

Bimaxillary Morphometry of Patients with Class II Division 1 Malocclusion Treated with Twin Block Appliances

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Abstract: To assess changes in bimaxillary morphology in patients with Class II division 1 malocclusion treated using Twin Block appliances (TBA), pre- and posttreatment lateral cephalographs of 100 patients seven to 16 years of age were compared. The patients were divided into four groups: (1) prepubertal boys (mean treatment time; 13.6 ± 4.0 months), (2) adolescent boys (20.1 ± 7.7 months), (3) prepubertal girls (12.3 ± 1.4 months), and (4) adolescent girls (22.3 ± 6.7 months). Five landmarks were digitized on pre- and posttreatment cephalographs for all groups, and the resulting configurations were analyzed using linear analysis, Euclidean Distance Matrix Analysis (WinEDMA), and Thin Plate Spline (TPS) analysis. Results of linear analysis indicated anteroposterior midfacial distances generally increased in all groups. In contrast, WinEDMA indicated that midfacial distances proportionately decreased in all groups treated with TBA. Graphical analysis with TPS showed anteroposterior compression of the configurations, most marked in the region of Prosthion. The affine components of the configurations following the TBA treatment indicated little deformation, but the nonaffine components demonstrated posterior displacement of Prosthion. Thus, improvements in facial balance following TBA treatment are associated with a relative restriction of anterior displacement within the midfacial complex as well as maxillary dento-alveolar effects. Orthodontic treatment methods exerting growth-inhibitory effects within the maxilla may be useful in the correction of Class II division 1 malocclusions. (*Angle Orthod* 2002;72:402–409.)

Key Words: Geometric morphometrics; Euclidean distance matrix analysis; Thin-plate spline

INTRODUCTION

Functional appliances are thought to correct malocclusions by guiding and directing the movement of the jaws and teeth. The success of treatment depends upon patient cooperation, as this has a direct correlation with the extent of correction of the malocclusion. The Twin Block Appliance (TBA) is a functional appliance used in the correction of Class II malocclusions,¹ and has been described by patients as being comfortable to wear.² The TBA can give good results relatively quickly, depending on patient cooperation,³ and has been considered to be advantageous when compared with other types of functional appliances such as the Bass or Bionator appliances.³ It is perhaps for these reasons that the TBA has become a popular choice

of corrective appliance for growth guidance in Class II division 1 malocclusion.^{4,5}

The TBA consists of mandibular and maxillary bite blocks that have inclined edges, meeting at an interlocking angle, to induce occlusal forces that guide the growth of the dental arches.² It has been claimed that this method of treatment stimulates growth of the mandible while simultaneously restricting growth of the maxilla, particularly if combined with extra-oral traction.¹ In previous studies, the mandible has been putatively shown to increase in length and height following TBA treatment,^{3,6–9} but there is equal evidence against this hypothesis.^{10–12}

There have been few studies focused on bimaxillary changes associated with TBA. Most previous studies have analyzed the pre- and posttreatment form changes of the mandible using conventional cephalometry. These procedures measure linear distances or angles without relating alterations in distance or angle to the whole form change,¹³ and do not take biological variation in size or inequality of variance into account. Geometric morphometrics, however, is a more recent development in the field of shape change analysis.¹⁴ It eliminates the problems of variation in size and inequality of variance by normalizing forms, registering them with respect to one another, and then utilizing Cartesian coordinates of homologous landmarks to identify

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morphologic changes. Geometric morphometric techniques have previously been used in clinical studies.¹⁵⁻¹⁹

In this investigation, longitudinal studies comparing bi-maxillary skeletal configurations in patients prior to, and on completion of, TBA treatment were undertaken in order to assess changes following treatment and to determine how the TBA affects growth of the facial complex. Thus, the null hypothesis tested in this study is that treatment using the TBA has no effect on the facial configurations of patients with Class II division 1 malocclusions. Therefore, the aim of this study is to assess changes in facial morphology following TBA treatment using geometric morphometrics. The changes will be localized to focus on areas that undergo significant morphological changes following TBA treatment. Rejection of the null hypothesis will provide evidence in the debate on how the TBA achieves its outcomes when used in combination with extra-oral traction.

