between the unloaded and loaded periods were not significantly different ($P = 0.07$).

CS (WF6 epitope) levels in PMICF can be detected and may be used as biomarkers for assessing alveolar bone remodelling around miniscrew implants during orthodontic loading.

Introduction

The stability of miniscrew implants has been based on clinical (Ohmae *et al.*, 2001; Miyawaki *et al.*, 2003; Cheng *et al.*, 2004; Liou *et al.*, 2004; Kim *et al.*, 2005; Park *et al.*, 2006), histological (Melsen and Costa, 2000; Ohmae *et al.*, 2001; Kim *et al.*, 2005; Freire *et al.*, 2007), biomechanical (Huja *et al.*, 2005; Motoyoshi *et al.*, 2005, 2006; Chen *et al.*, 2006), and biochemical assessments. Only one study was found in the literature in which biochemical assessments were used to investigate the stability of miniscrew implants (Sarı and Uçar, 2007).

Several biochemical markers have revealed the destruction and remodelling of peri-implant tissue (Last *et al.*, 1995; Johansson *et al.*, 2001; Plagnat *et al.*, 2002; Ma *et al.*, 2003; Liskmann *et al.*, 2004). Numerous studies have monitored glycosaminoglycans, particularly chondroitin sulphate (CS), in periodontal (Shibutani *et al.*, 1993; Waddington *et al.*, 1994; Okazaki *et al.*, 1995; Kagayama *et al.*, 1996; Ababneh *et al.*, 1998; Khongkhunthian *et al.*, 2008) and peri-implant (Last *et al.*, 1995; Okazaki *et al.*, 1996; Johansson *et al.*, 2001) tissue and concluded that glycosaminoglycans in peri-implant crevicular fluid are similar to those in gingival crevicular fluid (GCF; Last *et al.*, 1995; Okazaki *et al.*, 1995, 1996). Increased levels of glycosaminoglycans, particularly CS, in peri-implant crevicular fluid can be a marker for adverse tissue responses, particularly for bone resorption (Smedberg *et al.*, 1993; Waddington *et al.*, 1994; Last *et al.*, 1995).

In the one study in which biochemical assessments were used to investigate the stability of miniscrew implants, interleukin-1β (IL-1β) levels in peri-miniscrew implant crevicular fluid (PMICF) were used to determine the effects of mechanical stress on the miniscrew implants when used as anchorage for tooth movement. The results demonstrated that IL-1β levels in PMICF of healthy miniscrew implants were not increased during orthodontic loading (Sarı and Uçar, 2007).

A monoclonal antibody, 3B3, has been used to recognize epitopes of CS in GCF by the enzyme-linked immunosorbent assay (ELISA) method (Shibutani *et al.*, 1993). Some studies suggest that the expression of CS is related to the severity of inflammation, periodontal disease, and hyalinized periodontal ligament (Shibutani *et al.*, 1993; Kagayama *et al.*, 1996; Ababneh *et al.*, 1998). Monoclonal antibody WF6, a novel monoclonal antibody developed against embryonic shark cartilage proteoglycans, was applied as a biomarker for recognizing an epitope in CS chains. Using the ELISA with monoclonal antibody WF6, trace amounts of glycosaminoglycans present in GCF can be quantified (Khongkhunthian *et al.*, 2008). Two octasaccharides, unsaturated D–C–C–C and C–C–A–D, were recognized by the monoclonal antibody, WF6 (Pothacharoen *et al.*, 2007). This WF6 monoclonal antibody was applied as a serum biomarker for cartilage degradation in an *in vivo* study (Pothacharoen *et al.*, 2006a). Accordingly, the aim of the present study was to apply the competitive ELISA with monoclonal antibody WF6 to detect CS levels in PMICF during orthodontic loading.

Subjects and methods

The study was approved by the Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University. Informed consent was obtained from all patients.

Subjects

Ten patients (7 males and 3 females; aged 22.0 ± 3.4 years) requiring orthodontic treatment who met the following criteria: good general health; lack of antibiotic therapy during the previous 6 months; absence of anti-inflammatory drug administration in the month preceding the study; healthy periodontal tissue and no radiographic evidence of periodontal bone loss; requirement for four premolar extractions, distal canine movement, and maximum anchorage control, were included in the study.

Methods

Twenty miniscrew implants (8.0 mm in length, 1.6 mm in diameter; SIN, São Paulo, Brazil) were placed, two in each patient, buccally and bilaterally into the interradicular bone between the maxillary second premolar and first molar teeth. During the unloaded period, PMICF samples for each miniscrew implant were collected using 10.0 × 1.0 mm Whatman No. 1 (Whatman International Ltd, Maidstone, Kent, UK) filter paper strips on days 1, 3, 5, and 7. On day 7, after sample collection, a 50 g Sentalloy® closed-coil spring (Tomy, Tokyo, Japan) was used to connect the miniscrew implant head and the canine bracket in order to move the maxillary canine distally. During the loaded period, PMICF samples for each miniscrew implant were collected on days 14, 21, 28, and 35 (Figure 1).

PMICF collection

Before PMICF sample collection, the Sentalloy® closed-coil spring was removed. PMICF collection was undertaken following the method of Cliantar and Caruana (1998). Briefly, the miniscrew implant placement site was isolated from saliva and gently air-dried. PMICF samples were collected using Whatman No. 1 filter paper strips. An analytical instrument (Periotron 8000™, Oralflow Inc., Plainview, New York, USA) was used to measure the PMICF volume. Care was taken to avoid mechanical injury. Samples containing blood were discarded. The last 2.0 mm of filter paper strip containing the PMICF sample was cut off and individually frozen at −80°C in a microcentrifuge tube for further analysis.

Clinical mobility assessment of the miniscrew implant

After collecting the PMICF sample, the clinical mobility of each miniscrew implant was assessed using cotton forceps. An extremely light force was laterally applied to the miniscrew implant head. Mobility was scored either as 'yes' (mobile) or 'no' (immobile). If there was any discernible mobility, the miniscrew implant was categorized as mobile. Any miniscrew implants that were loose and thus could not serve as anchorage during the study period were considered as failures. The miniscrew implants that remained stable in the bone until the end of the study period or until intentional

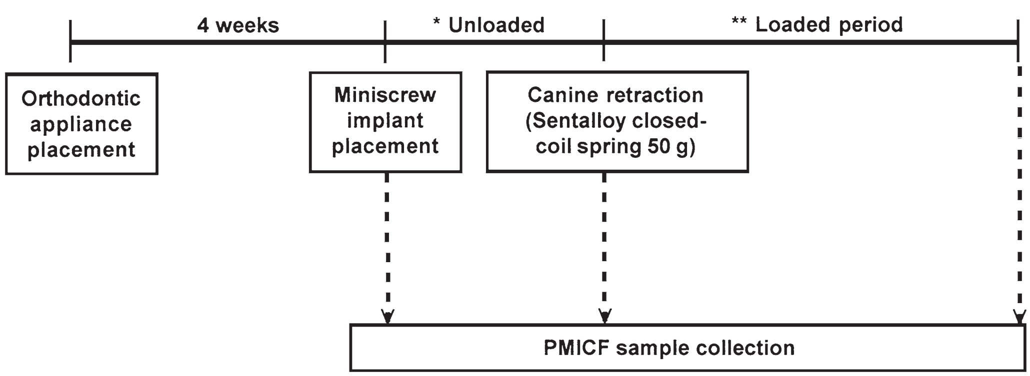

Figure 1 Diagram of the experimental design. *Unloaded period: sample collection on days 1, 3, 5, and 7 after miniscrew implant placement. **Loaded period: sample collection on days 14, 21, 28, and 35. PMICF, peri-miniscrew implant crevicular fluid.

removal (regardless of mobility) were considered to be successful.

Competitive immunoassay using monoclonal antibody WF6

PMICF was recovered from the paper strip by the addition of 200 µl of phosphate buffer saline, pH 7.4, and the tube was then vigorously shaken for a few minutes. The recovery rate (approximately 98.1 per cent) from each paper strip was determined by a dye-binding assay, using known concentrations of sulphated glycosaminoglycans as standards (Ratcliffe *et al.*, 1988).

A quantitative ELISA was modified from a previous study (Pothacharoen *et al.*, 2006a) for the epitopes recognized by monoclonal antibody WF6. The standard agent used in the assay was shark cartilage aggrecan (Pothacharoen *et al.*, 2006b). The coating antigen was shark PG-A_1, and the competitor agent was shark PG-A_1D_1. The primary antibody was monoclonal antibody WF6, and the secondary antibody was IgM-specific anti-mouse immunoglobulin with peroxidase. Microtiter plates (Maxisorp®, Nunc, Denmark) were coated overnight at room temperature with 10 µg/ml shark PG-A_1 fraction (100 µl/well) in the coating buffer (20 mM sodium carbonate buffer, pH 9.6). The following morning, the plates were washed three times with Tris-IB with 0.1 per cent bovine serum albumin (Sigma-Aldrich, St Louis, Missouri, USA; 150 µl/well) and left to air-dry. The uncoated area was then blocked with 150 µl/well of 1 per cent (w/v) bovine serum albumin in the Tris-IB for 60 minutes at 37°C. After washing, 100 µl/well of the mixture, which was the PMICF sample or standard competitor (shark PG-A_1D_1 fraction whose concentrations ranged from 39.06 to 10 000 ng/ml) mixed with the monoclonal antibody WF6 (patent number WO 2005/118645 A1; Pothacharoen *et al.*, 2007) at the dilution 1:100, was added. After incubation for 60 minutes at 37°C, the wells were washed and then IgM-specific anti-mouse immunoglobulin with peroxidase (1:2000) was added (100 µl/well; in Tris-IB). The plates were washed again, and the peroxidase substrate (100 µl/well) was then added and incubated at 37°C for 5–20 minutes to allow the colour to develop. The reaction was stopped by the addition of 50 µl/well of 4 M H_2SO_4. The absorbance ratio at 492:690 nm was measured using the Titertek Multiskan® MCC/340 multiplate reader (ICN/Flow Laboratories, Costa Mesa, California, USA).

Statistical analysis

The data were analyzed using the Statistical Package for Social Sciences version 13 for Windows (SPSS Inc., Chicago, Illinois, USA). The Kolmogorov–Smirnov one-sample test was used to determine the distribution of CS (WF6 epitope) levels. The differences between the CS (WF6 epitope) levels during the unloaded and loaded periods were determined by the Mann–Whitney *U*-test. The results were considered statistically significant at $P < 0.05$.

Results

Clinical observations

All 10 patients completed the 5-week study period, and PMICF was obtained from 20 miniscrew implants. At placement and during the unloaded period (1 week), all miniscrew implants remained clinically immobile. During the loaded period (4 weeks), two miniscrew implants were mobile. One miniscrew implant was mobile on day 14 and another on day 21. Both were later removed.

CS (WF6 epitope) levels in PMICF samples

The volume of PMICF collected from the last 2.0 mm of each filter paper strip was 0.1 µl (measured by the Periotron 8000™). It has previously been shown that it is possible to measure such a small volume with reliability and also check intra- and interassay variations, including expected recovery values (Pothacharoen *et al.*, 2006b). The CS (WF6 epitope) levels (in nanogram per millilitre) could be detected in almost all PMICF samples collected from peri-miniscrew implant sulci during the unloaded and loaded periods.

During the unloaded period, the CS (WF6 epitope) levels ranged from 0.00 to 758.03 ng/ml and the medians at each visit from 12.63 to 23.18 ng/ml. During the loaded period, the CS (WF6 epitope) levels ranged from 0.00 to 1025.11 ng/ml and the medians at each visit from 19.41 to 28.43 ng/ml (Figure 2).

The medians of CS (WF6 epitope) levels during the unloaded and loaded periods were 17.38 and 23.69 ng/ml, respectively. No significant difference was found between the median of CS (WF6 epitope) level during the unloaded period and that during the loaded period ($P = 0.07$; Figure 3).

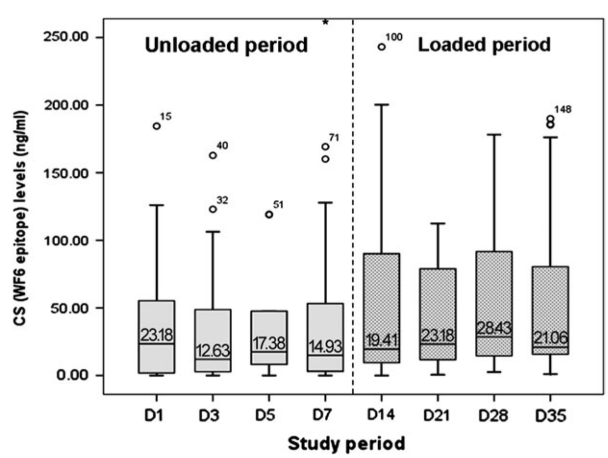

Figure 2 The medians of chondroitin sulphate (CS; WF6 epitope) levels (around 18 immobile miniscrew implants) at each visit during the unloaded (1 week) and loaded (4 weeks) periods.

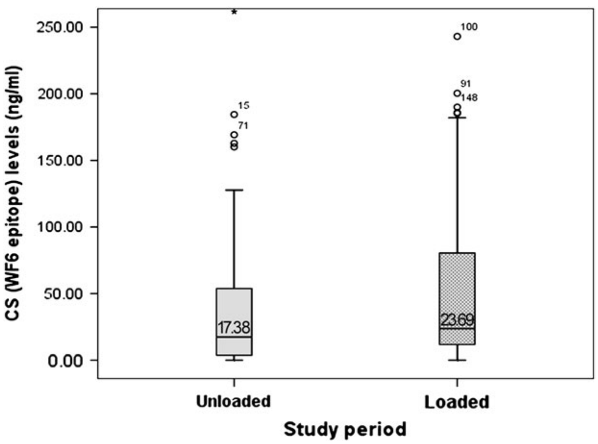

Figure 3 The medians of chondroitin sulphate (CS; WF6 epitope) levels (around 18 immobile miniscrew implants) during the unloaded (1 week) and loaded (4 weeks) periods (significant difference: $P < 0.05$).

The CS levels in the PMICF around one miniscrew implant (MI 5), that was mobile and was later removed on day 21, were high on days 3 and 5, while the CS (WF6 epitope) levels on the opposite side (MI 6, which was immobile) were relatively low (Figure 4).

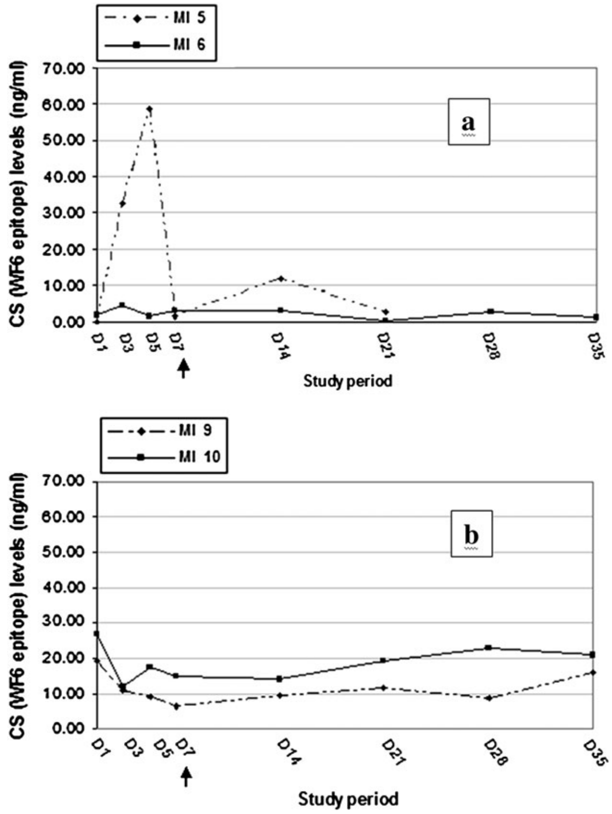

Figure 4 Graphs showing the chondroitin sulphate (CS; WF6 epitope) levels around two miniscrew implants (MI 5 and MI 6) at each visit during the unloaded (1 week) and loaded (4 weeks) periods. (a) One miniscrew implant (MI 5) was mobile on day 21 and later removed. The CS (WF6 epitope) levels in peri-miniscrew implant crevicular fluid were high on days 3 and 5, while the CS (WF6 epitope) levels around the miniscrew implant on the opposite side (MI 6, which was immobile) were relatively low. (b) The CS (WF6 epitope) levels around two immobile miniscrew implants (MI 9 and MI 10) in another patient from day 1 to day 35. The CS (WF6 epitope) levels around those miniscrew implants were low.

Discussion

Since the main component of glycosaminoglycans in alveolar bone is CS, its level in human GCF has been used to investigate alveolar bone remodelling as a result of periodontal disease and orthodontic tooth movement (Waddington *et al.*, 1994). Several studies have monitored CS in peri-implant tissue to evaluate the stability of dental implants and found that the levels of CS in peri-implant crevicular fluid may be an effective method of monitoring changes in bone metabolic activity (Smedberg *et al.*, 1993; Last *et al.*, 1995; Johansson *et al.*, 2001).

In the present study, only the PMICF samples collected from the last 2.0 mm of each filter paper strip were analyzed. The constituent in PMICF that was recognized by the WF6 antibody was CS. It is well known that CS comprises approximately 17 per cent of total glycosaminoglycans in gingival tissue (Bartold, 1987) and only a minor component in the periodontal ligament (Pearson and Gibson, 1982). On the other hand, much higher amounts of CS (94 per cent of total glycosaminoglycans) are present in mineralized tissue, i.e. alveolar bone and cementum (Waddington *et al.*, 1989). Consequently, detectable CS levels in PMICF are due to changes from mineralized tissue remodelling surrounding miniscrew implants, not from the inflammatory status of soft tissue.

In this research, the CS (WF6 epitope) levels in PMICF were investigated in a manner similar to that used for the determination of IL-1β levels of PMICF (Sarı and Uçar, 2007). It was found that the CS (WF6 epitope) in PMICF, both with and without the application of orthodontic force, could be detected. There was no statistical difference between the median CS (WF6 epitope) level during the unloaded period (1 week) and that during the loaded period (4 weeks). These results indicate that orthodontic force on miniscrew implants might not affect CS (WF6 epitope) levels in PMICF. The findings are in agreement with those of Sari and Uçar (2007), who evaluated IL-1β levels in PMICF during a 3 week loading period. There were no statistical differences in IL-1β levels in PMICF during the 3 week loading period. This indicates that orthodontic force might have a minimal influence on initial bone modelling, subsequent remodelling, and miniscrew implant anchorage stability (Huja *et al.*, 2005; Freire *et al.*, 2007).

In this study, two miniscrew implants were considered failures after the application of orthodontic forces. Miniscrew implant losses after the application of orthodontic forces have been reported (Melsen and Costa 2000). However, several authors have indicated that low-magnitude static force is not detrimental to miniscrew implant stability (Ohmae *et al.*, 2001; Deguchi *et al.*, 2003; Buchter *et al.*, 2005; Freire *et al.*, 2007). Therefore, the 50 g of static force applied to the miniscrew implants in this study might not affect their stability. A possible explanation for this observation is trauma from the miniscrew placement procedure (Kim *et al.*, 2005). The holes drilled prior to miniscrew implant insertion might decrease the contact area between the miniscrew implants and surrounding bone, which may lead to miniscrew implant failure (Last *et al.*, 1995; Heidemann *et al.*, 2001; Kim *et al.*, 2005; Wilmes *et al.*, 2006).

The levels of CS (WF6 epitope) from the failed miniscrew implants were high 14 days prior to miniscrew implant failure. It is suggested that the elevations of CS (WF6 epitope) level before miniscrew implant failure might be associated with bone resorption around the miniscrew implant. In an earlier investigation, high CS levels were reported to be a potential marker for adverse tissue responses and marked bone resorption (Last *et al.*, 1995). However, the results of the present study should be confirmed by applying various bone resorption biomarkers and increasing the sample size. The increase in sample size may lead to a reasonable conclusion regarding comparisons between successful and failing miniscrew implants, as the number of failing miniscrew implants would be increased.

While the rationale behind this research may be questioned since there is no need for a biochemical test to study, the success or failure of miniscrew implants that are used for a limited period of time, the present study shows the importance of a biochemical test to analyse constituents in PMICF, which was also studied by Sarı and Uçar (2007). Future research should compare the CS levels in GCF around orthodontically moved teeth with those in PMICF or assess the optimal force magnitude required for tooth movement, while a miniscrew implant remains stable, using this novel WF6 antibody.

Conclusions

CS (WF6 epitope) can be detected in PMICF samples during the unloaded and loaded periods. The CS (WF6 epitope) levels may be used as biomarkers for assessing alveolar bone remodelling around miniscrew implants during orthodontic loading.

Address for correspondence

Dr Dhirawat Jotikasthira
Department of Orthodontics
Faculty of Dentistry
Chiang Mai University
Chiang Mai 50200
Thailand
E-mail: dhirawat@chiangmai.ac.th

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Effects of mastication on mandibular growth evaluated by microcomputed tomography

Akiko Enomoto*, Junichi Watahiki*, Tetsutaro Yamaguchi*, Tarou Irie**, Tetsuhiko Tachikawa** and Koutaro Maki*
Departments of *Orthodontics and **Oral Pathology, School of Dentistry, Showa University, Tokyo, Japan

SUMMARY It is well known that mastication has a significant influence on mandibular growth and development, but the mechanism behind this effect has not yet been clarified. Furthermore, no studies have examined the effects of changes in mastication on the three-dimensional (3D) morphometry of the mandible. The aim of the present study was to investigate the influences of changes in mastication on mandibular growth and morphology. Twenty-five 3-week-old (at the time of weaning) imprinting control region mice were randomly divided into three groups: mice fed a hard diet (HD), mice fed a soft diet (SD), and mice alternately fed hard and soft diets (HSDs) every week for 4 weeks. The morphometry of the mandible was analysed using 3D microcomputed tomography (μCT). Statistical analysis was undertaken using a *t*-test.

μCT analysis showed that the condylar width was significantly greater in the HD group than in the SD group after 1 week. After 4 weeks, mandibular length was significantly longer and ramus height was greater in the HSD group than in the other two groups. Bone volume was significantly less in the SD group than in the other two groups after 4 weeks. These findings suggest that changes in mastication markedly affect mandibular condylar cartilage growth and mandibular morphology. It is considered that dietary education at an early age is important in order to prevent disruption of the development of the mandible.

Introduction

Mastication has a marked influence on mandibular growth and development (Luca *et al.*, 2003). It has previously been reported that changes in mastication affect gene expression in the mandibular condylar cartilage (Watahiki *et al.*, 2004). Therefore, it was hypothesized that mastication would influence the condylar cartilage and finally change the shape of the mandible.

The mandible is known to change shape with different diets because ramus height was found to be greater in rats fed a hard diet (HD) than in those on a soft diet (SD; Tuominen *et al.*, 1993; Maki *et al.*, 2002). Furthermore, the condylar dimensions were greater in a hard than in a SD group (Bouvier and Zimny, 1987), and the bone volume of the spongiosa was significantly greater in a HD group than in a SD group (Yamada and Kimmel, 1991). Bresin *et al.* (1999) found that bone mass was greater in a HD group than in a SD group, with significant differences for most of the points measured.

