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Morphometric analysis of treatment effects of bone-anchored maxillary protraction in growing Class III patients

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SUMMARY The aim of the present morphometric investigation was to evaluate the effects of bone-anchored maxillary protraction (BAMP) in the treatment of growing patients with Class III malocclusion. The shape and size changes in the craniofacial configuration of a sample of 26 children with Class III malocclusions consecutively treated with the BAMP protocol were compared with a matched sample of 15 children with untreated Class III malocclusions. All subjects in the two groups were at a prepubertal stage of skeletal development at time of first observation. Average duration of treatment was 14 months. Significant treatment-induced modifications involved both the maxilla and the mandible. The most evident deformation consisted of marked forward displacement of the maxillary complex with more moderate favourable effects in the mandible. Deformations in the vertical dimension were not detected. The significant deformations were associated with significant differences in size in the group treated with the BAMP protocol.

Introduction

The literature reports a series of preliminary investigations (De Clerck *et al.*, 2009, 2010; Cevidanes *et al.*, 2010) that have indicated the favourable effects of maxillary protraction in the late mixed or permanent dentition phases (at ages 10 –12 years) with innovative treatment techniques that use bone anchors and Class III elastics. The use of temporary anchorage devices in maxillary protraction has increased over recent years (Singer *et al.*, 2000; Enacar *et al.*, 2003; Hong *et al.*, 2005; Kircelli and Pektas, 2008; De Clerck *et al.*, 2009; Cevidanes *et al.*, 2010; De Clerck *et al.*, 2010) but have been assessed in controlled studies only in very recent times. De Clerck *et al.* (2010) and Cevidanes *et al.* (2010) have shown the significantly greater amount of advancement of the maxillary structures in subjects treated with bone-anchored maxillary protraction (BAMP) when compared with both untreated Class III controls and subjects treated with rapid maxillary expansion and face mask therapy. All these contributions, however, used conventional cephalometrics, which fails to differentiate between changes in size versus shape in the regions affected by treatment (Bookstein, 1982, 1991). The conventional metrical approach to the description of morphological forms, and conventional cephalometrics in particular, may be insufficient for the analysis of size and shape changes of complex anatomical forms, such as the craniofacial structures (Moyers and Bookstein, 1979; Moyers *et al.*, 1979).

New descriptive methods of shape and shape changes have been developed and implemented as major improvements when compared to conventional cephalometrics: Procrustes superimposition techniques, Euclidean distance matrix analysis, finite element morphometry/finite element scaling analysis, and thin-plate spline (TPS) analysis (McIntyre and Mossey, 2003). TPS analysis deforms one landmark configuration into another, illustrating this shape change as the deformation of a grid while allowing for statistical comparisons (Bookstein, 1991). TPS has specific cephalometric indications for displaying shape differences due to orthodontic treatment techniques or growth-related changes (McIntyre and Mossey, 2003). In fact, TPS analysis has been applied to the study of growth changes in treated and untreated subjects with different types of malocclusions (Singh *et al.*, 1997; Baccetti *et al.*, 1999; Lux *et al.*, 2001; Franchi *et al.*, 2001, 2007; Alarashi *et al.*, 2003; Chang *et al.*, 2005).

The purpose of the present controlled study was to evaluate the effects of the BAMP protocol by means of TPS morphometric approach. In this paper, TPS was used in order to assess active treatment effects both in terms of size and in terms of shape changes in the dentoskeletal facial structures of consecutively treated patients compared to growth changes in a matched control group of untreated subjects with Class III malocclusion.

Subjects and methods

Subjects

Class III treated group. The treated group consisted of 26 patients (14 females and 12 males) with dentoskeletal Class

III malocclusion treated consecutively by a single operator (HJDC) with the BAMP technique. Success of therapy at the end of the observation period was not a determinant factor for selection of patients as the treated sample was collected prospectively.