MATERIALS AND METHODS

Sample

After obtaining consent, pre- and posttreatment lateral cephalographs of 46 consecutive children seven to 11 years of age with Angle's Class II division 1 malocclusion treated with TBA were retrieved from an orthodontic practice. Lateral cephalographs of an additional 54 consecutive patients 12 to 16 years of age, with a similar Class II relationship treated with TBA, were also obtained. The anonymity of the patients was protected as none were identified specifically. Clinically, all patients had a large overjet, no missing teeth (except third molars) and a distal occlusion related to a moderate to severe Class II skeletal relationship, although this was not quantified. Exclusion criteria for the study were a history of previous orthodontic treatment, oral or maxillofacial surgery (or both), any facial injury that resulted in hospital attendance, or any other congenital craniofacial malformation.

The cephalographs of the Scottish patients who participated in this retrospective study (44 boys and 56 girls) were divided into four groups based on age and sex. It was presumed that all radiographs were taken from subjects exhibiting left-right symmetry and that the central x-ray passed along the transmeatal axis when the teeth were in occlusion. The magnification of each film was standardized to 8%. The chronological age was assumed to match developmental age in this study, as carpal radiographs were not available. Group PB consisted of 16 prepubertal boys with a mean age of 10.2 ± 0.9 years at the beginning of treatment, and had a mean treatment time of 13.6 ± 4.0 months. Group AB consisted of 28 adolescent boys with a mean age of 12.6 ± 0.9 years initially, and a mean treatment time of 20.1 ± 7.7 months. Group PG consisted of 30 prepubertal girls with a mean age of 10.8 ± 1.4 years initially, and a mean treatment time of 12.3 ± 1.4 months. Group AG consisted of 26 adolescent girls with a mean age of $12.2 \pm$

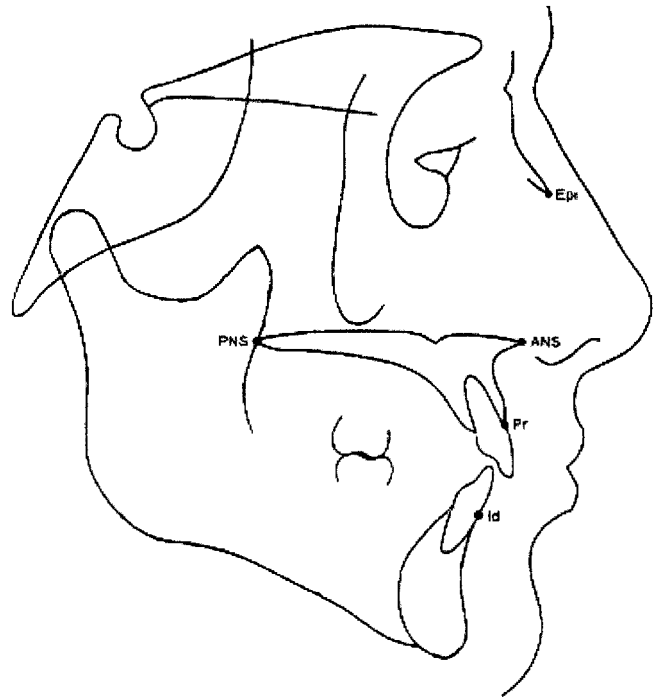


FIGURE 1. Definitions of midfacial landmarks employed. (1) Epinasale (Epi): inferiormost point on tip of the nasal bone; (2) Posterior Nasal Spine (PNS): posteriormost point on posterior nasal spine; (3) Infradentale (Id): anterosuperior point of mandibular alveolus; (4) Prosthion (Pr): anteroinferior point of maxillary incisor alveolus; and (5) Anterior Nasal Spine (ANS): anteriormost point on anterior nasal spine.

0.7 years at the beginning of treatment, and a mean treatment time of 22.3 ± 6.7 months. All TBA treatments included the use of extra-oral traction applied by a straight pull to a conventional head cap worn every night for 8-10 hours, using 200 g distal extraoral force on each side. Using a Concorde facebow with intermaxillary elastics, ≈ 150 g intermaxillary force was used to restrict downward and forward maxillary growth. The achievement of a Class I occlusion denoted the endpoint of treatment.

