British Journal of Orthodontics/Vol. 26/1999/97–102

The Influence of Maxillary Incisor Inclination on Arch Length

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Abstract. *This* ex vivo *study was designed to investigate Andrews' hypothesis that there is a space implication when incisors are torqued correctly. A working model was constructed to allow acrylic typodont incisors of varying known values of inclination to be substituted into the model. The arch lengths of the various 'set-ups' were measured using a reflex micro - scope linked to a PC. In order to quantify the space requirement of clinical relevance for adequate incisor torque, the method was repeated by substituting replicas of patients' 'natural' incisors.*

For both acrylic and natural incisors it was found that, as the inclination of the teeth increased, there was an increase in all arch lengths, this being greater for the natural incisors. This larger increase for the natural incisors was related not only to their increased size, but was also dependent on the morphology of the incisor. Those incisors which were parallel-sided showed the greatest increase in arch length, whereas the incisors that were relatively triangular in shape showed the smallest increase.

When the inclination of an 'average' set of 21\|12 is increased by 5 degrees, an increase in the arch length of approximately 1 mm may be expected.

Index words: Andrews' Six Keys, Space Analysis, Treatment Planning.

Refereed Paper

Introduction

The advent of sophisticated appliances and materials has helped to raise the standard of orthodontic treatment, and as a consequence achieving an 'ideal' occlusion has become a realistic aim. These current concepts of ideal static occlusion are based on Andrews' six keys of normal occlusion (1972). Andrews stated that if the six keys are not achieved, either a space discrepancy will arise in the dental arch or there will be a compromise in the occlusion.

The third key (labio-lingual inclination of the teeth to the occlusal plane) may have a significant implication on the space requirements in the dental arch. If the maxillary labial segment teeth are retroclined, space will be required within the arch to correct their inclination due to the palatal movement of contact points as the incisors are torqued.

Andrews illustrated that if there is insufficient torque in the upper labial segment, a space may be evident distal to the maxillary canine, whereas, if all the spaces are closed, the buccal segment relationship may no longer be Class I (Figure 1).

There is little in the literature which attempts to quantify the space implication of altering the inclination of the maxillary incisors. With the aid of a diagnostic set-up, Tuverson (1980) has demonstrated that by increasing the inclination of upright maxillary anterior teeth, 1 mm of additional dental arch length may be gained. Hussels and Nanda (1987) have attempted to quantify the effects of incisor angulation and inclination on arch length, but this assumes that teeth conform to a mathematical model.

Materials and Methods

The study was designed in two parts. The first part aimed to quantify the changes in maxillary arch length by altering the inclination of acrylic typodont incisor teeth. In the second part, the method was repeated using replicas of patients' incisors to evaluate the influence of natural tooth size and shape on arch length.

A working model was constructed in two parts (Figure 2):-

(1) a rigid block of acrylic holding 654\|456 in fixed positions;
(2) a free anterior section of 321\|123 supported by a rigid full thickness archwire, allowing the 321\|123 to be removed when required and replaced with alternative teeth.

In order to place both typodont and natural incisors at different values of inclination, brackets of known values were bonded to the labial face of the teeth in reproducible positions. When firmly ligated to the full thickness archwire using unstretched figure of eight elastomeric modules, the known value of inclination and angulation in each bracket was expressed. This allowed a range of inclinations to be assessed from retroclined to normally inclined incisors by substituting the bracketed incisors. The brackets used were A Company with a 0·022 × 0·028-inch slot size and the archwire a preformed 0·021 × 0·025-inch high quality stainless steel wire to ensure virtually complete slot engagement.