At the time of initial observation (T1), all patients had Class III malocclusion in the mixed or permanent dentitions characterized by Wits appraisal of −1 mm or less (mean: −4.8 ± 2.8 mm), anterior crossbite, or incisor end-to-end relationship and Class III molar relationship. All patients were of Caucasian ancestry, with a prepubertal stage of skeletal maturity according to the cervical vertebral maturation method (CS1–CS3) at T1 (Baccetti *et al.*, 2005). Twenty-one of the 26 patients were still prepubertal at the end of treatment, T2 (CS1–CS3), while five patients showed a CS4 at T2. Mean age at T1 for the BAMP sample was 11.9 ± 1.8 years and it was 13.1 ± 1.7 years at T2. Mean duration of T1–T2 interval was 1.2 ± 1.0 years.

Class III control group. A control group of 15 untreated subjects (7 females and 8 males) with dentoskeletal Class III malocclusion was obtained from the Department of Orthodontics of the University of Florence. The control group matched the treated group as to type of dentoskeletal disharmony, skeletal maturation, gender distribution, and mean duration of observation intervals. All subjects were of Caucasian ancestry, with a prepubertal stage of skeletal maturity according to the cervical vertebral maturation method (CS1–CS3) at T1 (Baccetti *et al.*, 2005). Thirteen of the 15 subjects were still prepubertal at the end of the observation period, T2 (CS1–CS3), while two subjects showed a CS4 at T2. Mean age at T1 for the control sample was 9.6 ± 1.6 years and it was 11.4 ± 1.6 years at T2. Mean duration of T1–T2 interval was 1.6 ± 1.0 years.

BAMP orthopaedic protocol

In each treated patient, four miniplates were inserted on the left and right infrazygomatic crest of the maxillary buttress and between the lower left and right lateral incisor and canine (Figure 1). Small mucoperiosteal flaps were elevated and the modified miniplates (Bollard; Tita-Link, Brussels, Belgium) were secured to the bone by two (mandible) or three (maxilla) screws (2.3 mm diameter–5 mm length; De Clerck *et al.*, 2009). The extensions of the plates perforated the attached gingiva near the mucogingival junction (Figures 2A and 2B). Three weeks after surgery, the miniplates were loaded. Class III elastics applied an initial force of about 150 g on each side, increased to 200 g after 1 month of traction and to 250 g after 3 months. The patients were asked to replace the elastics at least once a day and to wear those 24 hours/day. In 14 cases after 2–3 months of intermaxillary traction, a removable bite plate was inserted in the upper arch to eliminate occlusal interference in the incisor region until correction of the anterior crossbite was obtained.

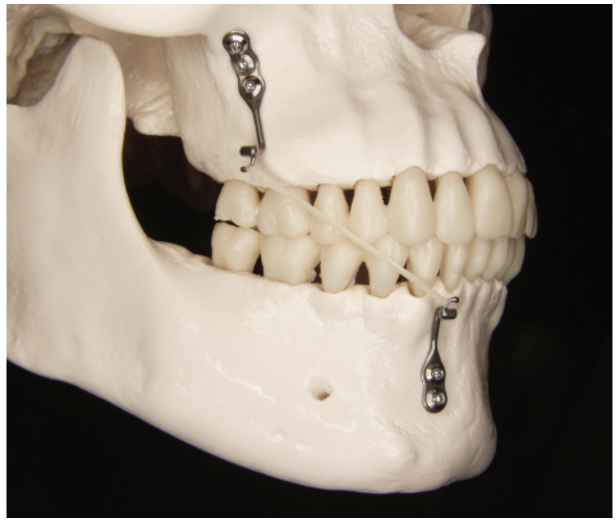

Figure 1 Miniplates for the BAMP protocol (lateral view on a dry skull model).