Methods

Five homologous, midsagittal, facial landmarks on the pre- and posttreatment lateral cephalographs were digitized (Figure 1), using appropriate software. To determine whether pre- and posttreatment parameters differed, conventional statistical analysis was carried out by calculation of 5 facial, linear distances between homologous landmarks. The mean, pre- and posttreatment lengths were compared statistically using paired *t*-tests.

To determine whether facial landmark configurations differed before and after treatment, geometric morphometric analyses were performed on the data. First, Procrustes superimposition was implemented using a generalized rotational fit (GRF) program on a personal computer.²⁰ The

GRF program normalizes data by translating, rotating, and scaling landmark configurations in a group and registering them with respect to one another.²⁰ This procedure ensures that the effects of variation in size within the groups are eliminated as all configurations are scaled to an equivalent size. The GRF program generated the mean facial configuration for each group of patients using Procrustes superimposition to provide a least squares fit of the configurations.

In addition, Euclidean Distance Matrix Analysis (WinEDMA)²¹ was performed on the facial configurations. Euclidean Distance Matrix Analysis is a coordinate free statistical program that takes into account inequality of variance of samples, and indicates which interlandmark distances are contributing to the form change. This multivariate method of statistical analysis attempts to describe change in form in terms of the entire shape, and localizes areas of major shape change.²² Using the mean, facial configurations, WinEDMA was used to calculate Form Matrices for the pre- and posttreatment data. The Form Matrices were then compared by the calculation of Form Difference Matrices. One Form Matrix acts as the numerator or reference sample; the other is the denominator. For example, if no difference exists between two landmarks, the relevant Form Difference Matrix value would be 1.00. Consequently, values of >1 or <1 indicate that distances between landmarks differ. For example, a value of 1.05 indicates that the numerator configuration distance is 5% longer than that of the denominator configuration. For WinEDMA, facial form comparisons were undertaken that employed the five-landmark configuration shown in Figure 1. The statistical method used to test the result was a nonparametric bootstrap method,²² and the P values obtained relate to the likelihood of no morphological difference existing between the two configurations.²²

Thin Plate Spline (TPS) analysis is another useful geometric technique as results are presented in a graphical form, allowing visualization of form changes. Thin plate splines are analogous to infinitely thin sheets of metal that extend infinitely in all directions.²³ The transformation grids (thin plate splines) consist of affine (uniform) and nonaffine (nonuniform) components. Affine changes consist of translation, scaling, rotation, and require no theoretical bending energy, as they correspond to tilting or lifting (not bending) of the plate.²³ Nonaffine changes are reported in terms of partial warps (PW). The number of PW is 3 less than the number of landmarks in the configuration. The extent to which each PW contributes to the whole nonaffine transformation is described in terms of eigenvalue, magnitude, and bending energy. A high eigenvalue represents a localized transformation, as opposed to a transformation affecting the whole form. A high magnitude is representative of a change affecting the entire configuration. Bending energy reflects the power of the transformation concordant with the analogy to the metal sheet; small, localized changes have

TABLE 1. Linear Analysis of Mean Oblique Midfacial Distance (\pm SD)