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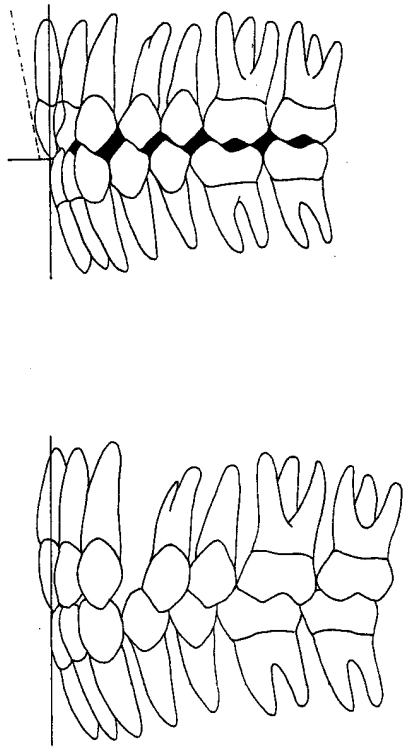

FIG. 1 Inadequate torque in the upper labial segment.

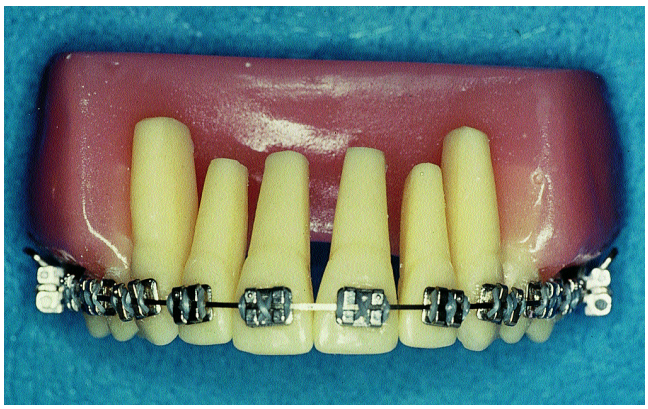

FIG. 2 Master model of 654321|123456.

Study of the Effect of Inclination on Acrylic Typodont Teeth

A clinician experienced in the use of the straight wire appliance placed the brackets in what he considered to be the ideal positions. These positions were then permanently scored into the labial face of these 'master' teeth. This master set of 321|123, with bracket locating markers, were then duplicated to produce a pool of identical acrylic teeth. This ensured reproducible bracket positioning when comparing different bracket prescriptions, and removed any inconsistency in the size and form of the manufacturers' teeth.

Five groups of models were set up from the pool of identical teeth and compared using:

a. Andrews' brackets placed on 321|123.
b. Andrews' brackets inverted on 21|12, to simulate retroclination of the incisors, but with Andrews brackets on 3|3 of conventional orientation. This adaptation converted the effective labial face inclination of 1|1 from +7 to –7 degrees, a change of 14 degrees, and of 2|2 from +3 to –3 degrees, a change of 6 degrees with unchanged angulation (Figure 3).
c. Roth brackets on 21|12, Andrews brackets on 3|3.
d. Roth brackets inverted on 21|12, but with Andrews' brackets on 3|3 of conventional orientation. This adaptation converted the effective labial face inclination of 1/1 from +12°to –12 degrees, a difference of 24 degrees as compared to normal Roth values and of 19 degrees when compared to Andrews. This conversion was designed to simulate a severe degree of retroclination of the incisors only, without incorporating any spatial effects on the arch length that might occur from changing the brackets on the 3|3.
e. Roth brackets on 321|123. This group, when compared to group (c), enabled the influence of Roth inclination and angulation of 3/3 to be assessed, and also when compared to group (a) demonstrated the effect on arch length of Andrews versus Roth prescription brackets in the labial segment.

In order to facilitate measurement, accurate impressions were taken and stone models produced of each acrylic teeth 'set up' as in groups (a)–(e). The arch lengths of the models were recorded through their incisal and occlusal surfaces from 6|6using a reflex microscope linked to a PC (Figure 4). Each point was digitized twice, recording the *x* and *y* coordinates with a tolerance of 0·1 mm, and the arch length was calibrated using a customized computer program. All recordings were carried out by one operator and their error in model measurement was calculated by digitizing one model on 10 consecutive days following a period of training in the use of the reflex microscope. Each of the remaining models were digitized twice at 1-week intervals in order to obtain a mean figure for the arch length.