However, no studies have examined the effects of diet of different hardness on the three-dimensional (3D) shape of the mandible. In the present study, how the shape and volume of the mandible in mice is affected by food hardness was investigated using microcomputed tomography (μCT).

Materials and methods

Animals

Twenty-five male imprinting control region mice (21 days of age) were randomly divided into five equal groups and provided with diets of differing hardness. The study protocol was approved by the Animal Research Committee of Showa University.

Dietary regimen

At the time of weaning (3 weeks of age), the mice were randomly divided into the following five groups ($n = 5$ per group): (1) mice fed a hard diet for 1 week (HD1W); (2) mice fed a soft diet for 1 week (SD1W); (3) mice fed a hard diet for 4 weeks (HD4W); (4) mice fed a soft diet for 4 weeks (SD4W); and (5) mice alternately fed a hard and soft diet every week for 4 weeks (HSD4W). The HD comprised ordinary laboratory chow for mice in a hard pellet form, while the SD comprised the ordinary diet after grinding and mixing with water in standardized proportions (two parts food to five parts water). There were no significant differences between the body weights of any of the five groups of mice.

Morphological analysis

Five mice from each group were killed at specified time points under deep anaesthesia with pentobarbital. The head were removed and fixed in 4 per cent paraformaldehyde solution (pH 7.4) overnight at 4°C and then stored in phosphate-buffered saline. To obtain a 3D digital image of the mandible, each craniofacial sample was scanned using μCT (SMX-90CT; Shimadzu, Tokyo, Japan). The voxel size was 49 μm per pixel in all spatial directions. The CT images were reconstructed at 512 × 512 pixels.

Linear analysis

The following six distances were calculated using 3D structural analysis software (TRI/3D-BON; Ratoc, Tokyo, Japan; Figure 1): These points were based on previously described methods (Bouvier and Hylander, 1984; Tuominen *et al.*, 1993; Maki *et al.*, 2002).

Bone volume analysis

Using the same 3D structural analysis software (TRI/3D-BON), the slice images obtained by μCT were reconstructed, the mandible was excised from each sample, and mandibular bone volume was analysed.

Statistical analysis

Measurements on each sample were undertaken on three separate occasions by one author (AE) and at 3 hour intervals in a single day, and the results were analysed using a *t*-test. Error variance, as a percentage of total variance, was calculated using Dahlberg's double determination method (Dahlberg, 1940). The error variance was less than 0.6–2.9 per cent for both the linear and volume analyses.

The significance of differences between groups was assessed using a Student's *t*-test for independent samples.

Results

Morphological analysis by μCT

Linear analysis. After 1 week of consumption of the different diets (4 weeks of age), the condylar width was significantly thicker in the HD1W group than in the SD1W group. However, there were no significant differences in the other mandibular points between the HD1W and SD1W groups (Figure 2; Table 1). After 4 weeks of feeding (7 weeks of age), mandibular length was longest in the HSD4W group, shorter in the SD4W group, and shortest in the HD4W group, while ramus height was greatest in the HSD4W group, lower in the HD4W group, and lowest in the SD4W group. There were no significant differences in the other mandibular points among the HD4W, SD4W, and HSD4W groups (Figure 2; Table 2).

Bone volume analysis. After 1 week of eating the different diets (4 weeks of age), there was no significant difference between the bone volumes in the HD1W and SD1W groups. After 4 weeks of feeding (7 weeks of age), bone volume was significantly lower in the SD4W group than in the HD4W and HSD4W groups (Figures 2 and 3). There was no significant difference between bone volumes in the HD4W and HSD4W groups.

Discussion

Mastication of a HD has been reported to load a significantly greater mechanical force on the temporomandibular joint than mastication of a SD (Boyd *et al.*, 1990). There have been many reports regarding the relationships between food properties and mandibular growth. In previous studies on changes in mandibular morphology associated with food consistency, a SD was found to increase mandibular length (Luca *et al.*, 2003). Condylar width was greater in rats fed a HD than in mice fed a SD (Bouvier and Zimny, 1987; Kiliaridis *et al.*, 1999), while ramus height was greater in rats fed a HD than in mice fed a SD (Tuominen *et al.*, 1993; Maki *et al.*, 2002). Histological examination has revealed that the hypertrophic chondrocyte zone of the mandibular condylar cartilage is thicker in rats fed a HD than in those fed a SD (Bouvier, 1988; Yamada and Kimmel, 1991), and reduced proliferative ability and matrix production have also been reported in rats fed a HD, compared with those fed a SD (Pirttiniemi *et al.*, 2004). Furthermore,

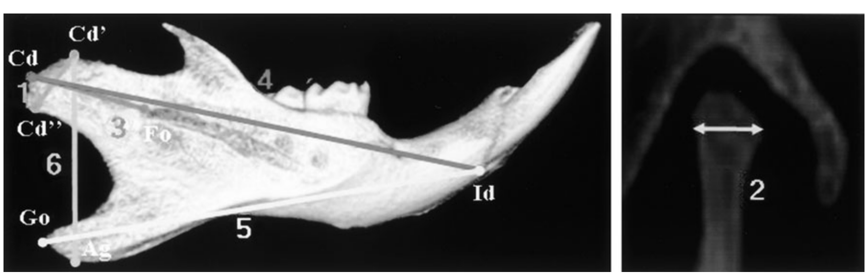

Figure 1 The following six mandibular distances were measured: ① Condylar length, Cd'-Cd''; ② Condylar width, left-to-right thickness of the condyle; ③ Condylar height, Cd-Fo; ④ Mandibular length, Cd-Id; ⑤ Mandibular body length, Go-Id; ⑥ Ramus height, Cd'-Ag; Cd, most posterior point of the condyle; Cd', highest point of the condyle; Cd'', lowest point of the condyle; Fo, mandibular foramen; Id, infradentale (labial side); Go, gonion; Ag, antegonion.

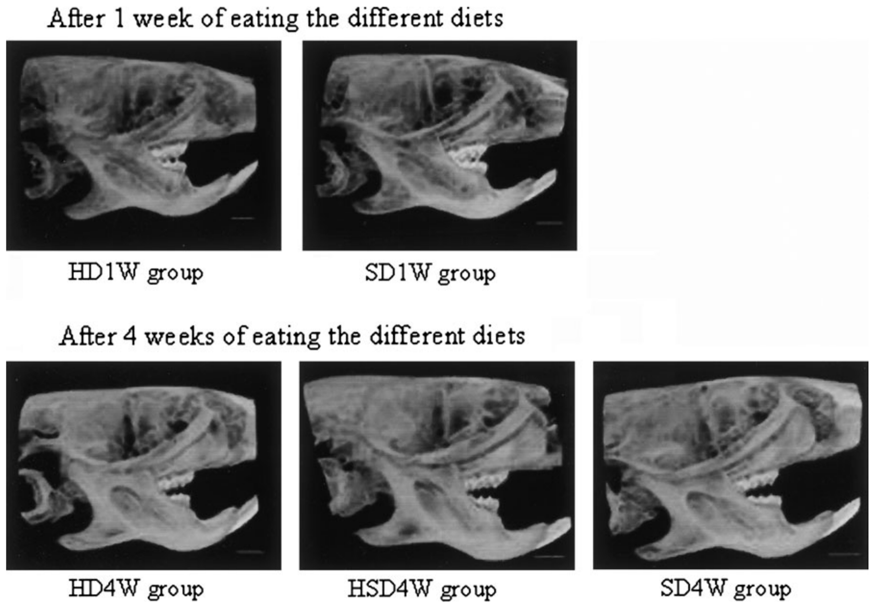

Figure 2 The morphometry of the mandibles of 4- and 7-week-old mice was evaluated by microcomputed tomography. Condylar width is significantly greater in the HD1W group than in the SD1W group. Mandibular length is shortest in the HD4W group, longer in the SD4W group, and longest in the HSD4W group. Ramus height is greatest in the HSD4W diet group, lower in the HD4W group, and lowest in the SD4W group. Scale bars: 2.0 mm. HD1W, hard diet for 1 week (at 4 weeks of age); SD1W, soft diet for 1 week (at 4 weeks of age); HD4W, hard diet for 4 weeks (at 7 weeks of age); HSD4W, hard and soft diets alternately every week for 4 weeks (at 7 weeks of age); SD4W, soft diet for 4 weeks (at 7 weeks of age).

Table 1 After 1 week of eating different diets in the soft (SD) and hard (HD) diet groups.

Measurement (mm)	SD	Standard deviation	HD	Standard deviation	HD versus SD
Condylar length-①	1.43	0.07	1.66	0.20	
Condylar width-②	0.60	0.02	0.79	0.04	**
Condylar height-③	2.49	0.09	2.35	0.10	
Mandibular length-④	10.82	0.05	10.62	0.29	
Mandibular body length-⑤	10.01	0.11	9.86	0.09	
Ramus height-⑥	4.49	0.60	4.85	0.11	

SD, soft diet; HD, hard diet.
$^{**}P < 0.01$.

gene expression levels related to mandibular condylar cartilage growth were found to differ markedly before and after the initiation of mastication in mice (Watahiki *et al.*, 2004). Overall, these reports suggest that mastication markedly affects mandibular shape.

To understand the associations between mastication and mandibular condylar cartilage growth, 3D mandibular morphology and mandibular bone volume were measured in the preset study using μCT and the results compared among groups of mice fed a HD alone, a SD alone, or a HSD alternately.

In mice fed the different diets for 1 week (4 weeks of age), the condylar width (L-R) was significantly greater in the HD1W group than in the SD1W group, which is consistent with previous reports (Bouvier, 1988; Kiliaridis *et al.*, 1999). In mice fed the different diets for 4 weeks (7 weeks of age), mandibular length was longest in the HSD4W group, decreased in the SD4W group, and was shortest in the HD4W group. However, these findings are inconsistent with those of previous reports (Bouvier and Zimny, 1987; Maki *et al.*, 2002). This inconsistency may be due to differences in the dietary consistency, the duration and frequency of feeding, or the age of the animals. Poorer masseter muscle development in mice fed a SD compared with those fed a HD (Urushiyama *et al.*, 2004), as well as an influence of the masseter muscle on the angle of the mandible (Hendricksen *et al.*, 1982), have been reported. In the present study, ramus height was greatest in the HSD4W group, lower in the HD4W group, and lowest in the SD4W group. This order differed from that of mandibular length because ramus height includes the mandibular condylar cartilage, which is affected by cartilage growth, and gonion, which is affected by the masseter muscle.

The bone volume in mice fed the different diets for 4 weeks (7 weeks of age) was significantly lower in the SD4W group than in the HD4W and HSD4W groups. There are only a few reports involving 3D measurements of mandibular bone volume. However, the presence of regions

Table 2 After 4 weeks of eating different diets in the SD, HD, and alternate HSD groups.

Measurement (mm)	SD	Standard deviation	HSD	Standard deviation	HD	Standard deviation	HD versus SD	HD versus SD	HD versus SD
Condylar length-①	1.96	0.22	1.81	0.12	2.48	0.34			
Condylar width-②	0.66	0.08	0.74	0.1	0.88	0.06			
Condylar height-③	2.98	0.12	2.99	0.05	2.71	0.21			
Mandibular length-④	11.34	0.09	11.75	0.1	11.02	0.81	*	**	*
Mandibular body length-⑤	10.44	0.3	10.74	0.33	10.44	0.14			
Ramus height-⑥	4.96	0.10	5.56	0.06	5.34	0.04	*	*	**

SD, soft diet; HD, hard diet; HSD, hard and soft diet.
$*P < 0.05$; $**P < 0.01$.

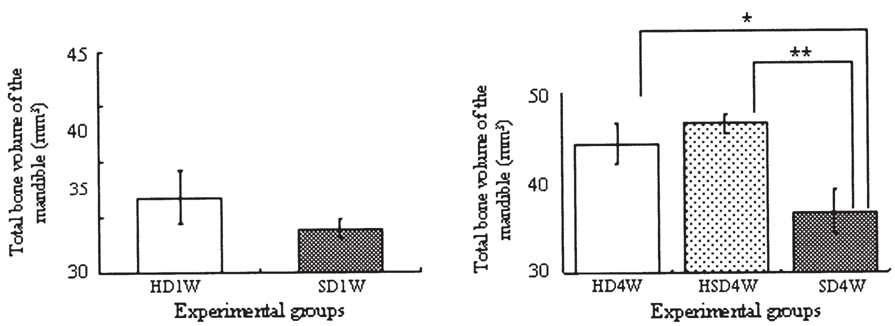

Figure 3 After 1 week of eating the different diets, total bone volume did not differ significantly between the hard diet for 1 week (HD1W) and soft diet for 1 week (SD1W) groups. After 4 weeks of eating the different diets, total bone volume was significantly smaller in the soft diet for 4 weeks (SD4W) group than in the hard diet for 4 weeks (HD4W) and hard and soft diet every week for 4 weeks (HSD4W) groups. $*P < 0.05$; $**P < 0.01$.

with significantly lower bone volumes in rats fed a SD compared with those fed a HD has been reported in two-dimensional cross-sectional images (Yamada and Kimmel, 1991; Bresin *et al.*, 1999).

As type II errors may have been introduced in the present study due to the small sample size, it is necessary to perform further investigations with larger sample sizes in order to investigate the sites that were not significantly affected in the current study. Significant differences were found, however, in mandibular length and ramus height, which are both important parameters.

The results of the present research suggest that mechanical stress induced by mastication markedly affects the mandibular condylar cartilage and the mandible around the masticatory muscles, as well as changing the pattern of growth and development of the mandible.

Conclusion

A change in adult masticatory function can have a significant influence on mandibular growth and development. Since mandibular shape plays an important role in development of the mandible, it is considered that dietary education should be provided at an early age.

Address for correspondence

Junichi Watahiki
Department of Orthodontics
School of Dentistry
Showa University
2-1-1 Kitasenzoku
Ohta-ku
Tokyo 145-8515
Japan
E-mail: junwata2000@ybb.ne.jp

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Maximum occlusal bite forces in Jordanian individuals with different dentofacial vertical skeletal patterns

Elham S. J. Abu Alhaija, Ibraheem A. Al Zo'ubi, Mohammed E. Al Rousan and Mohammad M. Hammad
Department of Preventive Dentistry, School of Dentistry, Jordan University of Science and Technology, Irbid, Jordan

SUMMARY This study was carried out to record maximum occlusal bite force (MBF) in Jordanian students with three different facial types: short, average, and long, and to determine the effect of gender, type of functional occlusion, and the presence of premature contacts and parafunctional habits on MBF. Sixty dental students (30 males and 30 females) were divided into three equal groups based on the maxillomandibular planes angle (Max/Mand) and degree of anterior overlap: included short-faced students with a deep anterior overbite (Max/Mand ≤ 22 degrees), normal-faced students with a normal overbite that served as the controls (Max/Mand = 27 ± 5 degrees), and long-faced students with an anterior open bite (Max/Mand ≥ 32 degrees). Their age ranged between 20 and 23 years. MBF was measured using a hydraulic occlusal force gauge. Occlusal factors, including the type of functional occlusion, the presence of premature contacts, and parafunctional habits, were recorded. Differences between groups were assessed using a *t*-test and analysis of variance.

The average MBF in Jordanian adults was 573.42 ± 140.18 N. Those with a short face had the highest MBF (679.60 ± 117.46 N) while the long-face types had the lowest MBF (453.57 ± 98.30 N; $P < 0.001$). The average MBF was 599.02 ± 145.91 in males and 546.97 ± 131.18 in females ($P = 0.149$). No gender differences were observed. The average MBF was higher in patients with premature contacts than those without, while it did not differ in subjects with different types of functional occlusion or in the presence of parafunctional habits.

Introduction

It is generally accepted that there is a relationship between occlusal forces and facial morphology. Three basic types of facial morphology are said to exist: short, average, and long. Those with a long face have excessive vertical facial growth which is usually associated with an anterior open bite, increased sella–nasion (SN)/mandibular plane (MP) angle, increased gonial angle, and increased maxillary/mandibular planes angle (Fields *et al.*, 1984; Cangiaolosi, 1989). The short face types have reduced vertical growth that is usually accompanied by a deep anterior overbite, reduced facial heights, and reduced SN–MP angle (Opdebeeck and Bell, 1978). Between the two types lies the 'average' face (Edgerton, 1976). The relationship between bite force and craniofacial morphology has been investigated (Sassouni, 1969; Ringqvist, 1973; Ingervall and Helkimo, 1978; Proffit *et al.*, 1983). The mean bite force in the molar region was twice as great in the normal as in long-face subjects; short-face subjects generating even higher forces than normal face subjects (Proffit *et al.*, 1983).

A wide range of maximum bite force values is reported in different studies. This can be attributed to several factors that can be individual or technique related. Individual-related factors include physical characteristics and craniofacial morphology. Shiau and Wang (1993) reported that bite force increased with age, height, and weight. Nonetheless, Braun *et al.* (1995) found a low correlation between bite force and body variables. Gender differences in bite force have also been reported. It was found that the mean bite force values were significantly higher in males than in females (Helkimo *et al.*, 1977; Kiliaridis *et al.*, 1995; Waltimo and Kononen, 1995; Tuxen *et al.*, 1999; Kovero *et al.*, 2002). Corruccini *et al.* (1985) reported higher bite forces among rural youths with forceful harder chewing habits. On the other hand, technique-related factors include interocclusal separation, location of the measuring device on the dentition, and head posture at the time of measurement.

A number of different devices have been used to obtain direct measurement of bite force including the bite fork (Helkimo *et al.*, 1977; van Steenberghe and de Vries, 1978; Kiliaridis *et al.*, 1993), strain gauge transducers (Hellsing and Hagberg, 1990; Lindauer *et al.*, 1993; Braun *et al.*, 1996), foil transducers (Burke *et al.*, 1973; Proffit *et al.*, 1983), the pressurized rubber tube (Braun *et al.*, 1995), the gnathodynamometer (Ortug, 2002), the pressure-sensitive sheet (Hidaka *et al.*, 1999; Sondang *et al.*, 2003), and force-sensing resistors (Fernandes *et al.*, 2003).

The aims of the present study were to

1. Measure the maximum bite force among Jordanian subjects using a hydraulic pressure–force gauge.

Table 1 Mean and standard deviations (SD) of age in the three groups.

	Number		Age		
	Female	Male	Males, mean ± SD	Females, mean ± SD	Total, mean ± SD
Short face	10	10	21.90 ± 0.88	21.70 ± 0.68	21.80 ± 0.77
Average face	10	10	21.55 ± 0.69	21.56 ± 0.88	21.55 ± 0.75
Long face	10	10	22.10 ± 0.57	21.55 ± 1.04	21.81 ± 0.87

2. Compare bite force between different vertical facial patterns.
3. Study the effects of gender, weight, height, type of functional occlusion, and the presence of parafunctional habits and premature contacts on occlusal bite force.

Subjects and methods

Ethical permission was obtained from Institutional Review Board at the Jordan University of Science and Technology. The objectives and methodology were explained to all participants and written consent was obtained.

Five hundred dental students at the Jordan University of Science and Technology were screened and 60 subjects (30 males and 30 females) were included in this study fulfilling the following criteria: a Class I skeletal pattern, no previous orthodontic treatment, no missing posterior teeth other than third molars, no large carious cavities or restorations in the permanent first molars, and no posterior crossbite.

The subjects were divided into three equal groups based on the maxillomandibular plane angle (Max/Mand) and degree of anterior overlap: included short-faced students with deep anterior overbite (Max/Mand ≤ 22 degrees), normal-faced students with a normal overbite that served as the controls (Max/Mand = 27 ± 5 degrees), and long-faced students with an anterior open bite (Max/Mand ≥ 32 degrees).

For each subject age, gender, weight in kilograms, height in metres, and body mass index (BMI; weight/height^2) were recorded. Their ages ranged between 20 and 23 years, with a mean of 21.80 ± 0.77, 21.55 ± 0.75, and 21.81 ± 0.87 years in the short-, average-, and long-face groups, respectively. Gender and age distribution are shown in Table 1.

The clinical examination and maximum bite force registration were carried out by two postgraduate students (IAZ and MER). The examination included assessment of dynamic occlusion and determination of the presence of parafunctional habits and premature contacts. Dynamic occlusion was classified into canine guidance or group function occlusion. A canine-guided occlusion was defined as canine-only contact on the working side on lateral mandibular movements and group function occlusion as posterior tooth contact on the working side on lateral mandibular movements.

Figure 1 Hydraulic pressure occlusal force gauge.

Bite force was measured bilaterally in the first molar region using a portable occlusal force gauge (GM10, Nagano Keiki, Tokyo, Japan; Figure 1), that consisted of a hydraulic pressure gauge and a biting element made of a vinyl material encased in a polyethylene tube. Bite force was displayed digitally in Newtons. The accuracy of this occlusal force gauge has previously been confirmed (Sakaguchi *et al.*, 1996). Before the recording, the subject was seated upright and without head support with the Frankfort plane nearly parallel to the floor. Each subject was instructed to bite as hard as possible on the gauge without moving the head. Bite force was measured alternately on the right and left sides with a 15 second resting time between each bite. Three readings were obtained on each side. From these six recordings, two values were used in the analysis; the maximum bite force (MBF), which is the maximum measurement achieved on each side, and the average MBF from both sides.

For allocation to the groups, lateral cephalograms were taken for each participant in centric using an Orthoslice 1000 C (Trophy, Marne La Vallee, France) cephalostat at 64 kV, 16 mA, and 0.64 seconds exposure. The cephalograms were traced manually by one author (ESJAA) and 13 hard tissue cephalometric points were registered yielding four angular and two linear measurements (Figure 2).

Method error

The reliability of the measurements was assessed by the sine integrator re-examining and re-measuring records of 10 subjects after an interval of 1 week. Kappa statistics were used to evaluate the reliability of the categorical data

(Cohen, 1960). The results of the kappa values were above 80 per cent for both intra- and interexaminer reliability which indicate a substantial agreement between readings (Landis and Koch, 1977). Method errors for numerical variables were examined using the formula of Dahlberg (1940) and coefficients of Houston (1983). The error ranged between 0.1 and 0.2 and the coefficient of reliability was above 90 per cent for all the measurements, indicating good agreement.

Statistical analysis

Data analysis was carried out using the Statistical Package for Social Science version 10 (SPSS Inc.®, Chicago, Illinois, USA). Descriptive data were tabulated. Pearson's correlation test was used to correlate different variables with MBF. Analysis of variance was used to determine whether significant differences existed between the groups. A least significant differences test and a multiple comparison test were applied to identify which of the groups were different.