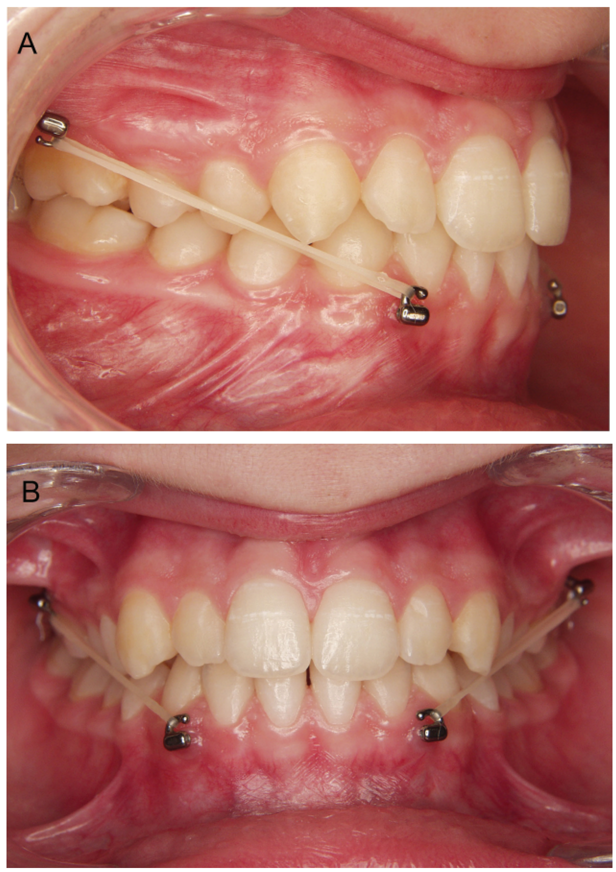

Figure 2 (A and B) Bone anchors and intermaxillary elastics of the BAMP protocol in a patient during the final phases of treatment (A, lateral view and B, frontal view).

TPS analysis

Lateral cephalograms for treated subjects in the study were extracted from cone beam computed tomograms (CBCTs), which were taken at T1 and T2. Scans were acquired using an iCat machine (Imaging Sciences International, Hatfield, Pennsylvania, USA) with a 16 × 22 cm field of view. The CBCTs were used to create synthetic lateral cephalograms with magnification of 7.5 per cent (Dolphin Imaging 10.5; Dolphin Imaging and Management Systems, Chatsworth, Califorina, USA; Cevidanes *et al.*, 2009; Ludlow *et al.*, 2009). The enlargement factor of the control cephalograms was very similar and no correction was made for enlargement in the analysis of the films. All cephalograms were digitally traced by two examiners, using the Dolphin 10.5 and Viewbox softwares (Viewbox 3.1; dHal, Kafissia, Greece).

The following homologous landmarks were digitized on the lateral films of all subjects at T1 and at T2: point T (the most superior point of the anterior wall of the sella turcica at the junction with tuberculum sellae), point TgEtm (point of tangency of the stable basicranial line to the lamina cribrosa of the ethmoid bone), FMN (fronto-maxillary-nasal suture), Point A (A), Point B (B), prosthion (Pr), infradentale (Id), gnathion (Gn), menton (Me), TgGo1 (point of tangency of the mandibular plane to the gonial region), gonion (Go), TgGo2 (point of tangency of the ramal plane to the gonial region), articulare (Ar), condylion (Co), centre of the condyle (Cs; i.e. a point equidistant from the anterior, posterior, and superior borders of the condyle head), pterygomaxillary fissure (Ptm), basion (Ba), anterior nasal spine (ANS), and posterior nasal spine (PNS; Figure 3).

TPS software (tpsRegr, Version 1.37, Ecology and Evolution; SUNY, Stonybrook, New York, USA) computed the orthogonal least-squares Procrustes average configuration of craniofacial landmarks in both treated and untreated Class III subjects at T1 and T2, using the