| | Pretreatment | | Post treatment | | Significance |
|----------|--------------|-----|----------------|-----|--------------|
| | Mean Length | SD | Mean Length | SD | |
| Group PB | | | | | |
| PNS-Epi | 5.05 | .22 | 5.18 | .18 | .001 |
| PNS-ANS | 4.06 | .20 | 4.13 | .18 | NS |
| PNS-Pr | 4.05 | .21 | 4.03 | .14 | NS |
| PNS-Id | 3.91 | .32 | 4.28 | .21 | .001 |
| Group AB | | | | | |
| PNS-Epi | 5.20 | .24 | 5.46 | .35 | .001 |
| PNS-ANS | 4.24 | .14 | 4.36 | .20 | .001 |
| PNS-Pr | 4.25 | .17 | 4.27 | .18 | NS |
| PNS-Id | 4.13 | .29 | 4.52 | .19 | .001 |
| Group PG | | | | | |
| PNS-Epi | 5.03 | .29 | 5.16 | .30 | .001 |
| PNS-ANS | 4.06 | .17 | 4.14 | .20 | .001 |
| PNS-Pr | 4.01 | .18 | 4.01 | .19 | NS |
| PNS-Id | 4.00 | .22 | 4.20 | .20 | .001 |
| Group AG | | | | | |
| PNS-Epi | 5.17 | .27 | 5.29 | .24 | .001 |
| PNS-ANS | 4.10 | .18 | 4.18 | .19 | .003 |
| PNS-Pr | 4.04 | .17 | 4.02 | .18 | NS |
| PNS-Id | 3.96 | .20 | 4.25 | .19 | .001 |

PB indicates prepubescent boys; SD, standard deviation; NS, not significant; AB, adolescent boys; PG, prepubescent girls; and AG, adolescent girls.

greater bending energies than widespread deformations. In this way, TPS transformations are geometric descriptions of shape change, ranging from the entire form to specific localized changes.²⁴ Thus, a graphical analysis of form changes was undertaken using TPS analysis.

RESULTS

Linear Analysis

Duplicate digitization indicated that digitization errors were not significant ($P > .05$). Therefore, all landmark data were utilized and considered for all three methods of analysis. Generally speaking, the results of cephalometry, WinEDMA, and TPS broadly complemented each other.

Linear analysis of the oblique midfacial distance PNS-Epi indicated that this distance had significantly increased following TBA treatment ($P < .01$) in all groups (Table 1). Similarly, following TBA treatment, the anteroposterior length of the midfacial complex (PNS-ANS) was found to increase significantly in adolescent boys and girls, and prepubertal girls. The increase in prepubertal boys, however, was nonsignificant (Table 1). In contrast, the midfacial length (PNS-Pr) was not altered significantly following TBA treatment in any of the four groups, but the length PNS-Id increased in all groups treated with the TBA (Table 1).

TABLE 2. Sorted Form Difference Matrices

| Group PB** | | | Group AB** | | | Group PG** | | | Group AG** | | |
|------------|-----|-------|------------|-----|-------|------------|-----|-------|------------|-----|-------|
| PNS | Pr | 0.940 | PNS | Pr | 0.910 | ld | Pr | 0.938 | PNS | Pr | 0.914 |
| PNS | Epi | 0.961 | PNS | ANS | 0.937 | PNS | Pr | 0.966 | ANS | Epi | 0.932 |
| PNS | ANS | 0.965 | Pr | ANS | 0.956 | ANS | Epi | 0.988 | ld | Pr | 0.941 |
| ANS | Epi | 0.971 | PNS | Epi | 0.957 | PNS | ANS | 0.989 | PNS | Epi | 0.943 |
| Pr | Epi | 0.971 | Pr | Epi | 0.982 | ld | Epi | 0.992 | PNS | ANS | 0.955 |
| Pr | ANS | 0.973 | ld | Pr | 0.984 | ld | ANS | 0.993 | Pr | Epi | 0.967 |
| ld | Epi | 0.986 | ANS | Epi | 0.996 | PNS | Epi | 0.994 | ld | Epi | 0.970 |
| ld | Pr | 0.988 | ld | ANS | 0.997 | Pr | Epi | 1.005 | PNS | ld | 0.991 |
| ld | ANS | 0.997 | ld | Epi | 1.001 | PNS | ld | 1.016 | ld | ANS | 1.004 |
| PNS | ld | 1.007 | PNS | ld | 1.007 | Pr | ANS | 1.034 | Pr | ANS | 1.037 |

PB indicates prepubescent boys; AB, adolescent boys; PG, prepubescent girls; and AG, adolescent girls.

** $P < .01$.

WinEDMA

The WinEDMA showed significant statistical differences ($P < .01$) between homologous distances in the facial region. Table 2 shows the sorted Form Difference Matrices for the study.