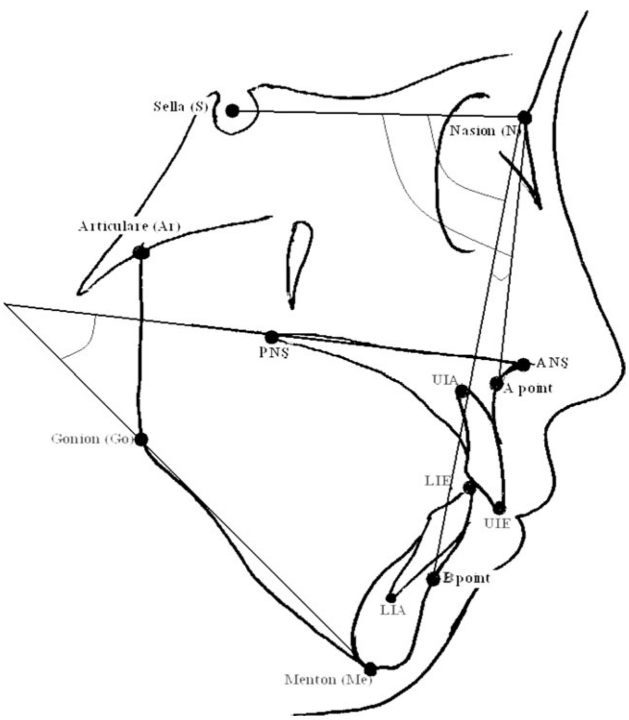

Figure 2 Points, lines, and measurements used in the cephalometric analysis. SNA: angle between sella–nasion–point A; SNB: angle between sella–nasion–point B; ANB: angle between point A–nasion–point B; Maxillomandibular planes angle (MM angle): angle between the maxillary and mandibular planes; overbite (OB) The vertical distance between the incisal edges of the upper and lower incisors; overjet (OJ) The horizontal distance between the incisal edges of the upper and lower incisors.

Results

Physical characteristics

The mean weight, height, and BMI for subjects in each group are shown in Table 2. The weight of the subjects ranged between 45 and 108 kg, with a mean of 67.05 ± 14.40, 65.50 ± 13.65, and 66.14 ± 14.82 kg in the short-, average-, and long-face groups, respectively. Height ranged between 1.50 and 1.80 m with a mean of 1.68 ± 0.06, 1.66 ± 0.06, and 1.67 ± 0.08 in the short-, average-, and long-face groups, respectively. BMI ranged between 19 and 27 with a mean of 22.96 ± 2.59, 22.86 ± 2.54, and 22.30 ± 2.60 in the short-, average-, and long-face groups, respectively.

Cephalometric measurements

The means, standard deviations, and differences between the means and *P* values for cephalometric measurements in the three groups are shown in Table 3. The Max/Mand averaged 19.05 ± 2.01, 26.95 ± 1.67, and 33.40 ± 1.14 degrees and overbite 5.68 ± 0.75, 2.55 ± 0.51, and −2.35 ± 1.80 mm in the short-, average- and long-face types, respectively. The three groups differed significantly in their vertical cephalometric measurements ($P < 0.001$).

Maximal occlusal bite force

The means, standard deviations, and differences between the means of bite force measurements in the three groups are shown in Table 4. The average MBF ranged between 290 and 965 N. On the right side, MBF was 669.90 ± 133.58, 590.55 ± 119.72, and 470.24 ± 115.04 N for the short-, average-, and long-face groups, respectively. Statistically significant differences were detected between the short and average faces ($P < 0.05$), normal and long faces ($P < 0.01$), and short and long faces ($P < 0.001$). On the left side, average MBF was 689.30 ± 105.56, 595.60 ± 106.28, and 436.90 ± 108.06 N for the short-, average-, and long-face groups, respectively.

Table 2 Means and standard deviations (SD) of the physical characteristics in the three groups.

	Short face, mean ± SD			Average face, mean ± SD			Long face, mean ± SD		
	Females	Males	All	Females	Males	All	Females	Males	All
Weight (kg)	55.40 ± 3.17	78.70 ± 11.24	67.05 ± 14.40	52.44 ± 2.35	76.18 ± 8.44	65.50 ±13.66	54.18 ± 3.49	79.30 ± 10.35	66.14 ± 14.82
Height (m)	1.61 ± 0.05	1.72 ± 0.03	1.68 ± 0.06	1.61 ± 0.03	1.71 ± 0.04	1.66 ± 0.06	1.63 ± 0.08	1.72 ± 0.04	1.67 ± 0.08
Body mass index	20.89 ± 1.12	25.04 ± 1.83	22.96 ± 2.59	20.34 ± 0.71	21.97 ± 2.61	22.86 ± 2.54	20.48 ± 1.59	24.30 ± 1.92	22.30 ± 2.60

Statistically significant differences were observed between the short and average faces ($P < 0.01$), normal and long faces ($P < 0.001$), and short and long faces ($P < 0.001$). The average MBF was 679.60 ± 117.46, 593.08 ± 99.69, and 453.57 ± 98.30 N in the short-, average-, and long-face groups, respectively. Statistically significant differences were found between the short and average faces ($P < 0.05$), normal and long faces ($P < 0.001$), and short and long faces ($P < 0.001$). The total group average MBF was 575.15 ± 146.71, 571.69 ± 148.86, and 573.42 ± 140.18 N for the right side, the left side, and the overall sample, respectively.

Effect of weight, height, and BMI on biting force

A positive correlation was found between average MBF and weight ($R^2 = 0.138$), height ($R^2 = 0.022$), and BMI ($R^2 = 0.275$). However, the only statistically significant correlation was between average MBF and BMI ($P = 0.032$).

Effect of gender on biting force

The average MBF was 599.02 ± 145.91 in males and 546.97 ± 131.18 in females ($P = 0.149$; Table 5). The MBF in males averaged 712.45 ± 114.20, 622.41 ± 88.19, and

Table 3 Means, standard deviations (SD), *F* values, differences between the means and significance for cephalometric measurements in the three groups using analysis of variance (ANOVA) and least significant differences (LSD) tests.

Cephalometric measurement	Short face (group 1), mean ± SD	Average face (group 2), mean ± SD	Long face (group 3), mean ± SD	ANOVA *F* value	Group 1 and 2		Group 1 and 3		Group 2 and 3	
					Mean difference	LSD	Mean difference	LSD	Mean difference	LSD
SNA (°)	82.37 ± 4.77	81.55 ± 3.14	82.30 ± 4.59	1.192	0.82	NS	0.07	NS	0.75	NS
SNB (°)	79.79 ± 3.58	79.05 ± 4.85	79.75 ± 5.20	1.201	0.74	NS	0.04	NS	0.70	NS
ANB (°)	2.58 ± 0.51	2.50 ± 1.36	2.55 ± 1.05	0.12	0.08	NS	0.03	NS	0.05	NS
MM angle (°)	19.05 ± 2.01	26.95 ± 1.67	33.40 ± 1.14	373.38***	7.90	***	14.35	***	6.45	***
Overbite (mm)	5.68 ± 0.75	2.55 ± 0.51	−2.35 ± 1.80	606.99***	3.13	***	8.03	***	4.90	***
Overjet (mm)	2.53 ± 0.51	2.40 ± 0.50	2.70 ± 0.47	1.85	0.13	NS	0.17	NS	0.30	NS

NS, not significant, ***$P < 0.001$.

Table 4 Means, standard deviations (SD), *F* values, differences between the means and significance for maximum bite force (MBF) on right and left sides in the three groups.

	Short face (group 1), mean ± SD	Average face (group 2), mean ± SD	Long face (group 3), mean ± SD	*F* values	Total	Differences in mean, groups 1 and 2	Differences in mean, groups 1 and 3	Differences mean, groups 2 and 3
Right MBF	669.90 ± 133.58	590.55 ± 119.72	470.24 ± 115.04	13.753	575.15 ± 146.71	79.35*	199.66***	120.31**
Left MBF	689.30 ± 105.56	595.60 ± 106.28	436.90 ± 108.06	29.427	571.69 ± 148.86	93.70**	252.40***	158.70***
Average MBF	679.60 ± 117.46	593.08 ± 99.69	453.57 ± 98.30	24.077	573.42 ± 140.18	86.53*	226.03***	139.50***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 5 Means, standard deviations (SD), and differences between means and significance in the subjects according to gender, type of dynamic occlusion, and presence of parafunctional habits and of premature contact.

Variables		Number	Bite force, means ± SD	Mean difference
Gender	Females	30	546.97 ± 131.18	52.05
	Males	30	599.02 ± 145.91	
Type of dynamic occlusion	Canine guidance	24	645.48 ± 116.52	122.10**
	Group function	36	523.38 ± 134.51	
Presence of parafunctional habits	Yes	15	563.97 ± 162.8	12.53
	No	45	576.50 ± 142.23	
Presence of premature contact	Yes	9	677.72 ± 166.49	122.36*
	No	51	555.37 ± 128.53	

*$P < 0.05$, **$P < 0.01$.

459.85 ± 113.15 in the short-, average-, and long-face groups, respectively, and females 646.75 ± 116.99, 557.22 ± 106.09, and 447.86 ± 87.91, respectively. No gender differences were found among the three groups studied.

Effect of the type of dynamic occlusion on biting force

In the short-face group, 13 subjects had a right-side canine guidance and 11 a left-side canine guidance, while in the average-face group, there were 10 subjects with right-side canine guidance and 10 with left-side canine guidance (Table 5). In the long-face group, there was only group function occlusion. The average MBF in subjects with canine guidance was 645.48 ± 116.52, while in patients with group function dynamic occlusion, it was 523.38 ± 134.51 ($P < 0.01$).

Effect of the presence of parafunctional habits on biting force

The majority of the subjects did not have any habits (Table 5). In the short-face group, six subjects had a parafunctional habit while in the average-face group there were five subjects. In long-face group, four subjects had a parafunctional habit. The average MBF in subjects with or without parafunctional habits was 563.97 ± 162.8 and 576.50 ± 142.23, respectively ($P = 0.764$).

Effect of premature contact on biting force

The majority of subjects had no premature contacts (Table 5). Five subjects had premature contacts in the short-face group, two in the average-face group, and two in the long-face group. No significant differences in the presence of premature contacts between the three groups were detected ($P = 0.271$). The average MBF in subjects with or without a premature contact was 677.72 ± 166.49 and 555.37 ± 128.53, respectively ($P < 0.05$).

Discussion

In this study, a hydraulic pressure gauge was used with a biting element encased in a plastic covering. This device has several advantages: it is easy to use, does not need any special mounting, has a small thickness of about 5.4 mm, does not interfere with the tongue, and can be easily disinfected by changing the disposable plastic coverings. However, it has a plastic covering that can still be considered hard to bite and this may be the main potential disadvantage. In this study, the only risk was tooth damage, and this was considerably reduced by excluding patients with large molar restorations. Bite force was measured at the first molar area unilaterally, which is more reproducible than bilateral measurements (Tortopidis *et al.*, 1998).

The average MBF in Jordanian adults in this study was 549 N. In females, MBF was 481 N, while in males, it was 610 N. The average MBF was higher than that measured by Sasaki *et al.* (1989), Bakke *et al.* (1990), Tortopidis *et al.* (1998), Raadsheer *et al.* (1999), Miyaura *et al.* (1999), and Ferrario *et al.* (2004). On the other hand, it was lower than that reported by Braun *et al.* (1995), Kovero *et al.* (2002), Okiyama *et al.* (2003), and Sondang *et al.* (2003).

This wide range in bite force can be explained by different factors. Firstly, different devices with different biting elements have been used to measure MBF. In this study, a bite force gauge with a plastic-covered biting element was used that may allow individuals to bite harder than a hard thick metallic transducer used in other research (Sasaki *et al.*, 1989; Tortopidis *et al.*, 1998; Raadsheer *et al.*, 1999; Ferrario *et al.*, 2004). This may explain the lower biting force reported by those authors. On the other hand, using thin biting sheets (Prescale system; Okiyama *et al.*, 2003; Sondang *et al.*, 2003) or a pressurized rubber tube (Braun *et al.*, 1995) may allow harder biting and this also may explain the higher biting force reported by those authors. Another possible factor is the composition of the study sample. All mentioned studies were conducted on a mixed sample with randomly selected individuals with no concentration on the facial morphology, while in the present investigation, a specific number of each facial type was selected. This may lead to a higher or lower number of extreme facial types (short or long faces) in the present than in the other studies.

Furthermore, this is the only study carried out on a Jordanian population, while the others were conducted on different populations (Bakke *et al.*, 1990; Sondang *et al.*, 2003; Ferrario *et al.*, 2004). It is possible that different races have different biting forces, which might be attributed to different eating habits and different facial morphology. Other factors such as the thickness of the biting element and control of measurement procedures can also play a role in the magnitude of MBF found in different studies.

MBF in the present investigation differed significantly between the different vertical facial morphologies. In the short-face group, a mean MBF of 680 N was found compared with 453 N in the long-face group, while the average-face group had an intermediate MBF value of about 593 N. These results are in agreement with Proffit *et al.*, (1983) who reported a mean MBF of 356 N in normal faces compared with 155 N in long-face subjects. Ingervall and Helkimo (1978) and Kiliaridis *et al.* (1995) also reported that strong muscles produce more uniform facial morphology, while weaker muscles produce more diverse facial morphology.

Regardless of the difference in measured MBF compared with the previous studies (Ingervall and Helkimo, 1978; Proffit *et al.*, 1983; Kiliaridis *et al.* 1995), an association between facial morphology and MBF was found. Deeper analysis showed a more pronounced difference in MBF between the short- and long-face groups than between the short- and average-face groups.

A significant positive correlation was observed between MBF and BMI. This is in agreement with the findings of Sasaki *et al.* (1989) and Kiliaridis *et al.* (1993).

The mean MBF in individuals with a parafunctional habit was similar to that in individuals with no habit. Cosme *et al.* (2005) found the same in an investigation of 80 young adults. However, that study had some limitations since only a small number of individuals had parafunctional habits. Therefore, further studies may be needed to clarify the correlation between parafunctional habits and MBF.

The mean MBF in individuals with a premature contact was higher than that recorded for subjects without a premature contact. This finding is contrary to the results of Ingervall and Minder (1997) who reported that as the number of teeth in contact increase, greater force distribution will be allowed thus reducing localized pain perception and permitting harder biting.

Conclusions

1. The average MBF in the Jordanian adults in this study was 573 N. In females, it was 547 N and in males, 599 N.
2. MBF significantly differed between subjects with different vertical facial morphologies. The short face type had the highest MBF of 680 N, the long-face type the lowest MBF of 454 N, and the average face type an MBF of 593 N.
3. The average MBF was higher in patients with a premature contact while it did not differ in subjects with different types of functional occlusion or in the presence of parafunctional habits.
4. No gender differences in average MBF were observed.

Address for correspondence

Elham S. J. Abu Alhaija
Preventive Dentistry Department
School of Dentistry
Jordan University of Science and Technology
PO Box 3030
Irbid
Jordan
E-mail: elham@just.edu.jo

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Are nano-composites and nano-ionomers suitable for orthodontic bracket bonding?

Tancan Uysal*, Ahmet Yagci*, Banu Uysal*** and Gülsen Akdogan**
Departments of *Orthodontics and **Mechanics, Erciyes University, Kayseri and ***Nimet Bayraktar Mouth and Teeth Health Center, Turkey

SUMMARY The aim of this study was to test nano-composite (Filtek Supreme Plus Universal) and a newly introduced nano-ionomer (Ketac™ N100 Light Curing Nano-Ionomer) restorative to determine their shear bond strength (SBS) and failure site locations in comparison with a conventional light-cure orthodontic bonding adhesive (Transbond XT). Sixty freshly extracted human maxillary premolar teeth were arbitrarily divided into three equal groups. The brackets were bonded to the teeth in each group with different composites, according to the manufacturers' instructions. The SBS values of the brackets were recorded in Megapascals (MPa) using a universal testing machine. Adhesive remnant index scores were determined after failure of the brackets. The data were analysed using analysis of variance, Tukey honestly significant difference, and chi-square tests.

The results demonstrated that group 1 (Transbond XT, mean: 12.60 ± 4.48 MPa) had a higher SBS than that of group 2 (nano-composite, mean: 8.33 ± 5.16 MPa; $P < 0.05$) and group 3 (nano-ionomer, mean: 6.14 ± 2.12 MPa; $P < 0.001$). No significant differences in debond locations were found among the three groups. Nano-composites and nano-ionomers may be suitable for bonding since they fulfil the previously suggested SBS ranges for clinical acceptability, but they are inferior to a conventional orthodontic composite.

Introduction

Since the introduction of the acid-etch bonding technique, the concept of bonding various resins to enamel surfaces has developed applications in all fields of dentistry, including the bonding of orthodontic brackets (Bishara *et al.*, 2007).

In routine orthodontic practice, it is essential to obtain a reliable adhesive bond between an orthodontic attachment and tooth enamel. Filled dental restorative materials have been used as orthodontic adhesives (Eversoll and Moore, 1988). These materials consist of an organic diacrylate (bisphenol A diglycidylether methacrylate: BIS-GMA), a coupler (silane), and a high percentage content of inorganic filler (quartz, silica). It is well known that the inorganic filler makes the material more abrasion resistant, increases the shear bond strength (SBS), and decreases the coefficient of thermal expansion to values closer to those of enamel to prevent long-term microleakage (Venhoven *et al.*, 1996). Ostertag *et al.* (1991), in an experimental study to evaluate the influence of adhesive filler concentration on bond strength, found an increase in shear and torsional bond strengths with increasing concentrations of adhesive filler.

One of the most important advances in the dental material field is the application of nanotechnology to resin composites. Nanotechnology is the production and manipulation of materials and structures in the range of about 0.1–100 nm by various physical or chemical methods (Kirk *et al.*, 1991). While the size of the filler particles lies between 8 and 30 μm in hybrid composites and 0.7 and 3.6 μm in microhybrid composites (Venhoven *et al.*, 1996), recently, new fillers with size ranging from approximately 5–100 nm have been developed (Moszner and Klapdohr, 2004). These materials could thus be considered as precursors of nanofilled composites. Due to the reduced dimension of the particles and to a wide size distribution, an increased filler load can be achieved that reduces polymerization shrinkage (Moszner and Salz, 2001) and increases mechanical properties such as tensile and compressive strength and resistance to fracture. Geraldeli and Perdigao (2003) reported that nano-composites had a good marginal seal to enamel and dentine compared with total-etch adhesives.

Demineralization of the labial surfaces of teeth during orthodontic therapy is of clinical importance (Gorelick *et al.*, 1982) and may present an aesthetic problem, even more than 5 years after treatment (Øgaard, 1989). One of the most effective agents in caries prevention is fluoride. It will inhibit the metabolism of the bacteria that cause caries and also will increase the resistance of enamel and dentine. Forsten (1998) emphasized the importance of fluoride use during treatment with fixed orthodontic appliances to prevent development of white spot lesions. Usually, the fluoride is applied as solutions, pastes, or varnishes designed for the whole dentition (Forsten, 1998). Because of the anticariogenic and re-mineralizing effects, resin-modified glass ionomer cements (RMGIC) can be used where a locally strong initial fluoride effect is desired in addition to a long-term effect (Forsten, 1998).

Recently, a new RMGIC has been introduced for operative dentistry. Ketac™ N100 light curing nano-ionomer includes fluoroaluminosilicate glass, nanofillers, and nanofiller 'clusters' combined to improve mechanical properties. The nanofiller components also enhance some physical properties of the hardened restorative. The manufacturer calls the new restorative cement a 'nano-ionomer' because the formulation is 'based on bonded nanofiller technology'. The manufacturer has suggested that Ketac N100 shows high fluoride release that is rechargeable after being exposed to a topical fluoride source. Additionally, *in vitro* tests showed that Ketac N100 has the ability to create a caries inhibition zone after acid exposure.

No research has been published in the literature that has evaluated and compared the SBS values and adhesive remnant index (ARI) scores of orthodontic brackets bonded with a nano-composite, a nano-ionomer, and a conventional orthodontic adhesive.

The aim of this study was to test nano-filled composite and ionomer to determine their SBS values in comparison with a conventional bonding adhesive and the site of bond failure of those materials. The null hypotheses to be tested were that there is no statistically significance in (1) the bond strength and (2) the failure site location of nano-composites, nano-ionomers, and conventional orthodontic adhesives.

Materials and methods

Ethical approval for this research was obtained from the regional committee of Erciyes University.

Sixty non-carious human maxillary premolars, extracted for orthodontic reasons, were used in this study. Teeth with hypoplastic areas, cracks, or irregularities of the enamel structure were excluded. The criteria for tooth selection dictated no pre-treatment with chemical agents such as alcohol, formalin, or hydrogen peroxide. The extracted teeth were stored in distilled water until use. The water was changed weekly to avoid bacterial growth. The sample was arbitrarily divided into three equal groups. Each tooth was mounted vertically in a self-cure acrylic block so that the crown was exposed. The buccal enamel surfaces of the teeth were cleansed and polished with non-fluoridated pumice and rubber prophylactic cups, washed with water, and dried.

A 37 per cent phosphoric acid gel (3M Dental Products, St Paul, Minnesota, USA) was applied to the premolars for 15 seconds. The teeth were then rinsed with water for 30 seconds and dried with an oil-free source for 20 seconds, until a frosty white appearance of the enamel was present. Ceramic brackets (3M Unitek, Monrovia, California, USA) were bonded to the teeth, according to the manufacturer's instructions. The average surface of the ceramic bracket base used was measured and recorded as 14.54 mm^2.

After acid etching, the brackets were bonded in the following manner:

Group 1 (control group): Transbond XT (3M Unitek) primer was applied to the etched surface in a thin film and left uncured. Transbond XT adhesive paste was applied to the bracket base, and the bracket was positioned on the tooth and pressed firmly into place. The excess adhesive was removed from around the bracket with a scaler, and the adhesive was light cured from the mesial and distal for 20 seconds each (total time 40 seconds).

Group 2 (nano-composite group): According to the manufacturer's instructions, the primer (Adper adhesive systems; 3M Espe, Seefeld, Germany) was applied to the etched surface in a thin film and light cured for 10 seconds. The bracket was positioned, and the composite (Filtek Supreme plus universal restorative, 3M Espe) was light cured for 40 seconds.

Group 3 (nano-ionomer group): After normal tooth preparation, Ketac Nano Primer (3M Espe) was painted over the enamel surface for 15 seconds. The primer was thinned using a gentle stream of dry air and cured for 10 seconds. The desired number of 'clicks' of nano-ionomer (Ketac™ N100) was squeezed onto a mixing pad and blended with a spatula for 20 seconds. The mixed paste was carefully injected using an orange AccuDose syringe (Centrix, Inc., River Road Shelton, Connecticut, USA) onto the bracket base, positioned on the tooth, and pressed firmly into place. The excess material was removed from around the bracket with a scaler, and the adhesive was light cured from the mesial and distal for 15 seconds each (total time 30 seconds) according to the manufacturer's instructions.

A quartz–tungsten halogen light unit (Hilux 350, Express Dental Products, Toronto, Canada) with 10 mm diameter light tip was used for curing the specimens.

Debonding procedure

After completion of the procedures, the embedded specimens were secured in a jig attached to the base plate of a universal testing machine (Hounsfield Test Equipment Ltd., Salford, Lancashire, UK). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned so that the leading edge was aimed at the enamel/adhesive interface. A crosshead speed of 0.5 mm/minute was used, and the maximum load necessary to debond the bracket was recorded. The force required to remove the brackets was measured in Newtons (N), (1 MPa = 1 N/mm^2) and the SBS was then calculated by dividing the force values by the bracket base area (14.54 mm^2).

Residual adhesive

After debonding, all teeth and brackets were examined under a stereomicroscope (SZ 40, Olympus, Tokyo, Japan) at ×10 magnification. The amount of adhesive remaining on the enamel surface was coded using the criteria proposed in the ARI of Årtun and Bergland (1984).