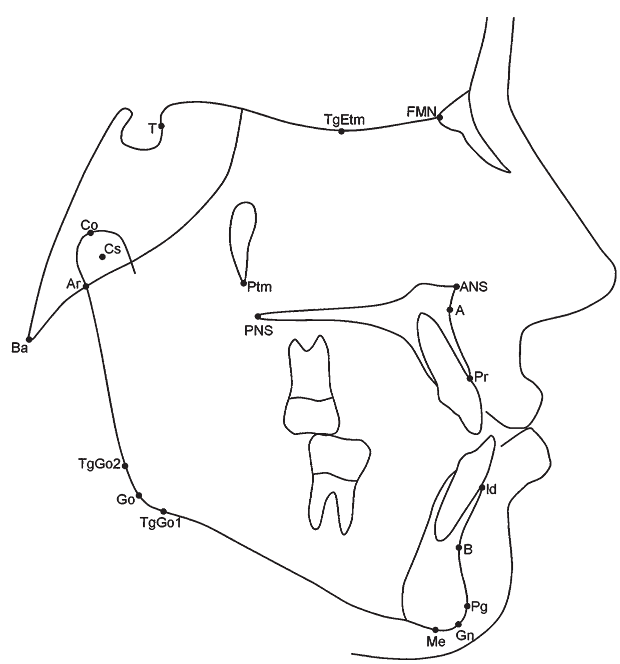

Figure 3 Landmarks used for morphometric analysis.

generalized orthogonal least-squares procedures described in Rohlf and Slice (1990).

Average configurations were calculated for the craniofacial region in the two groups, and they were subjected to TPS analysis by means of the following longitudinal comparisons:

1. BAMP sample at T1 versus BAMP sample at T2.
2. Untreated control sample at T1 versus untreated control sample at T2.

The visualization of the T1–T2 shape changes is performed by the TPS software both by means of transformation grids and by means of vectors. The length and orientation of the vectors are a direct expression of the amount and direction of the deformation, respectively, at a specific landmark. Statistical analysis of shape differences was performed by means of permutation tests with 1000 random permutations on Wilk's Lambda statistics.

Centroid size was used as the measure of the geometric size of each craniofacial region in all subjects and was calculated as the square root of the sum of the squared distances from each landmark to the centroid of each specimen's configuration of landmarks (Bookstein, 1991). Differences in size at the two developmental phases (T1 through T2) were tested by means of Wilcoxon tests ($P < 0.05$) for the longitudinal comparisons. Statistical computations for centroid size analysis were performed with computer software (SPSS, Release 12.0; SPSS Inc., Chicago, Illinois, USA). For those T1–T2 comparisons showing significant shape differences, a test for allometry checking for shape depending on size was carried out (tpsRegr, Version 1.37, Ecology and Evolution; SUNY).

To analyse the combined error of landmark location, tracing and digitization error of the method 20 lateral cephalograms selected randomly were retraced and remeasured within a week by the same operator (LF). The intraclass correlation coefficients (ICCs) varied between 0.916 and 0.999 for the landmarks used in TPS analysis. These ICC values indicated a high level of intraobserver agreement.

The assessment of the stages in cervical vertebral maturation (Baccetti *et al.*, 2005) on lateral cephalograms for each subject was performed by one investigator (TB) and then verified by a second (LF). Any disagreements were resolved to the satisfaction of both observers.

Results

The analysis of the longitudinal deformations of the craniofacial structures in the treated and control Class III samples showed significant T1–T2 differences in the BAMP group ($P = 0.011$; Figure 4), while T1–T2 deformations in the controls did not reach statistical significance ($P = 0.88$; Figure 5). In the BAMP group, the significant deformations induced by treatment consisted of a marked horizontal

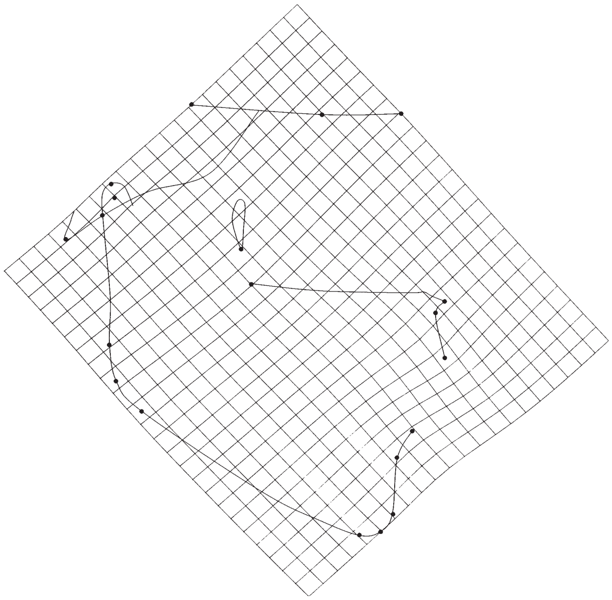

Figure 4 TPS grid deformation from T1 to T2 in the average configuration of the BAMP sample. The deformations are magnified X3.