In contrast to the size-incorporated measurements (Table 1), the oblique distance PNS-Epi showed a relative decrease of 4% to 5% in groups PB, AB, and AG, but remained unchanged in group PG (Table 2). Similarly, the anteroposterior length of the midfacial complex (PNS-ANS) relatively decreased by 3% in prepubertal boys, by 6% in adolescent boys, by 4% in adolescent girls, but remained unchanged in prepubertal girls. These findings contrast with the linear measurements (Table 1). The relative anteroposterior length of the midfacial complex (PNS-Pr) was reduced on completion of TBA treatment, by 3% to 6% in groups PB and PG, respectively, and by 9% in the adolescent groups (groups AB and AG). This finding contrasts with the results obtained from linear measurements that indicated that the midfacial length PNS-Pr was unaltered following TBA treatment (Table 1). Similar to the linear measurements, however, the length PNS-ld increased slightly in all treated groups, but remained unchanged in Group AG (Table 2).

Thin Plate Spline

Figure 2 shows the transformation grids for the prepubertal boys. The Total Spline shows anteroposterior compression of the facial configuration, most marked in the region of prosthion (landmark 4). The affine component of facial transformation following TBA treatment demonstrates that the facial complex is slightly skewed. In the nonaffine component, the posterior displacement of prosthion is highlighted.

Figure 3 shows the transformation grids for the adolescent boys. The Total Spline shows marked anteroposterior compression of the facial configuration in the region of prosthion (landmark 4). The affine transformation following TBA treatment demonstrates a slight clockwise

rotation. In the nonaffine component, the posterior displacement of prosthion is seen also. Thus, transformation grids of the adolescent boys indicate that the facial complex in the region of prosthion is subject to posterior displacement.

Figure 4 shows the transformation grids for the prepubertal girls. The Total Spline shows slight anteroposterior compression of the facial configuration in the region of prosthion (landmark 4). The affine component demonstrates the facial complex is slightly skewed. The nonaffine component demonstrates posterior displacement of prosthion. Thus, transformation grids of the prepubertal girls indicate that the facial complex in the region of Prosthion is subject to posterior displacement.

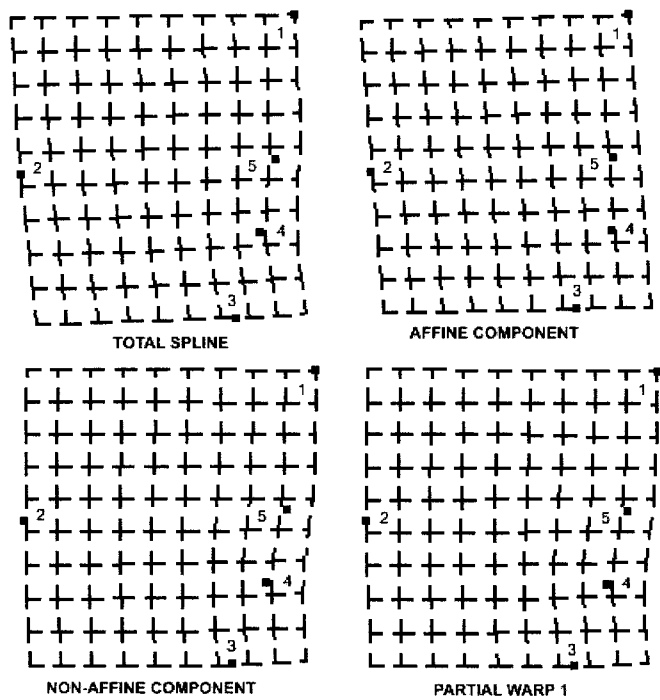
Figure 5 shows the transformation grids for the adolescent girls. The Total Spline shows anteroposterior compression of the facial configuration. The affine component demonstrates a slight anterior shear of the facial complex. In the nonaffine component, the posterior displacement of prosthion (landmark 4) is demonstrated. Thus, transformation grids of the adolescent girls indicate that the facial complex in the region of prosthion is subject to posterior displacement.

In general, TPS analysis complements the results of WinEDMA, indicating that regions of the facial complex are restricted from being displaced anteriorly and that prosthion is the landmark affected most.