The data was then processed by a statistics package (SPSS). A one-way analysis of variance was performed on

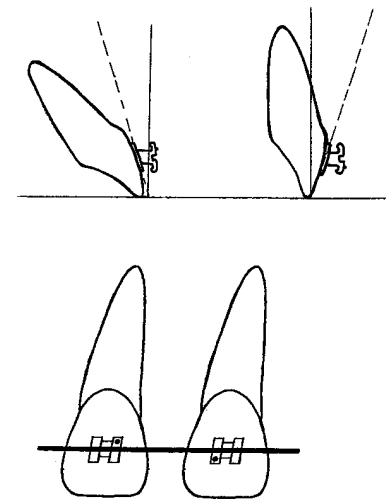

FIG. 3 Inversion of a bracket reverses the crown inclination (torque), while the angulation (tip) remains unchanged.

FIG. 4 Stone working model of the acrylic teeth.

the different sets of data for the acrylic teeth using SPSS/PC.

Method of Determining the Space Implication When Altering the Inclination of Patients' Incisor Teeth

In order to obtain an indication of the range of arch length change that natural teeth might produce from the same inclination changes, study models of 10 patients were selected where the incisors were undamaged and of normal morphology. This ensured that a range of authentic morphologies could be compared to artificial typodont teeth which might not otherwise be considered clinically relevant.

The patients' incisors were then duplicated and separated from the casts. These natural 21|12 were attached to the master model by substituting for the acrylic incisors and the experimental method repeated using the same standardized archform as for the acrylic teeth. The brackets used for the natural 21|12 were of Andrews prescription and inverted Andrews prescription only as this range of inclination change was considered to be of greater clinical significance.

TABLE 1 *Inclination change when altering bracket types*

Tooth type	Andrews *v.* inverted Andrews (°)	Roth *v.* inverted Roth (°)	Andrews *v.* Roth (°)
1|1	14	24	5
2|2	6	16	5

Results

The inclination changes which took place in 21|12 are shown in Table 1. When Roth canine brackets are substituted for Andrews canine brackets, the inclination changed from –7to –2 degrees, but the angulation was also changed from +11 to +13 degrees, whereas the incisors have the same angulation with both prescriptions.

Effect of inclination on total arch length using acrylic incisors

The arch lengths for the five different 'set-ups' with varying degrees of inclination expressed by the acrylic incisors are shown in Table 2.

The results of the one-way analysis of the data (ANOVA) showed that the population means of the five groups were different at the $P < 0{\cdot}01$ level. However, they did not reveal which group means were different from each other. Therefore, a Duncan Range test was carried out at the $P = 0{\cdot}05$ level. This test demonstrated that all group means were statistically different from each other.

The mean arch length change between the groups is shown in Table 3. This demonstrates the space implication of altering the inclination of the acrylic incisors by a known amount.

The unpaired *t*-tests for each of these groups at the $P < 0{\cdot}001$ level showed that there was a highly significant statistical difference between the mean arch length changes as the inclination of the incisors was altered. It can be confidently assumed, therefore, that the mean arch length changes as the inclination of the acrylic incisors is altered.

The operator error in model measurement was small (variance, $\sigma^2 = 0{\cdot}002$ mm^2). Speculand *et al*. (1988) have shown that the use of *x* and *y* co-ordinates only under high magnification produces greater accuracy.

Effect of Inclination on Arch Length Using Natural Teeth

There was an increase in arch length in all 10 sets of natural teeth as the inclination of 21|12 was increased. Although