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS for Windows 13.0, SPSS, Chicago, Illinois, USA). Descriptive statistics, including the mean, standard deviation (SD), and minimum and maximum values were calculated for the three groups of teeth tested. The Shapiro–Wilks normality test and the Levene variance homogeneity test were applied to the SBS data. The data showed normal distribution, and there was homogeneity of variances among the groups. Comparisons of the means of SBS values were made with analysis of variance (ANOVA). Multiple comparisons were undertaken using Tukey honestly significant difference tests. The chi-square test was used to determine significant differences in the ARI scores among the three groups.

Results

Descriptive statistics including the mean, SD, and minimum and maximum values for each of the three groups are presented in Table 1. ANOVA revealed statistically significant differences in bond strengths among the various groups ($P < 0.001$). Thus, the first null hypothesis of this study was rejected. The results demonstrated that group 1 (Transbond XT, mean: 12.60 ± 4.48 MPa) had higher SBS values than group 2 (nano-composite, mean: 8.33 ± 5.16 MPa; $P < 0.05$) and group 3 (nano-ionomer, mean: 6.14 ± 2.12 MPa; $P < 0.001$). No statistically significant differences were found between groups 2 and 3 ($P > 0.05$).

The ARI scores for the various groups tested are listed in Table 2. The results of the chi-square comparisons indicated that there were no statistically significant differences among three groups ($P = 0.679$). Therefore, the second null hypothesis was accepted.

Discussion

An optimal tooth restoration material should mimic the structural, mechanical, and physical characteristics of dentine and enamel (Sabbagh *et al.*, 2002). Manufacturers are continuously introducing new adhesives in operative dentistry that are more reliable, i.e. stronger, adhere better, are less prone to leakage at the margins, and/or are easier to handle (Bishara *et al.*, 2007). As new materials and techniques are introduced, orthodontists adopt some of these innovations and add them to their armamentarium (Bishara *et al.*, 2007), including the use of self-etching primers, RMGIC, chlorhexidine varnishes, and different adhesives.

Most bonding studies use commercially available adhesive systems that have different particle sizes, viscosities, and concentrations of filler particles (Ostertag *et al.*, 1991). This makes comparisons among studies difficult because of the increased number of variables involved in the material composition. Ostertag *et al.* (1991) found an increase in shear and torsional bond strengths with increasing concentrations of adhesive filler. From this starting point, the aim of the present study was to test two newly introduced restorative materials, filled with nano-particles, that were reported to have higher physical and mechanical properties, in comparison with a conventional light-cure orthodontic bonding adhesive.

Bishara *et al.* (2007) indicated that the nano-filled composite system, Grandio, achieved SBS values that were not significantly different from those obtained with Transbond XT. The SBS results of the present study are contrary to those findings, in that, the conventional orthodontic adhesive system showed higher values than the nano-composite and this difference was statistically significant. Due to the compact consistency of the adhesive paste, the findings of Bishara *et al.* (2007) that manufacturers should consider reformulating the composition of nano-composite to produce a paste with a more flowable consistency that can readily penetrate the mesh of the bracket base for orthodontic purposes is supported.

The anticariogenic and re-mineralizing effects of continuous fluoride release from conventional glass ionomer cements can be predicted and there are also indications of a similar effect with RMGIC. Ketac N100 nano-ionomer was evaluated in this study, which according to the manufacturers shows high fluoride release and is rechargeable after being exposed to a topical fluoride source. The nano-ionomer did not have the disadvantage of the nano-composite wherein the consistency of the adhesive paste is thick, and the nano-ionomer easily flowed into the retention pad of the bracket base. The flowability of the nano-ionomer may make it superior to composite resins for penetrating the bracket

Table 1 Descriptive statistics and results of analysis of variance (ANOVA) and Tukey tests comparing the shear bond strength of three groups tested ($n = 20$).

Groups tested	Mean (MPa)	SD	Minimum	Maximum	ANOVA comparisons (significance)	Nano-composite	Nano-ionomer
Control	12.60	4.48	6.43	18.57		$P = 0.017$*	$P = 0.000$***
Nano-composite	8.33	5.16	1.71	20.71	$P = 0.000$***		$P = 0.324$, NS
Nano-ionomer	6.14	2.12	2.43	10.00			

SD, standard deviation; NS: not significant; *$P < 0.05$; ***$P < 0.001$.

Table 2 Frequency of distribution of adhesive remnant index (ARI) scores (%) in the three groups tested.

Groups tested	ARI scores*					Significance *P* value
	ARI = 0	ARI = 1	ARI = 2	ARI = 3	*n*	
Control	0 (0%)	16 (80%)	2 (10%)	2 (10%)	20	
Nano-composite	0 (0%)	15 (75%)	4 (20%)	1 (5%)	20	0.679
Nano-ionomer	1 (5%)	13 (65%)	4 (20%)	2 (10%)	20	

*ARI scores: 0 = no adhesive remains on the tooth surface; 1 = less than half the adhesive remains on the tooth surface; 2 = more than half the adhesive remains on the tooth surface; 3 = all the adhesive remains on the tooth surface.

retention features and possibly coating the enamel during the bonding procedure. Such an attribute might reduce the possibility of caries forming under brackets during treatment. Fluoride release and recharge might also reduce the possibility of caries formation near the bonding material excess interface between the bonding material/enamel/oral environment line. This linear boundary must be of high free energy based on the free energy calculation of potentially unsatisfied valence states and fluoride ions in that area should be available to form fluorapatite from present hydroxyapatite. From this perspective, Ketac N100 nano-ionomer should be considered a potentially useful adhesive for bonding orthodontic brackets. However, the SBS value of this material was also statistically lower than orthodontic composite, while no statistically significant differences were found between the nano-composite and nano-ionomer.

Reynolds (1975) suggested that a minimum bond strength of 5.9–7.8 MPa is adequate for most orthodontic needs during routine clinical use. All mean bond strength values of the materials used in this study were above this minimum requirement and within clinically acceptable ranges. However, clinical conditions may differ significantly from an *in vitro* setting. It needs to be emphasized that this was an *in vitro* study and the test conditions were not subjected to the rigours of the oral environment. Heat and humidity conditions of the oral cavity are highly variable. Because of the probable differences *in vivo* and *in vitro*, a direct comparison cannot be made with the findings of other studies.

Bishara *et al.* (2007) indicated that 15 per cent of brackets tested in their study did not register any debonding force because of the difficulty in handling the material, contrary to the findings of the current research. Adhesive remnant data were not presented in the study of Bishara *et al.* (2007) but these probably showed similar failures between orthodontic and nano-composite, considering the SBS values that they reported. The differences in the SBS values among the three different groups are reflected in the distribution of the ARI scores (Table 2). In the present study, ARI scores were not statistically different between the groups and failures in all groups were mostly located at the adhesive/enamel interface.

Conclusions

1. The nano-composite and nano-ionomer tested in this study resulted in lower bond strength values than the conventional orthodontic adhesive but demonstrated SBSs which were within the range previously suggested for clinical acceptability.
2. There were no significant differences in the mean SBS values of the tested nano-composite and nano-ionomer.
3. No significant differences in debond locations were found among the three groups investigated.

Address for correspondence

Dr Tancan Uysal
Erciyes Universitesi
Dis Hekimligi Fakultesi
Ortodonti AD
Melikgazi
38039 Kayseri
Turkey
E-mail:tancanuysal@yahoo.com

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Degree of conversion and hardness of an orthodontic resin cured with a light-emitting diode and a quartz–tungsten–halogen light

Guilherme Pessôa Cerveira*, Telmo Bandeira Berthold*, André A. Souto**, Ana Maria Spohr* and Ernani Menezes Marchioro*
*Preventative Department, School of Dentistry and **School of Chemistry, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

SUMMARY The purpose of this study was to assess the influence of two light units, a quartz–tungsten–halogen (QTH) and a light-emitting diode (LED), on the hardness and degree of conversion of an orthodontic composite resin. Sixty specimen disks were prepared from Transbond XT composite resin (3M Unitek) and light cured for 10, 20, and 30 seconds with a QTH (Curing Light XL 3000, 3M Unitek) or a LED (Ortholux, 3M Unitek) light-curing unit for 5, 10, and 15 seconds. Composite resin polymerization was evaluated by Fourier-transform infrared (FTIR) spectrophotometry and Knoop hardness number (KHN). The results were statistically analysed using analysis of variance and Tukey's multiple comparisons test ($\alpha = 0.05$).

The highest KHN was obtained with the QTH at 30 (25.19 KHN) and 20 (24.01) seconds, which did not differ statistically, and in the LED 15 second (21.86) group. The QTH 10 second group (20.53) did not differ statistically from the QTH 20 second or the LED 5 (19.96) and 15, or 10 second (18.95) groups. According to FTIR, there was no statistical difference for the degree of conversion among the groups, QTH 10 (43.42 per cent), QTH 20 (46.12 per cent), QTH 30 (45.30 per cent), LED 10 (47.02 per cent), or LED 15 (47.24 per cent) seconds. The lowest degree of conversion was obtained for the LED 5 second group (38.97 per cent), which did not differ statistically from the QTH 10 second group.

Light curing with the LED resulted in a reduction of 50 per cent in the time recommended for use of the QTH light with the composite resin, Transbond XT.

Introduction

There have been many advances in dental resin light activation processes, such as the introduction of light-emitting diode (LED) technology (Mills *et al.*, 1999). One advantage attributed to the LED is the coincidence of peak irradiance of LED light with camphorquinone, a photoinitiator agent commonly found in composite resin formulations used in dentistry (Nicholls, 2000; Hammesfahr *et al.*, 2002; Swift, 2002; Bennett and Watts, 2004; Uhl *et al.*, 2004; Wiggins *et al.*, 2004; Bala *et al.*, 2005). Other advantages resulting from the use of LED are the possibility of a reduced curing time (Bishara *et al.*, 2003; Wiggins *et al.*, 2004), a lamp duration time of approximately 10 000 hours (Mills *et al.*, 1999), no heat generation, and resistance to impacts (Mills *et al.*, 1999; Duke, 2001; Dunn and Taloumis, 2002). In addition to this, the LED appliance consumes minimal power and can be run on rechargeable batteries, allowing it to have a lightweight, ergonomic design (Wiggins *et al.*, 2004).

Hardness tests have been used to assess composite resin. These tests are based on the material capacity to resist the penetration of a tip. For materials with an elastic recovery characteristic, such as composite resins, the Knoop hardness test is mostly recommended (Anusavice, 1996; Asmussen and Peutzfeldt, 2003; Bouschlicher *et al.*, 2004; Knobloch *et al.*, 2004; Uhl *et al.*, 2004). With this test, the efficacy of polymerization can be indirectly inferred (Eliades *et al.*, 1995). However, to determine the degree of conversion, tests that measure the conversion of monomer into polymer are required, and spectrophotometry has been indicated (Gioka *et al.*, 2005).

According to Gioka *et al.* (2005), little attention has been paid to research related to polymerization efficiency of materials used in orthodontics. These studies are important since the degree of conversion of dental resins may be influenced by factors inherent in the material, such as the type and concentration of the photoinitiator agent or the quantity and type of organic matrix.

Therefore, the aim of this study was to assess the degree of conversion and the hardness of an orthodontic composite resin submitted to light curing by quartz–tungsten–halogen (QTH) and LED lights.

Materials and Methods

Two light sources were used: a QTH (Curing Light XL 3000, 3M Unitek, St Paul, Minnesota, USA) and an LED (Ortholux, 3M Unitek).

Sixty cylindrical stainless steel matrices were constructed with an external diameter of 10 mm, an internal diameter of

8 mm, and a thickness of 1.5 mm. The matrix was filled with Transbond XT (3M Unitek) composite resin on a glass plate, insulated with a polyester strip. Thirty samples were cured with a QTH light for 10, 20, and 30 seconds (10 samples for each time) and the other 30 samples with a LED light for 5, 10, and 15 seconds (10 samples for each time). Half of the samples were submitted to Knoop hardness testing and the other half to infrared spectrophotometry (FTIR).

The light-curing times of 10, 20, and 30 seconds for the QTH light were based on the predetermined availability of the system, while the light-curing times of 5, 10, and 15 seconds for the LED light represented half the time of that of the QTH light. The light intensity of the appliances was monitored with a conventional digital radiometer (model 8000; EFOS, Lake Bluff, Illinois, USA) for the QTH light and with an analogue radiometer (Demetron, Danbury, Connecticut, USA) for the LED. Gauging was undertaken of the measurements of each group, with their respective items of equipment and sources. The mean intensity values were 638 mW/cm^2 for the QTH and 450 mW/cm^2 for the LED.

Immediately after light activation, the Knoop hardness number (KHN) was measured with a HMV hardness tester (Shimadzu, Tokyo, Japan). Three indentations were made on the opposite side of the light incidence, at different areas on the composite resin surface, under a 200 g load for 15 seconds. The final KHN of each specimen was the arithmetic mean of three measurements.

Fourier-transform infrared (FTIR) spectroscopy was performed with the attenuated total reflectance (ATR) accessory and a plate of zinc selenite crystal at 45 degrees. All measurements were obtained under the following conditions: resolution of 4 cm^{-1} and four internal scans per reading. For each cured resin matrix, the same non-cured matrix served as the control. The non-cured matrix measurement was recorded with the mass of resin inserted in the metal matrix; this being coupled to a metal plate, which served as a distance guide for the light source extremity (1 mm), placed on the crystal plate of the ATR accessory, and isolated with a pure mineral oil (Nujol, Shering Laboratory-Plough, Kenilworth, New Jersey, USA). After the reading, the resin mass was light cured in accordance with the type of light source and at specific times.

Before the first reading and between each new set of measurements of the non-cured resin (monomer) and cured resin (polymer), a baseline spectrum was obtained with all the artefacts that would be used when the resin mass filled the matrix. The purpose of this first measurement was to determine the spectra of the artefacts used in the measurements, which would be deducted by the equipment in the subsequent monomer and polymer measurements of each specimen.

The light was applied on the side opposite the infrared reading beam scan. Between each set of monomer/polymer spectra, the crystal plate of the ATR accessory was cleaned with absorbent paper and acetone and then dried with a serigraphic blower, so that there would be no residues to prejudice the new set of monomer/polymer spectrum measurements. The spectra of the monomers and their respective polymers were compared to determine the conversion rate of the double bonds into simple carbon bonds. The peaks were measured at the frequencies of 1608 per cm (corresponding to the aromatic ring bonds) and 1636 per cm (corresponding to the bonds between carbons of the methacrylate groups; Rueggeberg *et al.*, 1990). The following formula was used to calculate the conversion rate of the double carbon bonds into simple bonds (Eliades *et al.*, 1995):

$$\%\text{Conversion} = 100 \times 1 - \frac{\text{Polymer}(C = C) \times \text{monomer}(C - C)}{\text{Monomer}(C = C) \times \text{polymer}(C - C)}$$

According to the Kolmogorov–Smirnov test, the distribution was normal for all groups. The results were statistically analysed using analysis of variance and Tukey's multiple comparisons test ($\alpha = 0.05$).

Results

The highest KHN was obtained in the QTH 30 (25.19) and 20 (24.01) second groups, which did not differ statistically, and with the LED 15 second group (21.86). The QTH 10 second group (20.53) did not differ statistically from the QTH 20, the LED 5 (19.96) and 15, or the LED 10 (18.95) second groups (Table 1).

There was no statistical difference for the degree of conversion among the QTH 10 (43.42 per cent), 20 (46.12 per cent), 30 (45.30 per cent), or LED 10 (47.02 per cent) and 15 (47.24 per cent) second groups. The lowest degree of conversion was found in the LED 5 second group (38.97 per cent), which did not differ statistically from the QTH 10 second group (Table 2).

Table 1 Knoop microhardness number (KHN) in the experimental groups using a quartz–tungsten–halogen (QTH) light or a light-emitting diode (LED) for different exposure times.

Groups	*n*	Mean (KHN)	Standard deviation
QTH			
10 s	5	20.53^{AC}	0.81
20 s	5	24.01^{AB}	1.04
30 s	5	25.19^{B}	1.38
LED			
5 s	5	19.96^{C}	3.64
10 s	5	18.95^{C}	2.43
15 s	5	21.86^{ABC}	1.64

Different letters indicate statistically different mean values ($P < 0.05$).

Table 2 Polymerization degree (%) in the experimental groups using a quartz–tungsten–halogen (QTH) light or light-emitting diode (LED) with different exposure times.

Groups	*n*	Mean (%)	Standard deviation
QTH			
10 s	5	43.42^{AB}	2.84
20 s	5	46.12^{A}	3.72
30 s	5	45.30^{A}	4.41
LED			
5 s	5	38.97^{B}	2.08
10 s	5	47.02^{A}	1.84
15 s	5	47.24^{A}	2.44

Different letters indicate statistically different mean values ($P < 0.05$).

Discussion

The composite resin used in this study was Transbond XT, which is a light-cured material specifically for bonding in orthodontics and widely used in debonding strength studies; however, the literature has little information about its cure efficiency (Eliades *et al.*, 1995; Dunn and Taloumis, 2002; Cacciafesta *et al.*, 2005).

In the present study, a LED was compared with a QTH light. The latter is the most widely disseminated and has disadvantages such as heat generation, low useful life of the lamp, and degradation of the filters. However, they are accessible appliances and easy to maintain, in addition to being efficient for curing composite resins (Miyazaki *et al.*, 1998; St Georges and Miguez, 2001; Hammesfahr *et al.*, 2002; Pereira *et al.*, 2003).

The Knoop hardness test demonstrated that the LED can attain hardness similar to that of the QTH light, as the LED 15 second group did not differ statistically from the QTH groups. The results of the present study are contrary to the findings of Kurachi *et al.* (2001), Leonard *et al.* (2002), and Rahiotis *et al.* (2004), who reported that the QTH light presented higher hardness compared with the LED. The LED units used in those studies emitted low intensity (the highest being 280 mW/cm^2), which could explain this difference. Furthermore, there was a waiting time of 24 hours between light activation and hardness measurement in the studies of Leonard *et al.* (2002) and Rahiotis *et al.* (2004). This could influence the results since, with the passage of time, hardness significantly increases (Dannheimer *et al.*, 1996).

However, there is agreement when the results of research conducted with similar equipment are compared. Uhl *et al.* (2004) used the LED prototype with an intensity of 901 mW/cm^2 and found that the LED provided greater composite resin hardness 24 hours after light curing.

The present study used FTIR to verify the degree of conversion of monomer into polymer, being a method of surface analysis (Gioka *et al.*, 2005). The measurements were made before and immediately after light curing, in addition to using the double carbon aromatic bonds as the internal parameter. The reason for using this method was to make the results more accurate since the same resin mass was used as the parameter, before and after light curing.

The degree of conversion was similar for the QTH and LED lights. This finding corroborates the study of Wiggins *et al.* (2004), who also used second generation LED and QTH lights. However, Knezevic *et al.* (2001) and Bala *et al.* (2005) found higher percentages of conversion using transmittance with potassium bromide pellets. This FTIR technique allows the recording of a larger area of the cured resin since the resin is ground and the reading beam penetrates the specimen. Furthermore, in the study of Knezevic *et al.* (2001), the specimens were stored for 24 hours.

Rahiotis *et al.* (2004) used the same spectrophotometry method as in the present study and reported conversion of 55 per cent for the QTH light and 43 per cent for the LED after storage for 24 hours. The higher conversion rate of QTH light in that study in relation to the present findings can be explained by the higher power of the source used (840 against 638 mW/cm^2) and by the storage time. When comparing the performance in relation to the LED, similarity is found, in spite of the specimens having been stored for 24 hours, which would be expected to result in a higher conversion rate. This similarity is possibly explained by the low power of the appliance used in that study and the higher power of the appliance used in the present research.

In vitro investigations do not reproduce the clinical situation. The thickness of the specimens (1.5 mm) is more than the average thickness used when bonding teeth. In addition, brackets bonded to the teeth can interfere with polymerization of the composite resin. It would therefore be interesting to compare, *in vitro*, the bond strength of brackets to enamel using QTH and LED lights with different curing times to verify if the polymerization obtained is sufficient to bond brackets to enamel and withstand the applied forces. However, analysing the results obtained, it is feasible to reduce the exposure time of orthodontic resin Transbond XT with a LED by 50 per cent, compared with a QTH light.

Conclusions

1. The Knoop hardness of Transbond XT light cured with a LED for 15 seconds was similar to light curing with a QTH for 10, 20, or 30 seconds.
2. The degree of conversion of Transbond XT was similar when light cured with LED or QTH lights.
3. Light curing with a LED allowed a reduction of 50 per cent in the time recommended for the use of a QTH light with Transbond XT.

Address for correspondence

Ana Maria Spohr
Laboratory of Dental Materials, School of Dentistry (Block 6)
Pontifical Catholic University of Rio Grande do Sul (PUCRS)
Avenue Ipiranga 6681, CEP: 90616-900 Porto Alegre—RS
Brazil
E-mail: anaspohr@terra.com.br

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Shear bond strength of ceramic brackets with various base designs bonded to aluminous and fluorapatite ceramics

Boonlert Kukiattrakoon* and Buncha Samruajbenjakul**
Departments of *Conservative Dentistry, and **Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand

SUMMARY This study was conducted to evaluate the shear bond strength (SBS) of various ceramic bracket base designs bonded to glazed aluminous (Vitadur Alpha) and fluorapatite (IPS e.max Ceram) ceramics, to examine the mode of failure, and to determine the debonding characteristics of the brackets and the ceramic surfaces after bond failure.

Forty ceramic discs (15 mm in diameter and 1.5 mm thick) of each ceramic were prepared and divided into four equal groups. Ten pieces of each group of different bracket bases (beads, Inspire Ice; large round pits, Crystalline IV; and irregular base, Clarity) and one group of stainless steel brackets (Optimesh XRT, control) were bonded to glazed ceramics under a 200 g load. All specimens were then subjected to SBS evaluation using a universal testing machine at a crosshead speed of 0.2 mm per minute. The data were analysed using analysis of variance and Tukey's test at a significance level of 0.05. The mode of failure was examined under a stereomicroscope.

The results demonstrated that for Vitadur Alpha and IPS e.max Ceram, the highest SBS were found with Inspire Ice (25.1 ± 2.6 and 24.9 ± 2.1 MPa) and were significantly different than Crystalline IV (21.6 ± 1.1 and 20.9 ± 1.5 MPa), Clarity (19.6 ± 1.5 and 19.3 ± 2.3 MPa), and Optimesh XRT (14.9 ± 1.3 and 15.3 ± 2.2 MPa; $P < 0.05$). Inspire Ice and Crystalline IV had 100 per cent adhesive failure while Clarity and Optimesh XRT had combination failure. The various base designs gave different SBS, but the SBS of all base designs could withstand normal orthodontic force.