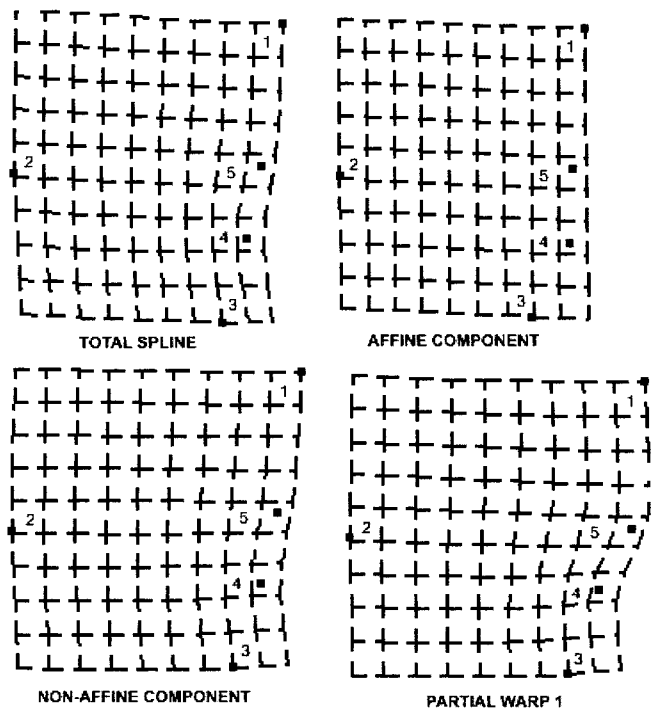
DISCUSSION

This study investigated the correction of Class II division 1 malocclusion using TBA treatment with extra-oral traction. A combination of conventional, WinEDMA, and TPS analyses was employed in this retrospective study, even though this is not in keeping with traditional approaches. Specifically, TPS analysis was performed on mean configurations after the elimination of size using a generalized rotational fit so that the linear and TPS analyses were carried out on group means. Nevertheless, cephalographic data for a well-matched control group were not available and it

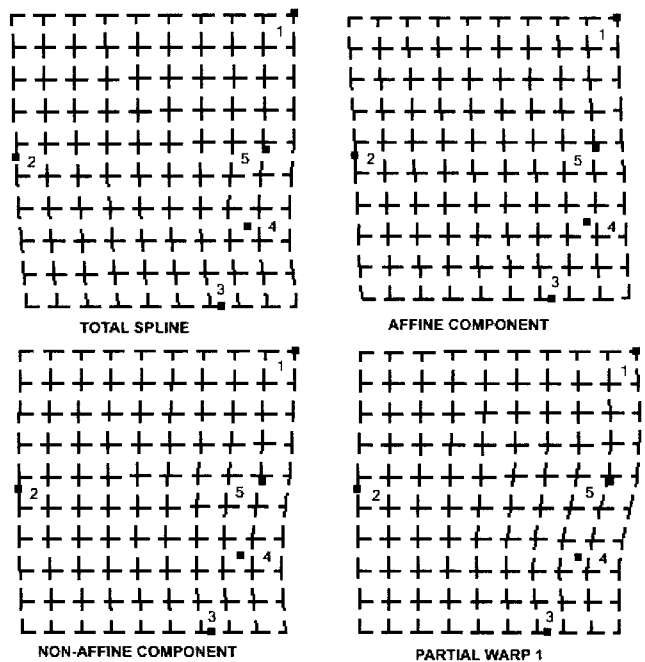
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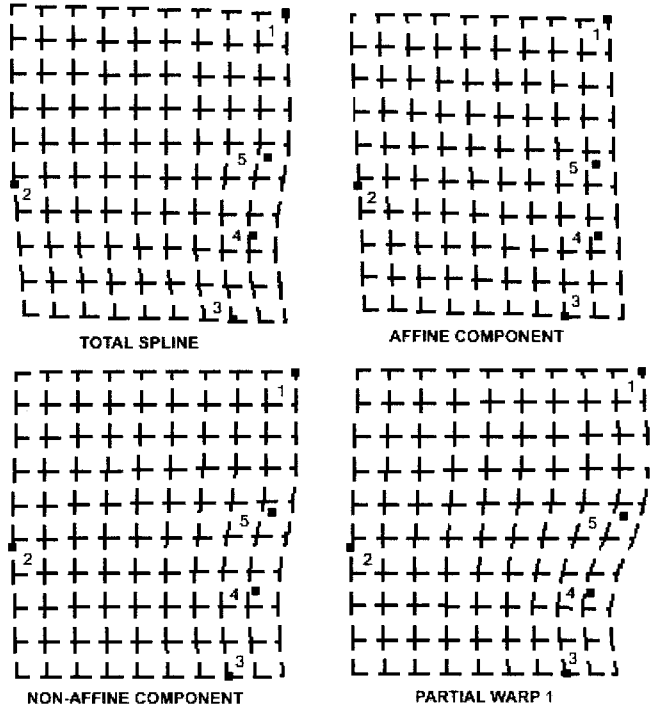