TABLE 2 *Arch length with varying inclinations of 21|12*

Group	Bracket prescription of 321|123	Inclination of incisors (°)	Mean A/L (mm)	SD (mm)	Range (mm)	σ^2 (mm^2)	SE (mm)
a	Andrews 21|12 Andrews 3/3	1 = +7 2 = +3	87·96	0·07	87·86–88·10	0·005	0·022
b	Inverted Andrews 21|12 Andrews 3|3	1 = –7 2 = –3	87·25	0·10	87·10–87·42	0·010	0·032
c	Roth 21|12 Andrews 3|3	1 = +12 2 = +8	88·65	0·13	88·45–88·77	0·017	0·058
d	Inverted Roth 21|12 Andrews 3|3	1 = –12 2 = –8	86·84	0·14	86·61–86·96	0·020	0·063
e	Roth 21|12 Roth 3|3	1 = +12 2 = +8	89·52	0·28	89·09–89·71	0·078	0·125

A/L = arch length; σ^2 = variance; SE = standard error of the mean.

this can be clearly seen from Table 4, a paired *t*-test was carried out on this data and this result was found to be highly statistically significant ($P < 0{\cdot}001$).

The sets of teeth have been ranked in ascending order of arch length change.

Discussion

Effect of Inclination on Arch Length

Increasing the inclination of the acrylic incisors produced a statistically significant increase in the arch length. Furthermore, this finding was reproduced when using the natural teeth, with the increase in the arch length being nearly twice that produced by the acrylic teeth. For acrylic teeth, the effect of producing a 14-degree change in inclination of the maxillary central incisors (6 degrees for the lateral incisors) increased the arch length by 0·71 mm (SD = 0·086 mm). However, for natural teeth, this same movement increased the arch length by 1·36 mm (SD = 0·48 mm). The range in values for the natural teeth of 0·90–2·25 mm and the wider standard deviation were not surprising, because the 10 sets of incisors were not identical.

For acrylic incisors a change in arch length of 0·59 and 0·69 mm was found due to an alteration in the inclination of all the incisors by 5 degrees comparing Andrews with Roth 21|12 (Table 3). Since natural teeth produce a greater change in arch length, a change in the order of 1 mm may be expected when increasing the inclination of 21|12 by 5 degrees, the exact amount being dependent also on the size and shape of the incisors.

From the results in Table 2 and Figure 5, the alteration in inclination may appear to produce a fairly proportional change in arch length. However, the range of inclination change in this study is limited. If extremes of inclination were taken, it is likely that this change would be reduced because the inclination of the teeth would become more parallel to the occlusal plane and so would demonstrate that the relationship is not a linear one.

The effect of changing the brackets on 3|3 from standard Andrews values to Roth values produced an increase in inclination of 5 degrees and angulation of 2 degrees. This increased the arch length by 0·87 mm (SD = 0·23 mm) for the acrylic teeth (Table 2). This increase was larger than expected, and this may be because the inclination and angulation change in the bracket has a larger effect than was previously thought.

TABLE 3 *Mean arch length change with alteration in the inclination of 321|123. Standard Andrews canine brackets were used on all groups unless stated*

Inclination change of: 1 and 2 (°)	Mean A/L change (mm)	SD (mm)	*P*
–12 to +12 –8 to +8	1·81	0·14	***
–12 to –7 –8 to –3	0·59	0·11	***
–7 to +7 –3 to +3	0·71	0·09	***
+7 to +12 +3 to +8	0·69	0·09	***
Andrews *v.* Roth 321|123	1·55	0·14	***
Roth 21|12 *v.* Roth 321|123	0·87	0·23	***

*$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}001$

Effect of Tooth Shape on the Change in Arch Length as the Inclination of the Incisors is Altered

There was considerable variation in the changes of arch length as the inclination of natural teeth was altered, mean = 1·36 mm (SD = 0·48 mm, range = 0·90–2·25 mm). Although there was a tendency for larger teeth (as reflected in the total arch length) to show greater change in arch length when increasing the inclination, this was not a consistent finding. This is demonstrated in the results of Table 4 (Figure 6), where patient 5 had a large initial arch length, yet produced only a 1·10-mm change, and patient 8 which had a small initial arch length, yet produced an arch length change of 1·71 mm for the same inclination change.

On examination of the shape of these teeth, it could be seen that the incisors of patient 5 (Figure 7a) were fairly triangular in shape, whereas the incisors of patient 8 (Figure 7c) were relatively parallel-sided. The teeth that were seen to produce a more 'average' arch length change in relation to their size were those that were barrel-shaped as, for example, patient 7 (Figure 7b).