Introduction

Ceramic orthodontic brackets have been available for clinical use since 1987. They were designed to combine aesthetics with the reliability of stainless steel brackets (Birnie, 1990). All currently available ceramic orthodontic brackets are composed of aluminium oxides (Harris *et al.*, 1992; Karamouzos *et al.*, 1997) which have many advantages such as biocompatibility, good aesthetics, resistance to temperature and chemical changes, and good bond strength that is higher or equal to that of stainless steel brackets (Odegaard and Segner, 1988; Swartz, 1988; Flores *et al.*, 1990; Viazis *et al.*, 1990). There are two types of ceramic brackets which are classified according to their distinct differences during fabrication, namely, polycrystalline and monocrystalline (single crystal) aluminas (Bordeaux *et al.*, 1994; Bishara and Fehr, 1997; Gautam and Valiathan, 2007).

Polycrystalline aluminas are made of sintered or fused aluminium oxide particles. The aluminium oxide particles are blended with a binder and the mixture is formed into a shape from which a bracket can be machined. Temperatures above 1800°C are used to 'burn out' the binder and fuse the particles of the moulded mixture together. This firing process is called 'sintering'. They are then heat treated to remove surface imperfections and stresses created by the curing process. These slight imperfections and impurities can serve as foci for crack propagation under stress and compromise a bracket during clinical use (Swartz, 1988).

Monocrystalline aluminas are also manufactured from aluminium oxides. Aluminium oxides are heat treated to temperatures in excess of 2100°C and then cooled slowly to permit complete crystallization. This process minimizes the stress-inducing impurities and imperfections found in polycrystalline aluminas (Swartz, 1988).

Both poly- and monocrystalline ceramic brackets come with various base designs such as beads, grooves, or round pits for the purpose of mechanical interlocking between the brackets and the teeth. In addition, they provide chemical bonding with silanes. Silanes (gamma-methacryloxyprophyl-trimethoxysilane) are coupling agents developed for bonding glass fillers into polymers, which increase the wettability of the ceramic surface (Bowen and Rodriguez, 1962). In most studies, silanes have been found to successfully increase the adhesion of the resin composite to the ceramic surface (Newman *et al.*, 1984; Kao *et al.*, 1988; Lu *et al.*, 1992; Whitlock *et al.*, 1994; Major *et al.*, 1995; Kocadereli *et al.*, 2001; Harari *et al.*, 2003; Türkkahraman and Küçükeşümen, 2006). However, there are contradictory reports regarding the efficacy of silane-coupling treatment in the long-term adhesion between resin composite and ceramic (Bailey, 1989; Diaz-Arnold and Aquilino, 1989; Wolf *et al.*, 1992;

Ozcan *et al.*, 2008). The efficiency of silane-coupling agents can be influenced by several factors. Single-bottle products have a limited shelf life because of rapid solvent evaporation and hydrolyzation. Silanes might have different chemical structures; this makes it important to use one bonding system and not interchange components that might not be compatible (Blatz *et al.*, 2003). Another factor of concern is that all silanes are sensitive to humidity. In humid conditions, silanized interfaces seem to be unstable; the silane bond was found to deteriorate under atmospheric moisture (Nergiz *et al.*, 2000). Additionally, it is recommended that only fresh silanes are used since aged silanes can compromise bond strength (Robbins, 1998).

Etching with hydrofluoric acid is widely recommended and used for ceramic surface modification which shows strong bond strengths (Zachrisson and Buyukyilmaz, 1993; Barbosa *et al.*, 1995). However, it is considered a hazardous agent which can produce a tissue rash, burns, and deep tissue necrosis (Moore and Manor, 1982). During intraoral use of hydrofluoric acid, special precautions should be used. Unlike phosphoric acid, at 37 per cent concentration, it is not toxic or corrosive and results in satisfactory bond strength (Bourke and Rock, 1999).

A more demanding sense of aesthetics has led to an increase in adults requesting orthodontic treatment. Thus, the orthodontist frequently encounters all-ceramic restorations, which are gaining popularity because of their superior biocompatibility and aesthetic appeal (Albakry *et al.*, 2004). These ceramics may be aluminous or fluorapatite. The aluminous ceramic (Vitadur Alpha, Vita Zahnfabrik, Bad Sackingen, Germany) is composed of glass powder and fused alumina crystals, which constitute up to 50 per cent by weight (McLean and Hughes, 1965). The fluorapatite ceramic (IPS e.max Ceram, Ivoclar Vivadent AG, Schaan, Liechtenstein) is used as the veneering ceramic of this system. This is a feldspathic-based ceramic with a microstructure dissimilar to IPS d.SIGN. This glass-ceramic consists of dispersed fluorapatite crystals in a feldspathic glassy matrix. Fluorapatite crystals, 2–5 μm in length and 300 nm in diameter of needle-like morphology, are known to be contained in natural bone and teeth. The very small crystals in dental microstructures result in optical properties such as translucence and opalescence, which is also seen in dental restorations (Holand *et al.*, 2003).

Orthodontic brackets may be bonded to ceramic restorations. Optimal bracket adhesion to a ceramic surface requires that the orthodontic forces be applied without bond failure during treatment and that the ceramic integrity is not jeopardized during debonding. Bond strengths between 6 and 8 MPa are clinically sufficient for successful bonding of brackets to enamel (Reynolds, 1975; Whitlock *et al.*, 1994). Unfortunately, little is known about the bond strength of various ceramic brackets base designs bonded to all-ceramic restorations. Therefore, the objectives of this study were (1) to evaluate the shear bond strength (SBS) of various ceramic brackets base designs bonded to glazed aluminous and fluorapatite ceramics, (2) to examine the mode of failure of the various bracket base designs and of both ceramics, and (3) to determine the debonding characteristics of the brackets and the ceramic surfaces after bond failure.

Materials and methods

Forty samples of glazed aluminous and fluorapatite ceramic discs were produced according to the manufacturers' instructions. Aluminous (Vitadur Alpha, Vita Zahnfabrik) and fluorapatite (IPS e.max Ceram, Ivoclar Vivadent AG) ceramics are used as veneering ceramics for Vita In-Ceram and the IPS e.max System, respectively. Ceramic powders were mixed with deionized water and condensed into a round shape silicone mould (Provil, Haraeus Kulzer, Wehrheim, Germany), 15 mm in diameter and 1.5 mm thick. The specimens were then fired according to the manufacturers' instructions (Table 1). After firing, sintered ceramic discs with a final diameter of 13.45–14.12 mm (5.87–10.33 per cent shrinkage) were polished (Phoenix 4000, Buehler GmbH, Düsseldorf, Germany) under running water using 600 and 1200 grit silicon carbide paper (3M Espe, St Paul, Minnesota, USA). The specimens were then cleaned in an ultrasonic cleanser for 10 minutes. Finally, the specimens were submitted to self-glazing according to the manufacturers' instructions (Table 1).

Subsequently, the discs were embedded in autopolymerizing clear acrylic resin (Takilon, Rodont srl, Milan, Italy), 20 mm in height and 30 mm in diameter. The specimens for each ceramic were randomly divided into four groups of 10 for bonding with three groups of ceramic brackets which had various base designs (beads, Inspire Ice; large round pits, Crystalline IV; and irregular, Clarity). Stainless steel brackets (Optimesh XRT) served as the control (Figure 1 and Table 2).

The ceramic surfaces were etched with 37 per cent phosphoric acid, (Ormco/Sybron Dental Specialties, Glendora, California, USA) for 60 seconds, and a thin coat of porcelain primer, (Ormco/Sybron) was applied twice with a microbrush for 10 and 60 seconds, respectively. The discs were then rinsed with a water spray for 15 seconds and

Table 1 Firing schedules for the ceramics used in the present study.

Ceramic	Type of firing	Starting temperature (°C)	Heating rate (°C/min)	Firing temperature (°C)	Holding time (min)
Vitadur Alpha	Dentine	600	60	960	1
	Glaze	600	85	940	1
IPS e.max	Dentine	403	50	850	0
Ceram	Glaze	403	50	800	0

thoroughly air-dried. System 1+ liquid activator (Ormco/Sybron) was then applied to both the ceramic surfaces and the bracket bases, and System 1+ paste (Ormco/Sybron) was applied to the activated bracket bases. The brackets were then positioned on the ceramic discs and 200 g of pressure was applied to the brackets. Excess adhesive was carefully removed from the bracket base with a sharp scaler and allowed to completely polymerize for 10 minutes. Finally, all specimens were stored in an incubator (Memmert, model BE500, Memmert GmbH, Schwabach, Germany) at 37°C and 100 per cent humidity for 24 hours before testing.

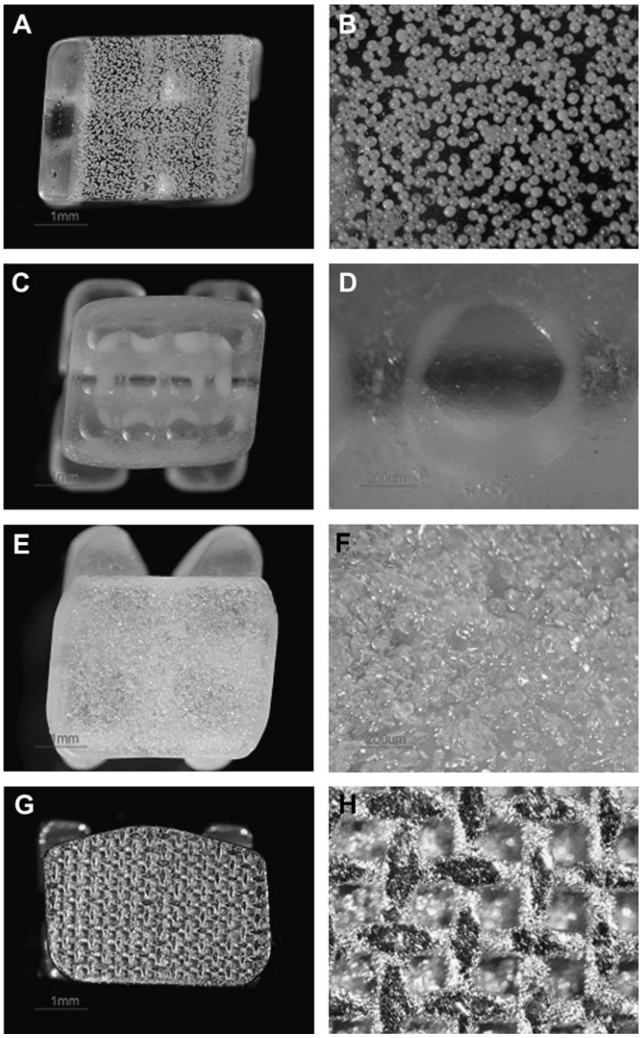

Figure 1 Stereophotomicrographs of base designs of ceramic bracket (×20 magnification, bar = 1 mm and ×100 magnification, bar = 200 µm, respectively). (A) and (B), beads base (Inspire Ice); (C) and (D), large round pits base (Crystalline IV); (E) and (F), irregular base (Clarity); (G) and (H), mesh base (Optimesh XRT).

SBS testing of the ceramic brackets on the ceramic specimens was performed using a single-bladed Instron machine (model 5583, Instron, Norwood, Massachusetts, USA) at a crosshead speed of 0.2 mm/minute. The load at failure was recorded in newtons and converted to megapascals to determine SBS (force per surface area of the bracket base). Bracket bond area was determined by measuring the width and length of the bracket base with a digital calliper (Mitutoyo, Tokyo, Japan) and the area calculated (Table 2). After debonding, the surfaces of the specimens were examined by one observer (BK) under a stereomicroscope (SMZ 1500m, Nikon Instech, Kanagawa, Japan) to determine the mode of failure. For determination of the mode of failure, each sample was recorded according to a modification of the method of Bordeaux *et al.* (1994; Table 3).

Statistical analysis

The data were statistically analysed using the Statistical Package for Social Sciences version 16.0 (SPSS Inc., Chicago, Illinois, USA). A two-way analysis of variance (ANOVA) was performed to assess the influence of the different ceramic brackets and the ceramics on SBS. A one-way ANOVA was used to determine differences between the groups. Tukey's Honestly Significant Differences (HSD) tests were used for *post hoc* comparisons ($\alpha = 0.05$).

Results

Table 4 presents the results of the two-way ANOVA, which revealed statistical differences among the different types of ceramic brackets ($P = 0.01$). However, there were no statistical differences between the different types of ceramics and the interaction between the type of ceramic brackets and the ceramics ($P = 0.57$ and $P = 0.83$, respectively). Therefore, the different types of ceramics did not affect the SBS values.

Table 2 Identification of ceramic brackets used in the present study.

Name of ceramic bracket	Manufacturer	Type	Base design	Area of surface (mm^2)
Inspire Ice	Ormco/Sybron Dental Specialties	Monocrystalline alumina	Bead	11.50
Crystalline IV	Tomy, Tokyo, Japan	Polycrystalline alumina	Large round pit	10.05
Clarity	3M Unitek, Monrovia, California, USA	Polycrystalline alumina	Irregular	10.55
Optimesh XRT	Ormco/Sybron Dental Specialties	Stainless steel	Mesh	11.71

The mean SBS values of the ceramic brackets to Vitadur Alpha and IPS e.max Ceram at fracture are presented in Figure 2. For Vitadur Alpha, one-way ANOVA and Tukey's HSD showed a significant difference among the groups (P = 0.01). The control group (Optimesh XRT) yielded the lowest mean SBS and standard deviation (SD) values (14.9 ± 1.3 MPa; P = 0.01). Inspire Ice produced the highest mean SBS values (25.1 ± 2.6 MPa; P = 0.01). There was no significant difference between Crystalline IV (21.6 ± 1.1 MPa) and Clarity (19.6 ± 1.5 MPa; P = 0.13). Similar to IPS e.max Ceram, ANOVA and Tukey's HSD showed a significant difference among the groups (P = 0.01). Inspire Ice produced the highest mean SBS values (24.9 ± 2.1 MPa; P = 0.01) while Optimesh XRT yielded the lowest mean SBS and SD values (15.3 ± 2.2 MPa; P = 0.01). The SBS values between Crystalline IV (20.9 ± 1.5 MPa) and Clarity (19.3 ± 2.3 MPa) were not significantly different (P = 0.14).

Table 5 and Figure 3 show the predominant site of bond failure after examination of the debonded surface using a stereomicroscope. None of the specimens evaluated in this study was found to display any cracks or fractures of the brackets or ceramic surfaces (type 4 and 5).

Table 3 Type of mode of failure and characteristics [after Bordeaux *et al.* (1994)].

Type	Characteristics
1	Failure at the adhesive–bracket base interface. Ninety per cent or greater of the bracket pad exposed and 10 per cent or less of the bonded ceramic free of adhesive.
2	Combination failure at the adhesive–bracket base interface and the ceramic–adhesive interface. Less than 90 per cent but more than 10 per cent of the bracket pad exposed or more than 10 per cent but less than 90 per cent of the bonded ceramic surface free of adhesive.
3	Failure at the ceramic–adhesive interface. Ten per cent or less of the bracket pad exposed and 90 per cent or more of the bonded ceramic free of adhesive.
4	Failure of the bracket itself. Fracture of the bracket during removal with a portion of the bracket still bonded to the ceramic
5	Failure of the ceramic itself. A portion of the ceramic removed with the bracket base without loss of more than 10 per cent of the adhesive from the bracket pad.

Discussion

The present study showed that the SBS of ceramic brackets bonded to either aluminous (Vitadur Alpha) or fluorapatite (IPS e.max Ceram) ceramic was greatly affected by base design but not by the type of ceramic. For Vitadur Alpha and IPS e.max Ceram, Inspire Ice resulted in the highest SBS, followed by Crystalline IV and Clarity. Optimesh XRT showed the lowest SBS in agreement with previous findings (Odegaard and Segner, 1988; Swartz, 1988; Flores *et al.*, 1990; Viazis *et al.*, 1990).

The characteristics of various base designs were the reason for the results for both ceramics. Base design with irregular shapes incorporate small glass particles fused to the polycrystalline alumina to increase the surface area for adequate bonding. However, these glass particles might not have adequately adhered to the alumina base or there might be inadequate mechanical retention of the adhesive resin to penetrate to the rough base surface (Solderquist *et al.*, 2006). Similarly, large round pit base designs, having about 12 pits of 1 mm diameter in one bracket surrounded by a flat surface (Figure 1C,D), did not have any undercut for mechanical interlocking of adhesive resin. These results were confirmed by the type 1 bond failure (adhesive–bracket failure). Thus, the SBS of irregular and large round pit base designs showed no significant difference. Conversely, the bead base surface had as many as 50 μm round monocrystalline beads completely distributed on the base surface (Figure 1A,B). These beads have undercuts for mechanical interlocking of adhesive resin resulting in the statistically highest SBS among all groups of both ceramics.

However, resin thickness and inherent flaws or defects in brackets or ceramics would influence bond strength. In this study, an attempt was made to control these factors. The ceramic brackets were bonded under pressure for the best fit on the ceramic surfaces and to minimize the thickness of the adhesive layers which may result in more imperfections, greater variability in the amount of polymerization obtained, and fracture (Whitlock *et al.*, 1994). No bracket or ceramic fractures were found in the present study; therefore, the inherent flaws did not affect SBS.

Table 4 Results of two-way analysis of variance.

Source	Type III sum of squares	df	Mean square	F	P value
Corrected model	1020.17	7	145.74	40.44	0.01
Intercept	32689.56	1	32689.56	9071.01	0.01
Type of ceramic	1.18	1	1.18	0.33	0.57
Type of bracket	1015.85	3	338.62	93.96	0.01
Interaction between type of ceramic and type of bracket	3.14	3	1.05	0.29	0.83
Error	259.48	72	3.61		
Total	33969.21	80			
Corrected total	1279.66	79			

The maximum bond strength of ceramic brackets bonded to ceramics which may be achieved is usually not required for orthodontic purposes. The ideal bond strength should be sufficiently strong to endure a course of orthodontic treatment, yet sufficiently weak to permit adhesive removal from the ceramic surface following bracket removal. Reynolds (1975) recommended a tensile force of 60–80 kg/cm^2 and Whitlock *et al.* (1994), based on the work of Reynolds (1975), also suggested that 6–8 MPa was adequate for orthodontic attachments. In the present study, the SBS of all groups of both ceramics exhibited higher values than the minimum orthodontic bracket bond strength and therefore could be considered sufficient for clinical application.

Glazed ceramic surfaces are not amenable to resin penetration for orthodontic bonding (Lu *et al.*, 1992). Glazed surface removal has been advocated to create mechanical retention for adhesive resin by surface roughening (Hulterström and Bergman, 1993). However, the aesthetic and structural qualities of the ceramic may be irretrievably lost with surface roughening. The glaze is effective in strengthening the ceramic and reducing crack propagation. When the ceramic restoration is heated, the self-glaze layer fills in surface flaws, reducing their depth and blunting the flaw tips. This should increase their strength because, for given ceramics, strength increases with decreasing sharpness and flaw depth (Griggs *et al.*, 1996). If the glaze is removed by grinding, the flexural strength of the ceramic unit may be reduced. For safety reasons several studies have recommended not removing the glaze by grinding (Kao *et al.*, 1988; Lu *et al.*, 1992; Zelos *et al.*, 1994). That recommendation is confirmed by the results of the present investigation. Even though this study used ceramic brackets bonded with the glazed ceramic surfaces, high SBSs occurred.

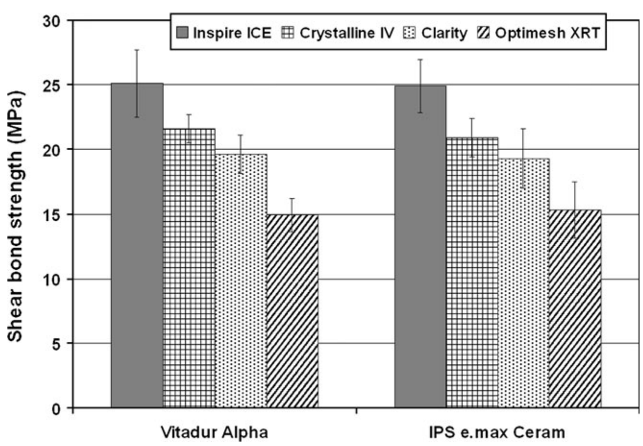

Figure 2 Mean shear bond strength (MPa) and standard deviation among various base designs of ceramic brackets.

The high SBS of ceramic orthodontic brackets bonded to glazed ceramic in this research may also be a result of phosphoric acids and silanes. Phosphoric acid, at 37 per cent concentration, does not etch ceramic and does not produce physical or topographical changes in the ceramic surface. Instead, the effect of phosphoric acid is to neutralize the alkalinity of the adsorbed water layer, which is present on all-ceramic restorations in the oral cavity and thereby enhance the chemical activity of subsequently applied silanes (Wolf *et al.*, 1993). Silane-coupling agents act as a chemical link between the inorganic ceramic surface and the organic resin adhesive agent (Lu *et al.*, 1992; Major *et al.*, 1995). The findings of the present research confirm the necessity of using silanes, which correspond with the results of other studies (Newman *et al.*, 1984; Kao *et al.*, 1988; Lu *et al.*, 1992; Whitlock *et al.*, 1994; Major *et al.*, 1995; Kocadereli *et al.*, 2001; Harari *et al.*, 2003; Türkkahraman and Küçükeşümen, 2006). Clinically, for bonding ceramic brackets to aluminous and fluorapatite ceramics, data from the present study indicate preserving the glaze, treating the porcelain with 37 per cent phosphoric acid, applying a porcelain primer, and using either type of ceramic bracket with adhesive resin.

The results of the stereomicroscope examination showed no damage to the ceramic surfaces in any group. It has been reported that if the bond between ceramic and adhesive resin is higher than 13 MPa, the ceramic will fracture

Table 5 Mode of failure of both ceramics after shear bond strength testing.