FIGURE 2. Transformation grids obtained when comparing pre- and postoperative midfacial configurations using Thin-plate spline analysis of prepubertal boys treated with TBA. The total spline shows anteroposterior compression of the midfacial configuration, most marked in the region of prosthion (4). The affine component demonstrates the midfacial complex is slightly skewed. In the nonaffine component, the posterior displacement of prosthion (4) is highlighted. Partial Warp 1 clearly demonstrates prosthion (4) being displaced posteriorly.

FIGURE 3. Transformation grids obtained when comparing pre- and postoperative midfacial configurations using Thin-plate spline analysis of adolescent boys treated with TBA. The total spline shows localized anteroposterior compression of the midfacial configuration in the region of prosthion (4). The affine transformation demonstrates a slight clockwise rotation. In the nonaffine component, the posterior displacement at prosthion (4) is clearly seen. Partial Warp 1 clearly demonstrates prosthion (4) being displaced posteriorly.

was not possible to separate the effects of TBA treatment from the effects of growth. As well, although tipping of the incisors can influence the landmarks prosthion and infradentale, there were no other midsagittal skeletal landmarks available in this vicinity, and the results are interpreted with caution under the conditions of parsimony. Similarly, the behavior of other landmarks such as epinasale with respect to cranial base are not considered in this particular study as discussion of these points might obfuscate the findings. Despite these potential sources of error, the techniques employed here have previously been used in clinical studies,^{12,25,26} and, generally speaking, the results of cephalometry, WinEDMA, and TPS found in this study broadly complemented each other.

First, linear analysis of the oblique midfacial distance PNS-Epi indicated that this distance had significantly increased following TBA treatment in all groups. Similarly, the anteroposterior length of the midfacial complex (PNS-ANS) was found to generally increase. These increases are to be expected in growing children and suggest that TBA has little or no effect on these midfacial parameters, concurring with previous studies that report no restriction of midfacial growth following TBA treatment.^{8,9,27} Indeed, the maxillomandibular length PNS-Id increased in all groups treated with the TBA. Thus, while it appears that there is no restriction of midfacial growth, the linear analysis supports the concept of anterior mandibular displacement in association with TBA treatment,²⁸ even though tipping of the incisors can influence landmarks such as infradentale and prosthion. Nevertheless, the anteroposterior midfacial length (PNS-Pr) was unchanged following treatment with TBA. Therefore, it appears that TBA might restrain specific regions of the midface (PNS-Pr) while enhancing others (PNS-Id). Moreover, the distance PNS-ANS representing maxillary length increased significantly in three of the four groups treated with TBA, suggesting that size-incorporated data masks the subtler form-change.