Larger teeth tend to have broader contact points which are also further from the incisal edges and so will produce an increased change in arch length as the contact point

TABLE 4. *The change in arch length as the inclination of 10 sets of natural teeth was altered*

Patient number	Arch length (mm) measured for inclination:		Arch length change (mm)
	1 = –7° 2 = –3°	1 = +7° 2 = +3°	
1	89·50	90·40	0·90
2	89·18	90·09	0·91
3	89·73	90·74	1·01
4	86·13	87·16	1·03
5	92·80	93·90	1·10
6	89·25	90·42	1·17
7	92·22	93·74	1·52
8	88·72	90·43	1·71
9	91·85	93·80	1·95
10	91·99	94·24	2·25

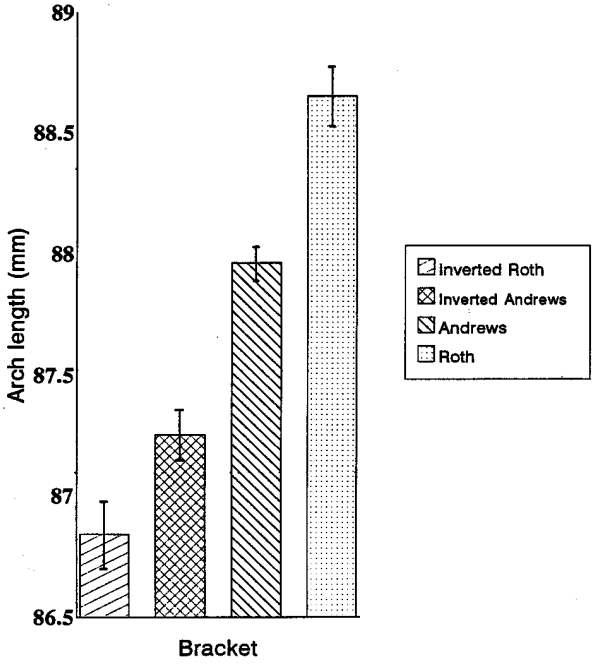

FIG. 5 Effect of inclination on arch length.

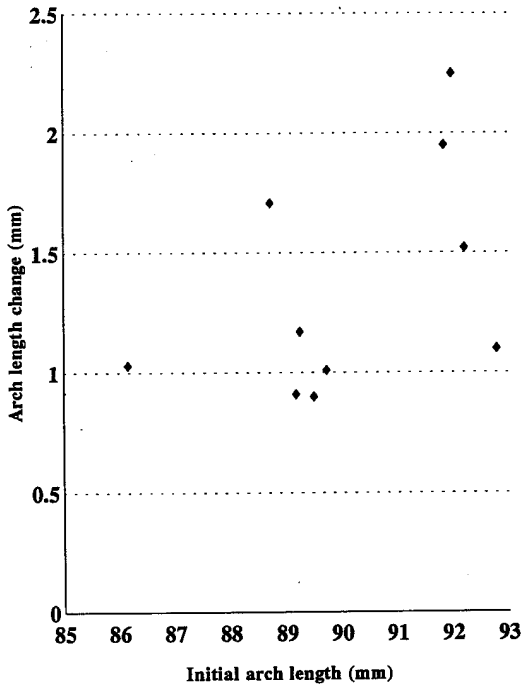

FIG. 6 Natural teeth—changes in arch length.

moves palatally. However, if the incisors are triangular in shape the contact points will remain more incisal and there will be little movement of these points palatally. Consequently, the increase in arch length change will not be so great. Conversely, if a small tooth is parallel-sided, although it may have a proportionately narrower contact point, there will be a larger component of movement of the contact point gingivally as the tooth becomes more proclined. This, in turn, will lead to greater palatal movement of the contact point/area, thereby increasing the additional space requirement in the arch. The unknown factor is what contribution does each of these variables make to the arch length change. This is extremely difficult to assess not only because of the complex anatomy of the contact area, but also because of its instability as the contact area moves with the slightest alteration in position of the teeth to one another. Nevertheless, the qualitative assessment shows that a greater change in arch length for a given change in inclination is found in larger and/or parallel-sided incisors, and least changes are found in smaller and/or triangular-shaped teeth.