Ceramic	Ceramic bracket (manufacturer)	Type of failure					Total
		1	2	3	4	5	
Vitadur Alpha	Inspire Ice (Ormco/Sybron)	0	0	10	0	0	10
	Crystalline IV (Tomy)	10	0	0	0	0	10
	Clarity (3M Unitek)	0	6	4	0	0	10
	Optimesh XRT (Ormco/Sybron)	0	10	0	0	0	10
IPS e.max Ceram	Inspire Ice (Ormco/Sybron)	0	0	10	0	0	10
	Crystalline IV (Tomy)	10	0	0	0	0	10
	Clarity (3M Unitek)	0	5	5	0	0	10
	Optimesh XRT (Ormco/Sybron)	0	10	0	0	0	10

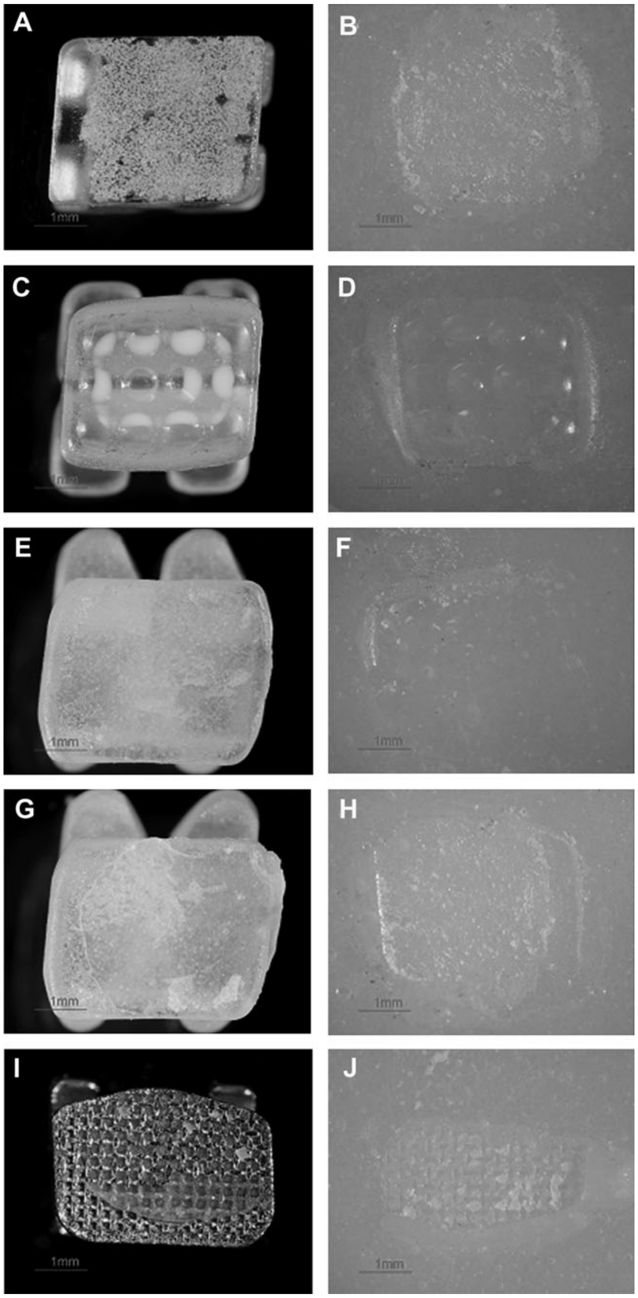

Figure 3 Stereophotomicrographs of failure characteristics (at the ceramic bracket base and ceramic, respectively). (A) and (B), type 3 failure of bead base; (C) and (D), type 1 failure of large round pit base; (E) and (F), type 3 failure of irregular base; (G) and (H), type 2 failure of irregular base; (I) and (J), type 2 failure of mesh base (×20 magnification, bar = 1 mm).

(Thurmond *et al.*, 1994). In this study, all groups of both ceramics achieved values higher than 13 MPa, which resulted in adhesive failures (type 1–3). No ceramic fractures were observed. This observation is important because bonding and debonding should not cause damage to the ceramic surfaces, which will affect the aesthetics and strength of the restoration.

The most significant finding in this study was that bonding of various ceramic bracket base designs to aluminous and fluorapatite ceramics resulted in high SBS in all groups. However, an *in vitro* study cannot replicate the same environment as the oral cavity. The presence of water, proteins, minerals, differences in pH levels, and temperature changes can affect the bond strength of ceramic brackets to ceramics. In addition, the present study demonstrated the results on a variety of ceramics and one type of adhesive bonding (Vitadur Alpha, IPS e.max Ceram, and System 1+). Therefore, it should not be presumed that other types of ceramic or adhesive will demonstrate the same pattern of bond strength. Further studies are required.

Conclusions

Within the limitations of this *in vitro* study, the following conclusions were drawn.

1. Bead base ceramic brackets and the glazed aluminous and fluorapatite ceramics yielded the statistically highest SBS among all groups.
2. The SBS of all groups exhibited higher values than the minimum orthodontic bracket bond strength range of 6–8 MPa.
3. Debonding characteristics showed no damage to either ceramic surface.

Address for correspondence

Boonlert Kukiattrakoon
Department of Conservative Dentistry
Faculty of Dentistry
Prince of Songkla University
15 Kanchanavanich Road
Hat Yai
Songkhla
Thailand
E-mail: boonlert.k@psu.ac.th

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Prince of Songkla University.

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Salivary *Streptococcus mutans* levels in patients with conventional and self-ligating brackets

Nikolaos Pandis*, William Papaioannou**, Efterpi Kontou***, Melachrini Nakou***, Margarita Makou**** and Theodore Eliades*****

*Private Practice, Corfu, Departments of **Preventive and Community Dentistry, ***Periodontology, and ****Orthodontics, School of Dentistry, University of Athens and *****Department of Orthodontics, Aristotle University of Thessaloniki, Greece

SUMMARY The objective of this study was to investigate the effect of bracket type (conventional and self-ligating) on the levels of *Streptococcus mutans* and total bacterial counts in whole saliva of orthodontic patients. Thirty-two male and female patients were selected using the following inclusion criteria: adolescents (mean age 13.6 years, range 11–17 years), fixed appliances in both arches, non-smoker, and no reported oral habits. Demographic and oral hygiene characteristics were determined for each subject. The patients were subdivided into two groups with random allocation of bracket type (conventional or self-ligating). An initial saliva sample was obtained before the initiation of treatment (T1) and a second sample 2–3 months following appliance bonding (T2). Salivary *S. mutans* and total bacteria were enumerated and analysed after growth in culture. The demographic and clinical characteristics of the samples were analysed with a *t*- or chi-square test, where applicable, to assess the random allocation of bracket group to participants. The results of *S. mutans* and total facultative bacterial counts were log transformed and statistically analysed with analysis of covariance with bracket (conventional versus self-ligating) as the categorical variable and initial total bacterial counts or initial *S. mutans* levels serving as the covariate.

No difference was found in the demographics and oral hygiene indices between the two groups, verifying the random assignment of brackets to the population sample. The levels of *S. mutans* in whole saliva of orthodontically treated patients do not seem to be significantly different between conventional and self-ligating brackets. The pre-treatment levels of *S. mutans* are significant predictors of the levels of *S. mutans* after placement of orthodontic appliances, while this was not the case for total bacterial counts.

Introduction

Although self-ligation in orthodontics was described several decades ago, the first commercially viable system, the Speed bracket, was not introduced until the early 1980s. The late 1990s marked a significant increase in the popularity of self-ligation with almost all major orthodontic companies listing them among their products (Harradine, 2003).

One of the proposed favourable aspects of self-ligating brackets is the elimination of elastomeric or stainless steel ligatures. It has been proposed that this feature brings two basic advantages: the eradication of cross-contamination, which may accidentally be involved in the process of ligature change, and the claimed improvement in the oral hygiene of patients. The latter has been attributed to the fact that the patient is given the opportunity to clean surfaces of reduced complexity and with less retentive sites for microbial colonization (Øgaard *et al.*, 1988).

The oral cavity is a rich ecosystem with a plethora of microorganisms. While both periodontal disease and caries are considered multifactorial diseases, plaque bacteria are the major factor in their onset and progression. However, there are situations which comprise what has been termed 'ecological stress', referring to the shift of the microbiological balance, creating conditions conducive to the growth, and appearance of cariogenic and/or periodontopathic bacteria (Marsh, 2003).

The different components of the fixed orthodontic system may contribute to a shift in the balance of the oral ecology. A large amount of research has dealt with the intimate contact of orthodontic materials with the tooth and periodontal tissue. The presence of brackets and ligatures has been shown to be related to an increase in gingival inflammation and increased risk of decalcification. This demineralization of the tooth surfaces results in the appearance of white spots or even carious lesions (Gorelick *et al.*, 1982; Øgaard *et al.*, 1988; Fournier *et al.*, 1998; Naranjo *et al.*, 2006).

Oral microbiota attachment in orthodontic patients has been mainly associated with increased risk of *Streptococcus mutans* and lactobacilli colonization, among other species, thus initiating a series of events, which may lead to the development of pathology of the hard tissues such as decalcification and, in specific cases, caries development (Gorelick *et al.*, 1982; Øgaard *et al.*, 1988; Fournier *et al.*, 1998). Moreover, the accumulation of plaque and the resultant alteration of the local microbial milieu may expose the tissues to the risk of developing periodontal inflammation, with notable changes in the biota (Naranjo *et al.*, 2006).

Even though the aforementioned effects have been studied extensively, there is a lack of substantiation of the hypothesis of decreased plaque retention related to the use of self-ligating brackets. The hypothesis investigated in the present research was that bracket ligation mode has an effect on the microbiological profile of the patients' oral environment. Therefore, the objectives of this study were to investigate the effect of bracket type (conventional or self-ligating) on salivary *S. mutans* counts and total bacterial count levels in patients undergoing treatment with conventional and self-ligating appliances.

Subjects and methods

The individuals participating in the study group were selected from a larger pool of patients from the practice of one author (NP), using the following inclusion criteria: adolescents treated with fixed appliances, no reported oral habits detrimental to health, including smoking, absence of restorations, and/or missing teeth due to dental caries. The patients who fulfilled these criteria were randomly assigned to one of the treatment groups. The orthodontist did not know the bracket group assignment at the time of the first saliva collection. Consent for saliva collection was obtained from all patients.

The 32 male and female patients were divided into two equal groups based on bracket type used, i.e. conventional (Microarch, GAC International, Central Islip, New York, USA), ligated with conventional (no fluoride-releasing) elastomeric modules, or self-ligating (In-Ovation-R, GAC International). From previous studies (Forsberg *et al.*, 1991; Attin *et al.*, 2005), it is inferred that a mean colony-forming unit (CFU) difference of approximately one log [standard deviation (SD) = approximately 1] will result in a clinically significant increase in *S. mutans* counts. Therefore, the sample size of 16 patients per group, at $\alpha = 0.05$, yields a statistical power very close to 0.80 for this study.

Whole stimulated saliva was collected from each patient at two time points before bonding and initiation of orthodontic therapy (baseline at T1) and after at a period of 2–3 months (T2) after full bonding had taken place. At both time points, each subject was asked to collect saliva in the mouth and to expectorate into a chilled empty Petri dish approximately 3 ml of saliva. The subjects had refrained from eating or drinking beverages for at least 1 hour before saliva collection. Collection of saliva samples was performed before any oral examination or manipulation so as not to disrupt the oral microbiota.

Standard oral hygiene instructions were provided at the beginning of treatment using a model, with specific attention to the orthodontic appliances. Prior to all examinations, no brushing or other hygiene measures were carried out. For each participant, the following clinical variables were assessed: the simplified plaque index (S-PlI), where the percentage of surfaces with plaque is recorded (taking into consideration all surfaces per tooth for all erupted teeth), and the decayed, missing, and filled teeth (DMFT) index for the prevalence of caries. Both indices were recorded after each saliva sample collection at each visit without the use of a plaque disclosing agent.

Serial 10-fold dilutions of the saliva samples were inoculated on a non-selective medium and on a selective growth medium for *S. mutans*. Aliquots of 0.1 ml of the dilutions were inoculated onto non-selective blood agar plates supplemented with 7 per cent sterile blood for the evaluation of the composition of the predominant cultivatable microbiota of the saliva. The blood agar plates were incubated at 37°C for 3 days in a CO_2 atmosphere, following which the total number of CFU was counted.

The selective medium used was Mitis Salivarius agar supplemented with sucrose (20 per cent w/v), bacitracin, and tellurite solution. The plates were incubated for up to 7 days in a CO_2 atmosphere at 37°C. The above process was repeated 2–3 months after the orthodontic appliances were bonded. The presumptive characterization and identification of *S. mutans* was based upon colony morphology, Gram stain, and catalase activity. From these, representative colonies were subcultured and biochemical tests performed for definitive species identification. All laboratory procedures were carried out without the personnel knowing the allocation of saliva samples to bracket groups. Additionally, in an effort to minimize variation, the *S. mutans* counts were also recorded as a proportion of total bacterial counts (*S. mutans* counts/total bacterial counts) at T1 and T2.

Demographic and clinical characteristics of the sample were investigated with conventional descriptive statistics. Differences of means (gender, age, S-PlI, DMFT, and days between T1 and T2 sample) were determined with a *t*-test, whereas differences in proportion (males–females proportion between the two groups) were studied with the chi-square test.

Comparisons of the total cultivatable counts (total number of CFU) and total CFU of *S. mutans* per millilitre of saliva between the two bracket groups were performed independently; they were log transformed and statistically analysed with analysis of covariance (ANCOVA) with bracket (conventional versus self-ligating) as the categorical variable and initial total bacterial counts or initial *S. mutans* levels serving as the continuous covariate. Data were further analysed with simple linear regression analysis to evaluate the initial levels of facultative total bacteria counts and *S. mutans* as predictors of the levels of these at the second time interval. Data analysis was conducted with the statistical package, Minitab 14.20 (State College, Pennsylvania, USA), at the 0.05 level of significance.

Results

Table 1 shows the distribution of demographic, oral hygiene variables, and the average number of days between the T1 and T2 saliva samples for the two groups. The distribution of gender, age, and treatment duration prior to the T2 saliva sample did not show any difference between the two bracket groups verifying the random selection of these variables across the two populations. Additionally, the oral hygiene status as determined by the S-PlI and DMFT indices for the prevalence of caries are shown.

The mean logs and SDs for total bacterial and *S. mutans* counts at T1 and T2 sample collection for the two bracket groups are shown in Table 2. Statistical analysis showed no difference with respect to total bacterial and *S. mutans* counts between the two bracket groups at either T1 or T2.

ANCOVA results for total salivary microbial counts for the conventional and self-ligating bracket groups are shown in Table 3. No statistically significant difference was detected between the bracket groups. Additionally, total bacterial counts at T1 were not found to be significant predictors of the total bacterial counts at T2.

The corresponding ANCOVA for the *S. mutans* levels are illustrated in Table 4; again the variable 'bracket' had no effect as depicted in Table 3, where no difference between the bracket groups was identified. However, the T1 levels of *S. mutans* in saliva (the covariate) were shown to be significant predictors of the levels of *S. mutans* at T2. This was also confirmed by simple linear regression ($r=0.474$, $P=0.022$). The low values for the adjusted r^2 signify the low fit of the model with regard to the variables used, which means that the variable bracket type and initial *S. mutans* counts (T1) in combination are not good predictors of *S. mutans* counts at T2. However, initial *S. mutans* counts on their own are significant predictors ($P=0.033$) of the final *S. mutans* counts (Draper and Smith, 1988; Kim and Dailey, 2008). Some of the individuals had no detectable *S. mutans* counts and the zero values were not included in the model because they would have produced misleading results by lowering the means and thus the *S. mutans* counts would have been under-represented.

Table 5 shows the mean logs and SDs for the ratio of *S. mutans* counts to total bacterial counts. Again, statistical analysis showed no difference in total *S. mutans*/total bacterial count ratios between the two bracket groups at T1 and T2, confirming the results of the previous analyses.

Table 1 Demographic and clinical characteristics of the subjects included in the study.

Variable—bracket group	Mean	SD	*P* level
S-PlI—conventional (initial, %)	48.1	13.2	NS
S-PlI—self-ligating (initial, %)	47.3	9.8	
S-PlI—conventional (2–3 months)	46.1	8.4	NS
S-PlI—self-ligating (2–3 months)	46.5	6.6	
DMFT—conventional	1.4	0.4	NS
DMFT—self-ligating	1.8	0.4	
Gender ratio—conventional	0.5		NS
Gender ratio—self-ligating	0.5		
Age (years)—conventional	13.38	1.5	NS
Age (years)—self-ligating	13.81	1.5	
Days from first sample—conventional	84.5	5	NS
Days from first sample—self-ligating	89.9	5	

NS, non-significant; S-PlI, simplified plaque index for percentage of surfaces with plaque considering all surfaces per tooth; DMFT, decayed, missing, and filled teeth, total indicating the sum of DMF.

Table 2 Mean and standard deviation (SD) of log-total bacteria and *Streptococcus mutans* counts per millilitre saliva before the start of treatment (T1) and following appliance bonding (T2) for the bracket groups.

Variable	Bracket type	Mean	SD	*P* level
Log-total count T1	Conventional	6.78	1.79	NS
	Self-ligating	7.24	2.09	
Log-total count T2	Conventional	7.76	1.32	NS
	Self-ligating	7.24	2.09	
Log-*S. mutans* T1	Conventional	4.53	1.02	NS
	Self-ligating	3.98	0.87	
Log-*S. mutans* T2	Conventional	4.66	1.45	NS
	Self-ligating	4.48	0.83	

NS, non-significant.

Discussion

The initial affinity of bacteria to solid surfaces is mostly due to electrostatic and hydrophobic interactions, while surfaces with high surface-free energy more easily attract bacteria such as *S. mutans* (Van Dijk *et al.*, 1987). A recent *in vitro* study (Papaioannou *et al.*, 2007) assessed the adhesion of a clinical strain of *S. mutans* on brackets of different composition, with a saliva coating as well as uncoated. The effect of *Streptococcus sanguinis* was also examined by allowing these bacteria to adhere before the adhesion of *S. mutans*. It was clear from the results that there were no significant differences in the adherence of *S. mutans* to the three different types of brackets. For uncoated brackets, it is expected that only surface characteristics would determine adhesion of bacteria, suggesting that bacteria with high surface-free energy such as *S. mutans* (Weerkamp *et al.*, 1985) should prefer surfaces with high surface-free energy materials such as stainless steel brackets. However, this has not been confirmed (Fournier *et al.*, 1998; Ahn *et al.*, 2005; Papaioannou *et al.*, 2007), and therefore, variations in surface-free energy in conjunction with other surface properties of bracket raw materials (Eliades *et al.*, 1995) may not produce a measurable effect on adhesion.

Even though the attachment of plaque on bracket surfaces constitutes a direct assessment of the effect of bracket on microbial colonization, this approach presents major

Table 3 Analysis of covariance for the salivary total microbial counts per millilitre of saliva of the subjects included in the study.

Source	df	Sequential sum of squares	Adjusted sum of squares	Adjusted mean of squares	*F*	*P* level	
Log-total counts	1	0.63	0.73	0.734	0.56	0.458	NS*
Bracket	1	0.34	0.34	0.335	0.26	0.615	NS†
Error	29	37.67	37.67	1.299			
Total	31	38.63					
$S=1.13970$	$R^2=2.49\%$		R^2(adjusted)$=0.00\%$				

*NS, non-significant. The initial (T1) log-total bacterial counts are not a significant predictor of the log-total bacterial counts at T2 (after bonding).
†NS, non-significant difference on the log-total bacterial counts between the two bracket groups, adjusted for initial log-total bacterial counts.

Table 4 Analysis of covariance for the salivary *Streptococcus mutans* counts per millilitre saliva of the subjects included in the study.

Source	df	Seq SS	Adjusted sum of squares	Adjusted mean of squares	*F*	*P* level	
Log-*S. mutans*	1	6.09	5.47	5.47	5.25	0.033*	
Bracket	1	0.16	0.17	0.17	0.16	0.694	NS†
Error	20	20.85	20.84	1.04			
Total	22	27.10					
$S=1.02095$	$R^2=23.09\%$		R^2(adjusted)$=15.39\%$				

*Significant. The initial (T1) log-*S. mutans* counts is a significant predictor of the log-*S. mutans* counts at T2.
†NS, non-significant difference on the log-*S. mutans* counts between the two bracket groups, adjusted for initial log-*S. mutans* counts.

Table 5 Means and standard deviations (SDs) of the ratio of log-*Streptococcus mutans* to log of total bacterial counts (TC) per millilitre saliva at baseline (T1) and following bonding (T2) for the bracket groups.

Variable	Bracket type	Mean	SD	*P* level
Log-*S. mutans*/log-TC@T1	Conventional	0.65	0.18	NS
	Self-ligating	0.62	0.29	
Log-*S. mutans* T2/log@TC	Conventional	0.59	0.17	NS
	Self-ligating	0.61	0.11	

NS, non-significant.

technical and methodological difficulties. First, microbial accumulation may follow different rates at various intraoral sites as a result of the proximity of the bracket to the gingival sulcus, the surface area of the labial enamel surface relative to the bracket, and the position relative to the mandibular glands. At low flow rates or under static conditions, the grooves of rough surfaces may act as stagnation points, thereby promoting biofilm maturation (Karino *et al.*, 1987). Also, elastomeric ligatures are frequently changed and therefore, the time elapsed after their renewal may have an effect on bacterial attachment since the substrate for colonization is eliminated and a new cycle of colony formation is initiated on new material.

On the other hand, direct assessment of microbes *in situ* and onto specific areas may not at present be feasible. It follows that for a general assessment of microbial colonization on tooth and bracket surfaces, salivary sampling may be selected based on the assumption that salivary levels of microbia may represent the variation of those attached to bonded teeth. The available literature supports such a correlation between the presence of *S. mutans* in saliva and plaque (Mundorff *et al.*, 1990; Sullivan *et al.*, 1996). High counts in the saliva usually correlate to more than 10^3 mean squares in the plaque. In the present study, the levels were around 10^4 before and after bonding in both groups. This is most probably due to the low levels of caries experience of both groups.

Other factors in the oral environment may further decrease any possible variations due to the different surface characteristics. One such factor for microbial colonization of oral hard surfaces is the salivary or acquired pellicle, which can form not only on tooth surfaces but also on restorations, and prosthetic and orthodontic appliances. Therefore, the adhesion of oral microorganisms to the bracket surface may be influenced to a large extent by interactions between salivary components in the pellicle and the properties of the different microorganisms, in addition to the adherent patterns of bacteria on the different types of orthodontic brackets. The presence of an early salivary pellicle has been found to reduce the number of adhering bacterial cells of *S. mutans* (Fournier *et al.*, 1998; Papaioannou *et al.*, 2007).

An interesting observation relates to the interaction between different bacterial species in adhesion to a surface.

Specifically, *S. sanguinis*, one of the initial colonizers of the oral cavity, has been found to further reduce the number of adhering *S. mutans* regardless of the type of surface. *Streptococcus mutans* and *S. sanguinis* would seem to have an antagonistic relationship and early colonization by the latter may have a significant effect on concentrations of *S. mutans* (Quirynen and Bollen, 1995). A delayed colonization by *S. mutans* may lead to less caries or caries susceptibility.

The morphology and design of orthodontic brackets, as well as the ligation mode may play a role by providing an increased number of retention sites as well as protection from plaque-removing shear forces arising from masticatory loads and fluid flow, thus facilitating dental plaque accumulation and maturation, and consequently increased levels of *S. mutans* in saliva. One of the proposed favourable aspects of self-ligating brackets is associated with the elimination of elastomeric or stainless steel ligatures. Teeth ligated with elastomeric ligatures, as in the present study, have been found to harbour in the area of the brackets, higher numbers of bacteria than those where steel wire is utilized (Caufield *et al.*, 2000). The type of bacterial morphotypes, as detected in a scanning electron microscopy study, was not, however, found to differ between the two ligation methods (Sukontapatipark *et al.*, 2001). Türkkahraman *et al.* (2005), employing a split-mouth protocol, examined the effect of the two ligation modes (elastomeric rings and ligature wires) on the accumulation of specific cariogenic species (*S. mutans* and lactobacilli) as well as the periodontal status, before therapy and at 1 and 5 weeks after treatment initiation. Slightly higher total counts of bacteria around the elastomeric rings were found that, however, did not reach statistical significance, even though, in all 21 patients, significant increases of bacteria counts were recorded. Finally, elastomeric rings appeared more conducive to gingival bleeding, perhaps due to their slightly higher affinity to plaque. For this reason, those authors suggested that the use of elastic ligatures should be avoided in patients with inadequate oral hygiene.