In support of the above contention, using WinEDMA the anteroposterior midfacial lengths PNS-Epi and PNS-ANS generally decreased in relative size. However, the relative anteroposterior length of the midfacial complex (PNS-Pr) was reduced on completion of TBA treatment, contrasting with the results obtained from linear measurements above, which suggest that the midfacial length

(PNS-Pr) was unaltered following TBA treatment. Similar to the linear measurements, the length PNS-Id increased slightly in nearly all treated groups. Taken together, these findings contrast with previous conventional studies that found TBA treatment had no growth-restricting effect on the midface; support the concept that, left untreated, Class II jaws transpose ventrally²⁹; and support the notion that the TBA enhances mandibular advancement. Accordingly, WinEDMA indicated that the anteroposterior midfacial length (PNS-Pr) was relatively shorter on completion of TBA treatment, but showed growth increases during treatment, as might be expected.²⁹ These findings suggest that the use of extra-oral traction with TBA restricts specific regions of the midface (PNS-Pr) while permitting anterior advancement of others associated with the mandible (PNS-Id). These results corroborate the findings of a previous study that demonstrated an association between TBA treatment and restriction of forward growth of the facial complex, contributing to a more balanced facial form.³ Nevertheless, it should be emphasized that the restriction of forward growth of the maxilla is relative (ie, the midfacial length is only proportionately smaller in all groups treated with TBA).

Visual inspection of the TPS transformation grids of all four groups treated with TBA confirmed that the facial complex in the region of prosthion (landmark 4, Figures 2–5) was prevented from being displaced anteriorly, even though no statistical testing was undertaken on the splines as this was considered to be outside the scope of this study. Nevertheless, this finding suggests that the limitation of forward growth of prosthion is attributable to TBA treatment when combined with extra-oral traction. Moreover, the transformation grids of the treated patients did not show evidence of clockwise mandibular rotation, which sometimes occurs if normal midfacial growth is impeded. However, the concordance of findings of WinEDMA and TPS analyses demonstrates that the midfacial complex was restricted from anterior displacement resulting from TBA treatment. This restraint contrasts with previous conventional studies that found TBA treatment had no growth-restricting effect on the midface.^{8,9,27} Thus, it is likely that linear analysis of size-incorporated data masks specific regions of anterior restraint of the facial complex in patients treated with the TBA.

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FIGURE 4. Transformation grids obtained when comparing pre- and postoperative midfacial configurations using Thin-plate spline analysis of prepubertal girls treated with TBA. The total spline shows some anteroposterior compression of the midfacial configuration in the region of prosthion (4). The affine component demonstrates the midfacial complex is slightly skewed. The nonaffine component demonstrates posterior displacement of prosthion (4). Partial Warp 1 clearly demonstrates prosthion (4) being displaced posteriorly.

FIGURE 5. Transformation grids obtained when comparing pre- and post-operative midfacial configurations using Thin-plate spline analysis of adolescent girls treated with TBA. The total spline shows localized anteroposterior compression of the midfacial configuration. The affine component demonstrates a slight anterior shear of the midfacial complex. In the nonaffine component, the posterior displacement of prosthion (4) is demonstrated. Partial Warp 1 clearly demonstrates prosthion (4) being displaced posteriorly.

Both WinEDMA and TPS analyses indicated that TBA treatment was associated with restriction of anterior advancement of specific facial regions. Both procedures demonstrated that prosthion was a pivotal landmark, being prevented from being displaced anteriorly while ANS and infradentale were not restricted from forward translation. It is recognized, however, that TBA treatment achieves correction of Class II malocclusion through some dento-alveolar effects. For example, it has been reported that dento-alveolar effects contribute to overjet correction²⁸ and this improvement may be achieved by maxillary incisor retroclination.²⁷ Others⁸ have also reported retroclination of the maxillary incisors and a reduction in upper incisor angle⁹ following TBA treatment. Similarly, another report³⁰ noted overjet reduction through improvement in dental base relationship. Therefore, the posterior displacement of prosthion demonstrated here is likely to be associated with the incisor correction.

CONCLUSION

Our findings support the contention that orthodontic treatment methods exerting a growth-inhibitory effect on the maxilla, such as the TBA with extra-oral traction, may be useful in the correction of Class II division 1 malocclusions. The results obtained in this study led to the rejection of the null hypothesis that treatment using the TBA has no effect on the skeletal facial morphology of patients with Class II division 1 malocclusion. We conclude that, although TBA treatment may affect the position of the mandible and the upper and lower incisor teeth, modulation of growth in specific regions of the midfacial complex may also contribute to the attainment of well-balanced facial profiles.

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