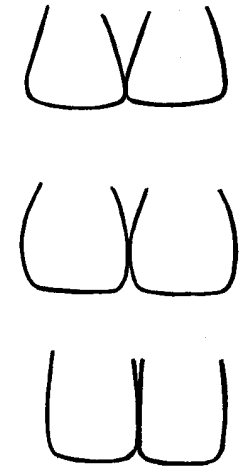

FIG. 7 (a) Triangular-shaped teeth. (b) Barrel-shaped teeth. (c) Parallel-sided teeth

The effect of the incisor inclination on arch length will also depend on the arch shape (Hussels and Nanda 1987). Where there are large teeth, the contact points will be further round the arc of the anterior section of the archwire, thereby producing a comparatively narrow arch form for these teeth. In comparison, when the incisors are small they will effectively take up less of an arc of a circle and so the teeth will lie on the flatter part of the anterior arch. Using a mathematical model, Hussels and Nanda have also shown that teeth lying on a large arc of a circle produce a proportionately smaller arch length change. Indeed, if the archform were a straight line, a change in inclination would have no impact on arch length. Therefore, for a fixed arch form, where teeth are in contact, incisors which are large in the mesiodistal dimension will produce a greater difference in the arch length for a given inclination change and this change is not solely dependent on the contact area or shape of the tooth.

Clinical Implications

The inclination changes were considered to be of clinical significance because a 14-degree change in the inclination of the maxillary central incisors might be produced during treatment. In comparison, the 24-degree variation between the Roth value bracket when inverted or correctly orientated might represent the correction of a more severe Class II division 2 malocclusion. Therefore, if additional upper

incisor torque is required, the posterior teeth may require further distal movement in order to maintain a fully corrected incisor relationship. Both the torque and the molar positions will produce increased demands on anchorage and space during treatment, and should be assessed in the treatment planning stages. The additional space requirement may then be incorporated into a space analysis in order to prevent either a compromised result or problems over anchorage control towards the end of treatment.

Where there is a tooth size disproportion in the dental arches, an increase in inclination and angulation of the teeth in the arch, where tooth structure is deficient, can help to take up space and camouflage the space discrepancy. However, in clinical practice, the ideal amount of palatal root torque placed in the upper incisors should consider not only the dental arch space implication, but more importantly the effect that the upper incisor labial face inclination has on facial aesthetics.

Conclusions

1. There is an increase in the dental arch length when the inclination of the acrylic maxillary incisors is increased in relation to the occlusal plane. This increase is not directly proportional to the degree of inclination.
2. The space requirement in the maxillary labial segment differs, depending on which bracket prescription series is used. There is a greater space requirement when using the Roth series of brackets on 321|123 in comparison with the Andrews' series on 321|123.
3. The increased change in arch length with an increase in inclination was reproduced when using stone casts of natural incisors, duplicated from patients' models.
4. There was a large variation in the space requirement when altering the inclination of the natural incisors due to their wide range in shape and size. All the arch length changes found in the natural teeth were greater than those found in the acrylic ones.
5. Triangular-shaped natural incisors appeared to produce least change in the arch length for a given change in inclination, whereas those teeth that were parallel-sided produced a proportionately larger change. Barrel-shaped teeth produced an intermediate amount of change.
6. There is a great variation in the space requirement of patients' teeth as their inclination is altered. In order to quantify this space requirement, a change in the order of 1 mm can be expected when the inclination of the 21|12 is altered for each 5 degrees for an 'average' set of incisors. However, the exact amount will vary with the shape and size of the incisors. This allowance should be included in a space analysis when planning treatment for a patient.

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