The hypothesis of the present study that self-ligating bracket should have a beneficial effect due to the absence of ligatures, is not confirmed. However, as shown (Table 2), although the oral concentrations of *S. mutans* were found to be slightly lower in patients with self-ligating compared with conventional brackets, this difference did not reach significance. There seemed to be a small effect on the total bacterial load of the saliva, with the patients bonded with the self-ligating brackets showing a smaller increase of load at T2 compared with the conventional group, but again no significant effect was detected.

Based on the present findings, total facultative bacterial and *S. mutans* counts in saliva do not seem to be significantly different between the bracket groups tested. Locally though, i.e. in the tissues adjacent to brackets and peripheral marginal adhesive resin, the situation may be totally different and there may be an effect.

For the self-ligating brackets, the data are extremely poor. Only one study is presently available and that focuses on periodontal factors and associated bacteria. In that study (van Gastel *et al.*, 2007), an important local effect of bracket type was found. Indeed, at the area around the brackets, there were significant alterations in both periodontal and microbiological parameters, with the self-ligating Speed brackets showing poorer scores.

The results of the present study suggest that bracket design parameters may not have a significant effect on bacterial colonization on orthodontic appliances. This could be attributed to the implementation of an oral hygiene programme, which is taught at the early stages of orthodontic treatment, and the potential minute role of bracket design to offer sites for microbial adherence when such oral hygiene is exercised. However, the initial concentrations of *S. mutans* did exert a significant effect upon the counts of this bacterium over time. This may be an important factor to take into consideration when determining the risk a specific patient may be exposed to, thus necessitating a more individualized preventive programme.

Other approaches to alter the relationship between ligature elastomers and dental plaque accumulation have often been sought. The most common includes the use of fluoride-releasing elastomers (Wilson and Gregory, 1995; Benson *et al.*, 2004). Stannous fluoride is the fluoride of choice when the focus is placed on bacteria due to the antibacterial properties it possesses (Camosci and Tinanoff, 1984). A significant decrease in salivary levels was found when fluoride-releasing elastomers were placed in a group of orthodontic patients; however, there was no significant effect after 2 or more weeks of retention of elastomers (Wilson and Gregory, 1995). In a more recent split-mouth crossover study (Benson *et al.*, 2004), the bacteria that the elastomeric rings retained were examined after 6 weeks of intraoral use. No significant differences in culture growth for streptococcal and anaerobic bacteria were found.

Conclusion

Total bacterial counts in whole saliva did not differ significantly among patients with conventional and self-ligating brackets. Additionally, bracket type (conventional versus self-ligating) does not seem to significantly alter the levels of *S. mutans* in whole saliva.

Address for correspondence

Theodore Eliades
57 Agnoston Hiroon
Nea Ionia 14231
Athens
Greece
E-mail: teliades@ath.forthnet.gr

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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).

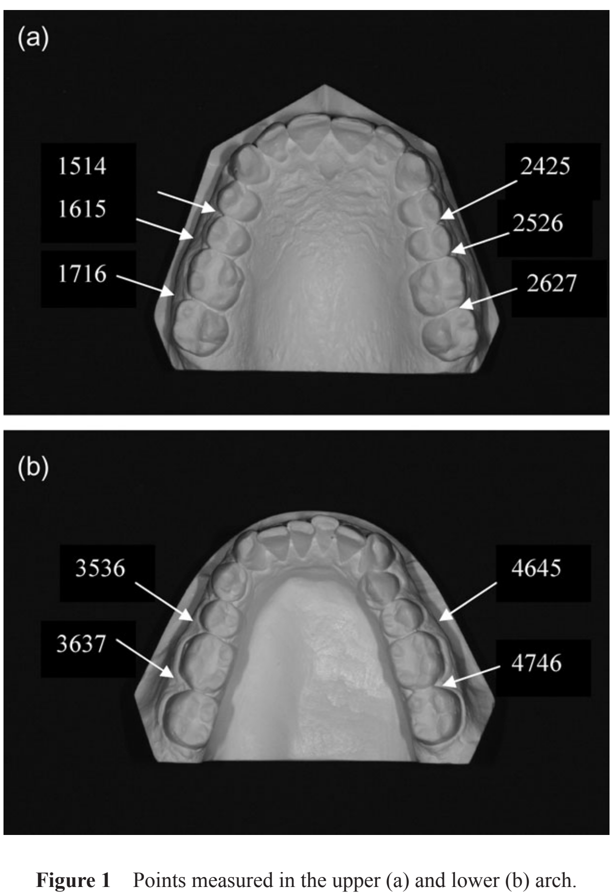

Figure 1 Points measured in the upper (a) and lower (b) arch.

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 ($P < 0.05$).

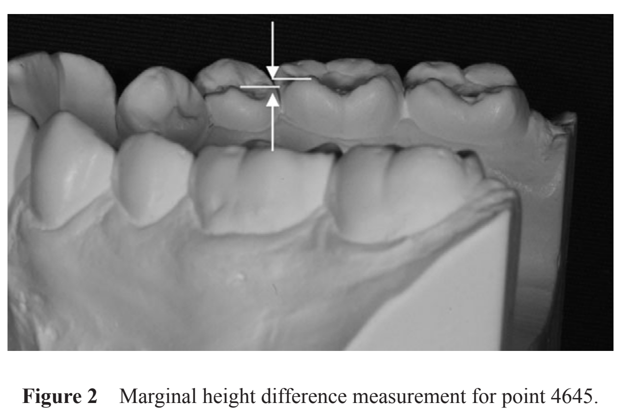

Figure 2 Marginal height difference measurement for point 4645.

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

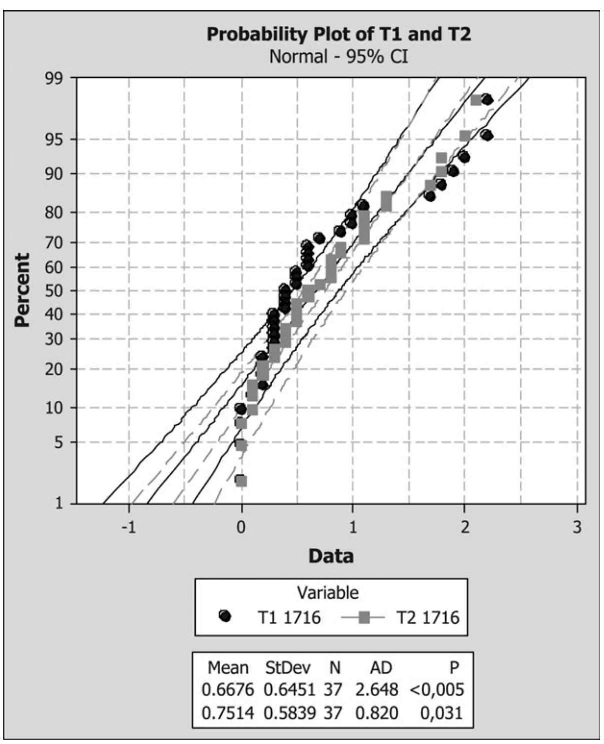

Figure 3 Probability plot for the initial (T1) and final (T2) values of point 1716 at T1 and T2.

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

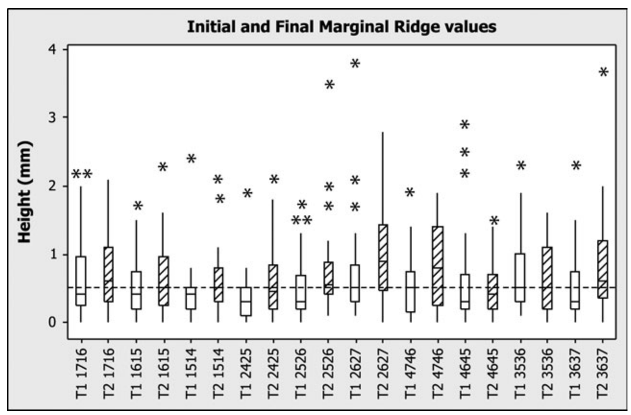

Figure 4 Changes in the descriptive statistics of marginal ridges from the start (T1) to following (T2) virtual treatment.

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*

*$P < 0.05$.

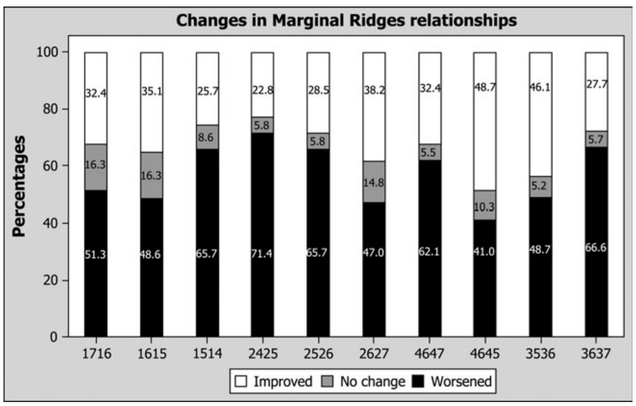

Figure 5 Changes in marginal ridge points (values in %).

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

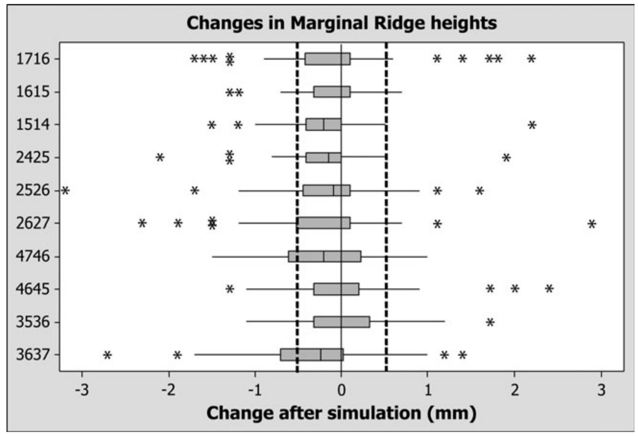

Figure 6 Changes in marginal ridges heights (values in mm).

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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Tooth movements in foxhounds after one or two alveolar corticotomies

Payam A. Sanjideh*, P. Emile Rossouw**, Phillip M. Campbell**,
Lynne A. Opperman*** and Peter H. Buschang**
*Private Practice, Calabasas, California and Departments of **Orthodontics and ***Biomedical Science, Baylor College of Dentistry, Texas A&M Health Science Center, Dallas, USA

SUMMARY The aim of this split-mouth experimental study was to determine (1) whether corticotomy procedures increase tooth movement and (2) the effects of a second corticotomy procedure after 4 weeks on the rate of tooth movement.

The mandibular third and maxillary second premolars of five skeletally mature male foxhounds, approximately 2 years of age, were extracted. One randomly selected mandibular quadrant had buccal and lingual flaps and corticotomies performed around the second premolar; the other quadrant served as the control. Both maxillary quadrants had initial buccal flaps and corticotomies; one randomly selected quadrant had a second buccal flap surgery and corticotomy after 28 days. Coil springs (200 g force), along with a 0.045 mm diameter tube on a 0.040 mm diameter guiding wire, were used to move the mandibular second and maxillary third premolars. Records, including digital calliper measurements and radiographs, were taken on days 0, 10, 14, 28, 42, and 56. Multilevel statistical procedures were used to model longitudinal tooth movements.

The radiographic measurements initially showed increasing mandibular tooth movement rates, peaking between 22 and 25 days, and then decelerating. Total mandibular tooth movements were significantly ($P < 0.05$) greater on the experimental (2.4 mm) than on the control (1.3 mm) side. The rates of maxillary tooth movement slowed over time, with significantly ($P < 0.05$) more overall tooth movement on the side that had two (2.3 mm) than one (2.0 mm) corticotomy procedure.

Alveolar corticotomy significantly increases orthodontic tooth movement. Performing a second corticotomy procedure after 4 weeks maintained higher rates of tooth movement over a longer duration and produced greater overall tooth movement than performing just one initial corticotomy, but the difference was small.

Introduction

According to the American Association of Orthodontists (AAO), the length of comprehensive orthodontic treatment ranges between approximately 18–30 months, depending on treatment options and individual characteristics (AAO, 2007). To increase efficiency, orthodontists have tried various approaches to decrease treatment times. A method of orthodontic treatment using corticotomies has recently become popularized (Wilcko *et al.*, 2001), which uses bone-healing mechanisms in combination with orthodontic loads to decrease treatment times.

Corticotomy procedures are based on the regional acceleratory phenomenon (RAP) and normal bone-healing mechanisms (Frost, 1981, 1983). Under normal circumstances, any regional noxious stimulus of sufficient magnitude can evoke a RAP (Esterhai *et al.*, 1981; Frost, 1981). Accelerated RAP processes include perfusion, growth of bone and cartilage, accelerated turnover of bone, and bone modelling (Frost, 1983). Once evoked, regional soft and hard tissue processes accelerate above normal values. The main effects of RAP appear to be restricted to the region of the stimulus; even areas in close proximity seem to be relatively unaffected by the RAP response (Bogoch *et al.*, 1993).

Previous experimental studies have shown that various stimuli, such as vitamin D, thyroxine, or electrical stimulus, can evoke a RAP in alveolar bone and increase tooth movements (High *et al.*, 1981; High, 1987; Collins and Sinclair 1988). When RAP is initiated in alveolar bone, there is an initial burst of osteoclastic activity, which decreases bone density and eventually enhances osteoblastic activity (Ferguson *et al.*, 2001). This is important because alveolar mineralization plays a role in tooth movement; the greater the mineralization of the alveolar bone the more difficult teeth are to move (Kole, 1959). It has also been established that osteoclastic activity is integral in tooth movement. Bisphosphonates, for example, decrease osteoclastic activity (Licata, 2005) and produce slower tooth movements (Igarashi *et al.*, 1994). Therefore, any stimulus that increases bone turnover and decreases bone density might be expected to result in faster tooth movement.

Accelerated treatment times with corticotomies are based primarily on clinical case reports (Suya, 1991; Owen, 2001; Wicko *et al.*, 2001). Two studies have experimentally evaluated the effects of corticotomies on tooth movement. Iino *et al.* (2007) and Cho *et al.* (2007), who performed corticotomies and protracted the third premolars for 4 and 8 weeks, respectively, reported approximately twice as much tooth movement associated with corticotomies. However, only one of the studies (Cho *et al.*, 2007) evaluated tooth movement beyond 4 weeks and this was limited to two beagle dogs. To minimize RAP effects associated with the extractions that were performed, both studies had healing periods ranging from 4–16 weeks. In terms of potential treatment efficiency, it is also important to understand the effects of corticotomies performed at the same time as extractions. These combined effects remain unknown. The effects of performing a second corticotomy on tooth movement have also not been investigated, although differential tooth movement might be expected.

The present study was designed so that the extraction of teeth and corticotomies were performed simultaneously in order to determine whether this novel approach may be clinically feasible. The null hypotheses of this study were:

1. Corticotomy procedures do not increase rates of tooth movements.
2. Performing a second corticotomy after 4 weeks produces the same amount of tooth movement as a single, initial, corticotomy.

Materials and methods

Sample population

The housing, care, and experimental protocol were in accordance with the guidelines set forth by the Institutional Animal Care and Use Committee. This study used five skeletally mature male foxhounds 2 years of age and weighing between 60 and 70 kg. The dog model was used because the size of the dentition approximates that of humans (Ren *et al.*, 2007) and studies have shown that tooth movements in dogs occur most efficiently when subjected to forces that approximate human clinical conditions (Pilon *et al.*, 1996; Daimaruya *et al.*, 2001; Cirelli *et al.*, 2003). All dogs were fed a soft diet for the duration of the experiment in order to prevent breakage of the appliances and to aid in healing after surgery.

Experimental design and group assignment (Figure 1)

All procedures were performed under general anaesthesia using ketamine (22 mg/kg/intramuscular; Bioniche Animal Health, Athens, Georgia, USA) and rompin (2.2 mg/kg/intramuscular; Loyd, Shenandoah, Iowa, USA). Lidocaine (Novocol Pharmaceutical Inc., Cambridge, Ontario, Canada) 2 per cent (1/200K epinephrine) served as the local anaesthetic. Prior to surgery (day −21), maxillary and mandibular impressions of each dog's dentition were taken with heavy and light body polyvinylsiloxane material (Coltene Affinis;

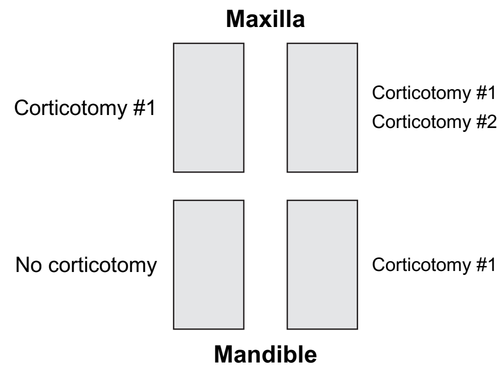

Figure 1 Schematic representation of the maxillary and the mandibular corticotomies performed.

Coltene/Whaledent, Altstatten, Switzerland). Mesh-backed bonding bases were fabricated from the models for the mandibular second, fourth, and maxillary third premolars; bands were fabricated for the maxillary canines. Headgear tubes (0.045 mm diameter) were soldered to the bonding bases to maximize the diameter of the archwire (0.040 inch round stainless steel) with sliding mechanics, thus minimizing the chance of wire distortion.

Extractions (day 0)

The first surgery was performed on day 0. The third premolars in the mandibular quadrants and the second premolars in the maxillary quadrants were extracted. (They were hemisected, elevated, and delivered via forceps.)

Bone markers (day 0)

Bone markers (BM), made of 99.95 per cent tantalum, 1.5 mm long, and 0.5 mm in diameter, were placed in the mandible and maxilla (2 per quadrant) of each dog. They served as stable reference points for quantifying tooth movements. The distance between each set of BM was measured with callipers when they were placed.

Maxillary and mandibular corticotomy procedures (day 0)

One mandibular quadrant was randomly assigned to have corticotomy procedures (flap surgery and corticotomies) performed (Figure 2) at the buccal and lingual surfaces adjacent to the second premolar. The opposite side served as the untreated control, without flaps or corticotomies. A size 12 surgical blade (Hu-Friedy, Chicago, Illinois, USA) was used to cut and reflect full thickness buccal and lingual flaps just mesial and distal to the second mandibular premolar. A high-speed drill with a #702 tapering fissured bur (SS White Bur Inc., Lakewood, New Jersey, USA) was then used to make buccal and lingual cortical cuts (approximately 1—2 mm deep) around the premolar root, with copious saline irrigation. The flaps were closed with Goretex non-resorbable sutures, which were removed after 10 days.

Figure 2 (A) Mandibular experimental side with buccal and lingual corticotomies. (B) Maxillary buccal corticotomy.

Using the same protocol as in the mandible, maxillary corticotomy procedures were performed around the third premolars in both quadrants but only on the buccal side. The anatomy on the palatal side of the foxhound maxilla did not allow for corticotomies. Following surgery, post-operative analgesic (Trophaject 0.2 mg/kg/intramuscular; Butler, Dublin, Ohio, USA) and antibiotics (Benzathine penicillin 300 IU/intramuscular three times/36hours; Butler) were administered.

The appliances were then bonded with Panavia F2.0 (Kuraray America, Inc., New York, New York, USA) according to manufacturers' instructions. Each quadrant had a constant force of 1.96 N (200 g) delivered by a 9 mm heavy Sentalloy® spring (GAC International, York, Pennsylvania, USA). In the mandible, the spring was attached to the second premolar with a 0.012 inch stainless steel ligature wire, then stretched and tied to the fourth premolar and molar. In the maxilla, the coil spring (also delivering 1.96 N) was attached with a 0.012 inch ligature wire from the canine to the third premolar.

Coil springs used for tooth movements were checked (*in situ*) and calibrated with a gram force gauge (Correx, Haag-Streit, Bern, Switzerland) every 2 weeks. After etching with 37 per cent phosphoric acid for 15 seconds, Transbond XT primer was applied, followed by Transbond XT composite (3M Unitek, Monrovia, California, USA), which was light cured with a 3M Unitek Ortholux® (3M, St Paul, Minnesota, USA) light emitting diode light for 20 seconds. Composite was bonded around the ligature wire to help keep it in place. The animals were fitted with Elizabethan hoods (Ejay International Inc., Glendora, California, USA) to prevent appliance damage.

Second surgery (day 28)

After 28 days, a second corticotomy procedure was undertaken in one randomly selected maxillary quadrant of each animal. Full thickness buccal flaps and cortical cuts were performed at the buccal surface of the third premolar, as previously described. The flaps were closed and sutured as previously described.

Records

The records included radiographs and calliper measurements. Records and force calibration were performed on day 0 (appliance delivery) and on days 10, 14, 28, 42, and 56. Periapical radiographs were used to evaluate tooth movement in each quadrant. Each radiograph was taken with the source angled at 45 degrees. To ensure standardization, an acrylic radiographic guide tray (Fastray®, Bosworth Co., Skokie, Illinois, USA) was fabricated. A film holder was fixed to the acrylic tray to attach a removable indicator arm and aiming ring (Dentsply, York, Pennsylvania, USA). Each animal had four radiographic trays, one for each quadrant, which were fitted to the canines and the first molars.

As an independent measure of tooth movement, intraoral measurements were taken with a digital calliper (Fowler ultra-cal II, Fred V. Fowler Co., Newton, Massachusetts, USA) by one operator (PAS) from the mesial of the second premolar buccal tube to the tip of the mandibular canine. Maxillary measurements were taken from the mesial of the third premolar tube to the canine tip. Each measurement was carried out three times and averaged.

Necropsy (day 56)

Prior to necropsy, the animals were anaesthetized with ketamine (22 mg/kg/intramuscular) and rompin (2.2 mg/kg/intramuscular) and full final records were taken including radiographs, calliper measurements, and force magnitudes. The animals were then sacrificed using 1cc of Beuthanasia-D (Schering-Plough Animal Health Corporation, Summit, New Jersey, USA).

Radiographic analyses

The radiographs were scanned (Epson perfection 4990, Long Beach, California, USA) and seven landmarks were digitized (Viewbox version 3.1.1.7, dHal, Athens, Greece) on each radiograph (Figure 3) by one operator (PAS) who was blinded as to experimental procedures performed.

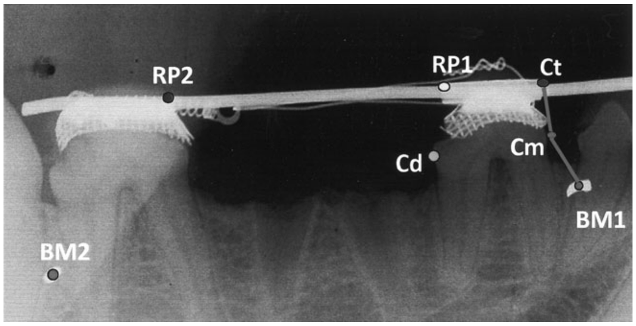

Figure 3 Radiographic landmarks and measurements including Cm, the most mesial point on the crown of the tooth; Cd, the most distal point on the crown of the tooth; Ct, the most superior/mesial point on the edge of bracket tube; BM1, the centre of the mesial bone marker; BM2, the centre of the distal bone marker; RP1, the superior intersection of the archwire and the distal of the bracket tube on second premolar; and RP2, the superior intersection of the archwire and the mesial of the bracket tube on the other banded tooth.

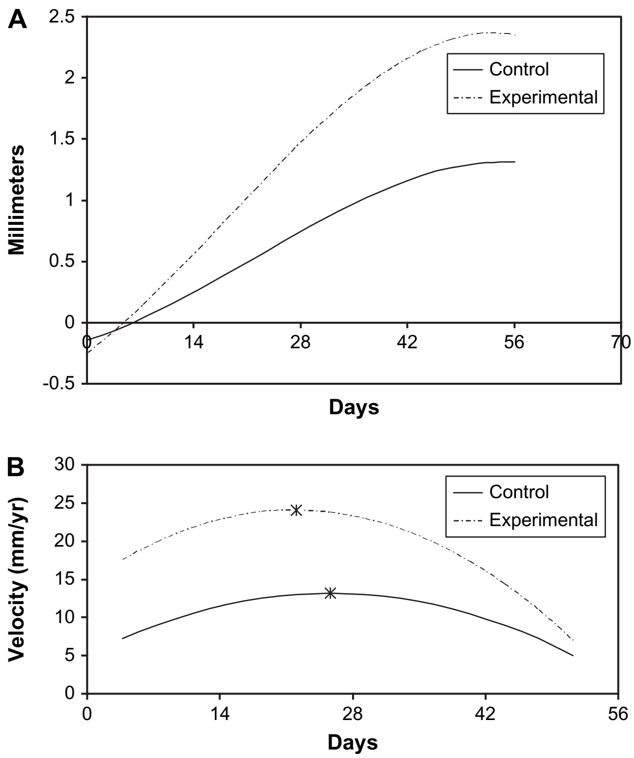

Figure 4 Average horizontal tooth movement (A) and velocities (B) of the mandibular second premolars on the control (no corticotomy) and experimental (buccal and lingual corticotomies) sides.

Following superimpositions on BM1 and BM2, the reference plane (RP1–RP2) digitized on the first (day 0) radiograph was transferred to the subsequent radiographs and used for orientation. Using BM1 as the origin, the horizontal and vertical distances of points Cm, Cd, and Ct from BM1 were measured. The angle Ct–Cm–BM1 was used to evaluate second premolar tipping. All measurements were made using the Viewbox software. To correct for possible magnification differences between radiographs, the linear measurements were multiplied by the ratio of the actual inter-bone marker distance divided by the radiographic inter-bone marker distance.

Technical errors were assessed based on replicate analyses of 20 randomly chosen radiographs. Paired *t*-tests showed no significant ($P > 0.05$) systematic errors between replicates. Methods error $\left(\sqrt{\left(\frac{\sum d^2}{2n}\right)}\right)$ ranged from 0.09–0.65 mm for the linear measurements and was 0.09 degrees for Ct–Cm–BM1.

Statistical analysis

Multilevel models were used to statistically determine treatment differences in the amount of tooth movement. The models were developed using the MLwiN (Centre for Multilevel Modelling, Institute of Education, London, UK) software and iterative generalized least squares estimating procedures (Goldstein, 1987).

The fixed portion of each model determined the polynomial that best fitted the repeated measurements of tooth movement as a function of time. The terms were tested statistically based on the standard errors; higher order terms were rejected sequentially until a lower order term attained significance ($P < 0.05$). The constant term described the tooth movement at day 56, the linear term the rate of change (velocity), the quadratic term acceleration, and the cubic term changes in acceleration. The random portion of each model partitioned variation between animals at the higher level and between measurement occasions (within animals) at the lower level.

Results

None of the dogs showed clinical signs of swelling or displayed healing problems of the periodontal tissues beyond 10 days post-surgery. Within 2 weeks of surgery, the tissues on the side with the corticotomy procedures appeared similar to the side without corticotomies. The radiographs showed no perceivable bone loss and there was no clinically evident recession of the tissues. After 10 days, none of the dogs displayed eating difficulties and there was no significant weight loss.

Statistical analysis showed no significant vertical movements of the teeth and no significant changes of Ct–Cm–BM1 angle.

The calliper measurements showed a significant difference in the total amount of horizontal tooth movement between the experimental and the control (averages of 2.5 versus 1.5 mm) sides of the mandible (Figure 4A). Mandibular tooth movement followed a cubic polynomial, with rates accelerating initially and then decelerating (Table 1; Figure 4B). The rates of tooth movement on the corticotomy side

Table 1 Polynomial model describing mandibular second premolar movements (mm) in foxhound dogs subjected to a force of 200 g for 56 days.

Variables	Constant		Linear		Quadratic		Cubic	
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
Control								
Radiographic	1.31	0.08	−1.17	3.64	−154.20	60.65	−552.336	267.77
Digital calliper	1.54	0.10	0.19	0.08	−0.10	0.04	−0.016	0.01
Experimental								
Radiographic	2.35	0.13	−4.29	5.74	−274.47	95.60	−884.90	422.03
Digital calliper	2.53	0.11	0.02	0.12	−0.27	0.06	0.04	0.01

SE, standard error.

increased until day 22 and then decreased. The control side showed increasing rates of movement until day 25. At peak velocity, the rate of tooth movement on the experimental side was 85 per cent faster than that on the control side. The rates of control and experimental tooth movement were similar at the end of the experimental period. Radiographically, there was approximately twice as much total mandibular tooth movement on the experimental than on the control side, averaging 2.4 and 1.3 mm respectively, over the 56 day experimental period.

In contrast to the mandible, the maxilla showed a simpler quadratic pattern of tooth movement, with rates of tooth movement decreasing regularly overtime (Table 2; Figure 5). Tooth movement on the two sides were similar through to day 36, after which the side with two corticotomies showed progressively more tooth movement than the side with one corticotomy. At 56 days, the calliper measurements showed no significant difference in tooth movement between the two sides. Radiographically, there was a significant difference in tooth movement between the side that received only an initial corticotomy (2.0 mm) and the side that received two corticotomies (2.3 mm).

Table 2 Polynomial model describing maxillary third premolar movements (mm) in foxhound dogs subjected to a force of 200 g for 56 days.

Variables	Constant		Linear		Quadratic	
	Estimates	SE	Estimates	SE	Estimates	SE
Control (one corticotomy)						
Radiographic	1.96	0.11	0.20	2.37	−97.329	16.58
Digital calliper	2.37	0.08	−0.06	0.11	0.19	0.05
Experimental (two corticotomies)						
Radiographic	2.33	0.10	10.11	2.52	−45.12	17.60
Digital calliper	2.64	0.08	−0.53	0.02	NS	NS

SE, standard error.
NS, not significant ($P > 0.05$).

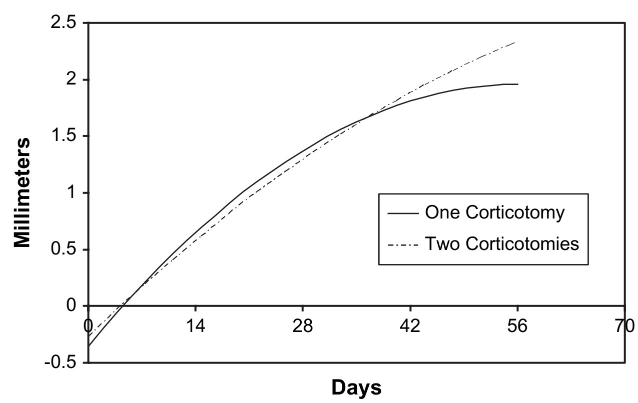

Figure 5 Average horizontal tooth movement of the maxillary third premolar on the side with one initial corticotomy and on the side with two corticotomies.

Discussion

Orthodontic forces with the corticotomy procedures produced substantially greater mandibular tooth movements than orthodontic forces alone. Tooth movement based on the calliper measurements were consistently larger than those derived from the radiographic measurements, suggesting that the calliper points measured were not taken in the same plane of space. The relative differences between the control and the experimental sides support the findings of Iino *et al.* (2007) and Cho *et al.* (2007), who also found approximately twice as much tooth movement in beagle dogs. However, they reported greater absolute amounts of tooth movement, which could have been due to the animal model used. The foxhounds used in the present study have larger mandibles and thicker cortical bone than beagle dogs. Previous investigations that also used calliper measurements were not able to discount the possibility of tipping. The lack of change in Ct–Cm–BM1 angle suggests that the appliance system used in the present study was effective in minimizing tipping. The differences were probably not related to the forces used because little or no difference in tooth movement occurs between forces of 50, 100, or 200 g (Pilon *et al.*, 1996). The corticotomies may have produced greater tooth movements due to increased bone turnover (Collins and Sinclair, 1988; Verna *et al.*, 2000; Kale *et al.*, 2004).

Both sides of the mandible initially showed accelerating rates of tooth movement. The initial pattern of tooth movement on the control side differed from those previously described for the controls, which tended to slow down within a few days after initial tooth movement due to hyalinization and undermining resorption (von Bohl *et al.*, 2004; Cho *et al.*, 2007; Iino *et al.*, 2007). While previous studies evaluating corticotomies waited from 1–6 months after extractions before initiating tooth movement, tooth movements were initiated immediately in the present study. This suggests that extraction of the third premolars caused a RAP on the control side, which has been shown to eliminate hyalinization of the periodontal ligament (Iino *et al.*, 2007). RAP on the control side could have produced an accelerating pattern of tooth movement similar to but less than that on the experimental side. Alternatively, it is possible that the reduced mineralized bone that filled the extraction sites could explain the faster tooth movements observed at both the experimental and control sides.

Orthodontic tooth movements might also be expected to initiate a RAP. As shown experimentally by Deguchi *et al*, (2006), bone turnover rates are significantly greater on the side of mouth subjected to orthodontic forces than on the control side. Thus, both extractions and orthodontic tooth movements might be expected to have influenced the results of the present study, but these effects were controlled because both sides of the mouth were similarly treated.

The initial acceleratory phase was much greater on the corticotomy side than on the control side, with differences in tooth movement evident during the first 2 weeks. By day 10, the corticotomy side showed twice as much tooth movement compared with the control side. Iino *et al.* (2007) and Cho *et al.* (2007) also found approximately twice as much tooth movement after 1 week on the corticotomy side versus the control side. It has also been suggested that greater amounts of noxious stimulus produce a greater RAP effect (Frost, 1981, 1983), which might explain the difference in tooth movement between the experimental and the control sides.

In the mandible, the rates of tooth movement peaked at day 22 on the corticotomy side and at day 25 on the control side; peak velocity was 85 per cent greater on the corticotomy side. This finding is similar to previous studies that showed tooth velocities peak between the first (Iino *et al.*, 2007) and third (Cho *et al.*, 2007) week after corticotomies were performed. Peak tooth velocities indicate a transition from the catabolic to the anabolic phase of RAP, when bone density is least and tooth movements might be expected to be greatest. After the peak, there was a deceleration of tooth movement in both the corticotomy and the control groups, with the rates on the corticotomy side approaching those on the control side at the end of the experiment. These findings support those of Iino *et al.* (2007) and Cho *et al.* (2007), who were not able to identify differences in rates of tooth movement between the corticotomy and the control sides at the end of their experimental periods. It has been shown that in rats, osteoid begins to mineralize after about 20–55 days (Ferguson *et al.*, 2001). According to those authors, anabolic modelling of alveolar trabecular bone adjacent to decortication increases 150 per cent by 3 weeks. Since the anabolic levels of RAP increase through time, it is reasonable to expect that tooth movement would slow as bone density increased, which possibly explains the decreased tooth movement seen during the last 2 week of the experiment.

At the end of the experiment (day 56), there was only marginally more tooth movement on the maxillary side that had two corticotomy procedures performed than on the side with one corticotomy. The side with only one corticotomy showed decreasing amounts of tooth movement during the last few weeks; the side with two corticotomies showed steadier rates of tooth movement throughout the experimental period. In other words, the second corticotomy maintained a higher rate of tooth movement for a longer period of time. However, the differences in tooth movement between one and two corticotomy procedures were small and seem insufficient to warrant a second surgical procedure for orthodontic patients. Considering the added expense and time involved, along with the potential health factors associated with periodontal surgery, a second corticotomy may not be warranted. Other methods of initiating the RAP, such as corticision (Young-Guk *et al.*, 2006), laser (Youssef *et al.*, 2008), or electrical stimulation (Takahashi *et al.*, 1985) may provide a less invasive and a more cost-effective alternative, but all of these possibilities require further investigation. Based on the tooth movement rates in the mandible, a greater overall effect might have occurred if the second corticotomy had been performed at 6 weeks instead of 4 weeks because tooth movements on the side with one corticotomy would have had more time to slow down.

While corticotomies clearly increased the rates of tooth movement, significant reductions in treatment time of comprehensive cases remain questionable. Case reports have indicated that comprehensive orthodontic treatment can be completed in 4–9 months with corticotomies (Suya, 1991; Wilcko *et al.*, 2000, 2001), whereas conventional orthodontics takes 18–30 months (AAO, 2007). Based on the present study and other longitudinal experimental evidence (Cho *et al.*, 2007; Iino *et al.*, 2007), tooth movement rates approach control values after approximately 3–7 weeks. As such, it is difficult to understand how treatment can be accelerated by 14–21 months with a single corticotomy. Even though dogs heal only slightly faster than humans (Frost *et al.*, 1969), it is possible that there the RAP effect is different in humans than in dogs. The thicker cortical bone of dogs could also account for some of the differences. Since the greatest tooth movement during orthodontic treatment occurs during aligning and levelling of the dentition, which typically takes approximately 6 months (Franchi *et al.*, 2006; Tagawa, 2006), corticotomies might be best suited for this treatment phase. Importantly, controlled randomized trials are needed to ascertain the true efficacy and most appropriate time to perform corticotomies.

Contrary to expectations, there was greater tooth movement on the corticotomy side of the mandible than on the side of the maxilla that had only one corticotomy. Considering that mandibular cortical bone is thicker and more dense than maxillary bone (Miyawaki *et al.*, 2003; Deguchi *et al.*, 2006), less movement might have been expected. However, the second premolars were moved in the mandible, while the third premolars were moved in the maxilla and the size difference between these teeth could explain the observed differences in tooth movement. The differences may also have been due to the fact that the mandible had buccal and lingual corticotomies, while the maxilla had only a buccal corticotomy. This could have produced a greater RAP in one jaw than the other.

Case reports suggest little or no loss of gingival attachment associated with corticotomy (Kole, 1959; Suya, 1991; Wilcko *et al.*, 2001). The present study showed increased swelling and inflammation during the first 10 days following both the first and the second corticotomy. After 10–14 days, the tissues on the corticotomy side appeared similar to those on the control side. While no adverse effects have been noted, well controlled trials have not been performed to establish the health of the periodontal tissues after corticotomy. Histological data must also be evaluated to verify the mechanisms responsible for accelerating tooth movement. In order to more fully understand differences in tooth movement with and without corticotomies. It is also important to establish a clear association between the magnitude of injury and the duration and magnitude of RAP response in alveolar bone.

Conclusion

1. Alveolar corticotomies and associated soft tissue surgery create conditions that significantly increase tooth velocities and tooth movements when orthodontic forces are applied.
2. Performing a second corticotomy procedure after 4 weeks maintains the enhanced velocities of tooth movement for a longer duration. However, the differences in tooth movement do not appear to justify a second corticotomy.

Address for correspondence

Professor Peter H. Buschang
Orthodontic Department
Baylor College of Dentistry
Texas A&M Health Science Center
Dallas
Texas 75246
USA
E-mail: phbuschang@bcd.tamhsc.edu

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Book Reviews

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Advance Access Publication 3 December 2009

Biological mechanisms of tooth movement

Editors: Vinod Krishnan and Ze'ev Davidovitch,
Publisher: John Wiley & Sons Limited, Chichester, West Sussex, UK,
Price: £99.50,
ISBN: 978-1-4051-7690-3

A textbook solely devoted to biological mechanisms of tooth movement is now available for the orthodontic community. A topic usually confined to single chapters in orthodontic textbooks, or presented in up-to-date review articles, has now received its proper attention. An international team of expert contributors, including the editors, 'have generously and without hesitation shared their valuable knowledge and wisdom' and created a classic reference book.

The book is divided into 12 chapters. It starts with an overview of the evolution of biological concepts in orthodontics and a brief review of the biological responses to orthodontic forces. Further, in-depth information is given on key topics such as genetic influences, the role of inflammation, bone biology, and the characterization of gingival crevicular fluid in orthodontic patients. The effect of systematic diseases, drugs, and diet on orthodontic tooth movement is covered in Chapters 8 and 9 giving full support to the notion that teeth are not separate entities, but integral parts of the human body. The chapter on optimal orthodontic forces and how they are applied failed to meet my expectations. It promotes the 'amalgamated technique' through case reports, rather than dealing with research on optimum force magnitude. The comprehensive review of the current, though scarce, knowledge of the biological background of relapse of orthodontic tooth movement is a real jewel. The last chapter, as expected, deals with the iatrogenic damage of orthodontic treatment, how to minimize this, and, eventually, how to avoid further complications.

This large-format hardback textbook is well designed and illustrated throughout. Being one of the 'initiated', I enjoyed every single page of the book and consider it as a real treat. However, practitioners must not be put off by the book's title, as its contents prove to be a 'scientific spice' in the library of every orthodontist and is highly recommended. To quote the editors: ' . . . the time is approaching when the nature of optimal orthodontics will be fully exposed as a consequence of the increasing widening of the highway connecting clinical and basic sciences . . .'.

Vaska Vandevska-Radunovic

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Current therapy in orthodontics (2010)

Editors: Ravindra Nanda and Sunil Kapila,
Publisher: Mosby, Elsevier, Jordan Hill, Oxford, UK,
Price: £114.00,
ISBN: 978-0-323-05460-7

The rate of technological and scientific advancement in contemporary orthodontics is accelerating. The present book was designed to update clinicians on new knowledge and recent developments in orthodontics. As with any Mosby publication, it is well indexed and richly illustrated; 298 fully coloured figures and 30 tables are used very effectively. No fewer than 42 authors, all experts in their fields, have contributed to the 396 pages of this book, which is divided into four parts.

Part I details orthodontic diagnosis and treatment. Chapters are dedicated to quality of life as an indicator for treatment need, patient compliance, the non-numeric determination of form and balance in cephalograms, the assessment of occlusal patterns in orthodontic patients, and the three-dimensional superimposition of cone-beam computed tomographic images for the evaluation of anatomical changes during growth or orthodontic treatment. The section dealing with orthodontic treatment contains a comprehensive and well-referenced chapter on adhesives and bonding, discusses the impact of bracket selection and placement on expressed tooth movement, and challenges popular trends in orthodontic treatment, such as appliance-driven procedures.

The second part of the book focuses on the clinical management of sagittal and vertical discrepancies. Three chapters are dedicated to the treatment of Class II malocclusions. They explain the concept of functional therapy and present treatment strategies to reduce reliance on patient compliance, such as the use of fixed functional appliances and intramaxillary distalization appliances. The chapters on the treatment of vertical discrepancies address aetiology, diagnosis, and treatment of open- and deep-bite malocclusions.

Part III deals with the management of adult and complex cases and occupies more than one-third of the volume. The orthodontic treatment of patients with reduced periodontal attachment is discussed, as well as the management of those with chronic obstructive sleep apnoea. The chapter on biomechanics gives an excellent overview of continuous and segmented archwire mechanics and emphasizes the need to design an individualized biomechanical treatment plan for each patient. It advocates an approach called 'hybrid sectional mechanics', which combines the advantages of both continuous and segmented archwire mechanics to optimize treatment outcomes in complex cases. The chapter on aesthetics in interdisciplinary patients challenges the traditional treatment planning sequence and shows the striking results that can be achieved when the highest level of clinical care is delivered by several dental disciplines. Three chapters on skeletal anchorage discuss the use of microscrews and miniplates in specific orthodontic situations and describe the surgical procedures involved in their placement.

The final part of the book addresses the applications of biomedicine to orthodontics. It discusses the biological background of the mechanotransduction of orthodontic forces, the process of orthodontic root resorption, and the surgical restoration of oral and craniofacial defects.

The diverse pool of authors not only lends expertise and experience to each topic discussed but also contributes to perceptible differences in style and quality of the treatment results and clinical photographs among the chapters. As stated in the preface, the book was not meant to be a compendium of every aspect of orthodontics—and it is not. It is a selection of topics that have evolved or received increased attention during recent years. However, the book effectively does what it was designed for. It provides access to state-of-the-art concepts in orthodontics, covering both clinical aspects and scientific background. As the book extends standard orthodontic textbooks, it might not be well suited for learners but can be recommended to every general practitioner, senior graduate student, and orthodontic specialist who is looking for a compact update on the latest advances in the field of orthodontics.

Thorsten Grünheid

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Detection, assessment, diagnosis and monitoring of caries (2009)

Editor: Nigel Pitts
Publisher: Karger, Basel, Switzerland
Price: €113.50
ISBN: 978-8055-9184-3

This is a 15 chapter, 216 page book on the topic clinical management of dental caries. Each chapter starts with a small abstract and concludes with a citation list of 20–67 references. Nigel Pitts has assembled 22 collaborators, so that different chapters, except for the four written solely by the editor, are put together by multiple authors well known in the field. Presentation standards are high with quality photographs, diagrams, and figures.

The chapters read as a series of review articles with the aim of identifying and explaining evidence concerning the detection and diagnosis of the caries process in both children and adults. Not surprisingly, the International Caries Detection and Assessment System (ICDAS) is prominent in the text as the epidemiology of caries detection is a major theme of the monograph.

While these issues will be of interest to orthodontists, the sections concerning the management, by dentists, of carious lesions will be of less direct interest. The specific concern for orthodontists of early, reversible carious lesions does figure briefly. However, there are two chapters that are of particular interest. Chapter 4 describes 'Novel lesion detection aids' and Chapter 12 'Novel preventive treatment options'. In these two chapters, there are explanations of non-invasive diagnostic techniques and some recently developed preventive strategies that are of practical use in clinical orthodontics.

This monograph represents a comprehensive expression of the current evidence base for caries diagnosis and management. The problem with a book of this type is that the field of study moves forward fairly rapidly. For example, ICDAS has already been through a number of iterations. The techniques used to identify carious lesions are also evolving. This text is a sound contemporary representation.

Neil Pender

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Self-ligation in orthodontics (2009)

Editors: Theodore Eliades and Nikolaos Pandis
Publisher: John Wiley & Sons Limited, Chichester, West Sussex, UK
Price: £79.50
ISBN: 978-1-405-18190-7

This is a well-written and presented book, delivering the clinical and scientific evidence base for self-ligation in orthodontics. The format is succinct and easily understood with unbiased delivery of the key facts and current knowledge.

The content includes the history, evolution, and core advantages of self-ligation systems and a summary of biomechanics including *in vitro* forces and moments. The authors have also addressed the effects and outcomes of clinical importance, including treatment duration, dental arch changes, space closure, and chair-side time. There is an extremely useful chapter on treatment mechanics with self-ligating systems. In addition, detailed information on clinical research design is included, and the biology of tooth movement and root resorption chapters provide a detailed general overview before focussing on the potential effects of self-ligating systems.

The authors and contributors should be congratulated on this high-quality and extremely well-referenced book that summarizes current knowledge. It will be incredibly useful to both clinical and academic orthodontists.

Nicky Mandall