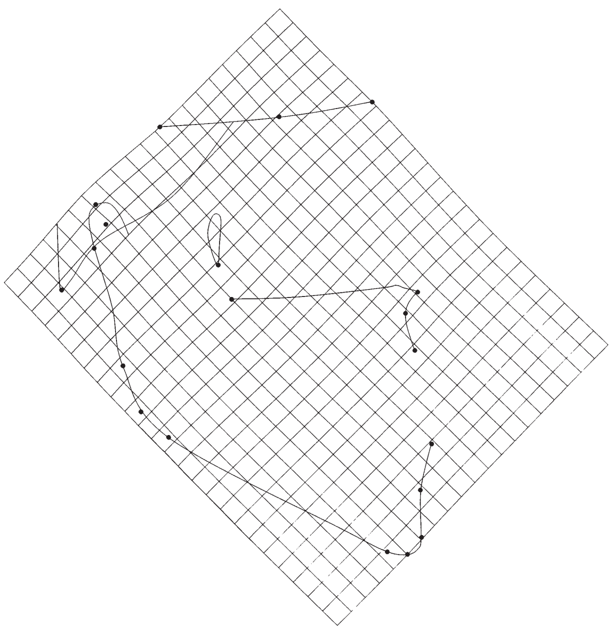

Figure 5 TPS grid deformation from T1 to T2 in the average configuration of the untreated Class III control sample. The deformations are magnified X3.

extension of the maxillary structures in a forward direction. The deformation in the horizontal forward direction was detectable also at the level of the posterior nasal spine and of the pterygomaxillary fissure (Figure 4). In the BAMP sample, the mandibular region revealed moderate amount of deformation in an horizontal backward direction.

A certain amount of deformation in an upward and backward direction was evident in the condylar region of the control sample, which exhibited also a moderate deformation in an horizontal forward direction of the mandible at the symphysis and a mild tendency to a deformation in an horizontal backward direction in the maxillary region. Virtually, no deformations were detected in the cranial base landmarks in either the BAMP or the untreated groups.

These significant deformations of the BAMP sample as well as the insignificant shape modifications in the controls were associated with significant differences in centroid size differences for both samples ($P < 0.05$). Allometry was significant for the BAMP sample ($F = 3.36$; $P < 0.01$), thus indicating dependence of size differences on shape differences in the treated group.

Discussion

The present study applied morphometric analysis to the evaluation of the effects of Class III treatment using bone anchorage. Specific characteristics of the study samples were that 1. Class III subjects were treated consecutively within a prospective clinical trial, 2. a matched control group of untreated Class III subjects was used for comparisons, and 3. all subjects were prepubertal before treatment.

TPS analysis allowed to identify significant deformations in the skeletal components of the maxilla and mandible induced by the BAMP protocol that can be interpreted as follows. The transformation grids corresponding to the deformations induced by treatment in the average configuration of the treated sample clearly illustrated a significant advancement of all skeletal maxillary structures produced by treatment. The maxillary advancement was more marked at the anterior nasal spine and at A point; however, a noticeable forward movement of the maxilla could be registered at the posterior nasal spine and at pteygo maxillary fissure points, thus demonstrating a profound effect of the BAMP protocol on the skeletal maxillary structures.

The deformations in the mandible were generally less dramatic and they could be interpreted as follows. It should be noted that no vertical changes in the shape of any craniofacial structure was induced by the BAMP protocol. All these morphological changes corroborate fully previous cephalometric findings on a smaller sample of subjects treated with the BAMP protocol (De Clerck *et al.*, 2010). It is interesting to note that the direction of the morphological changes in the posterior portion of the maxilla and in the anterior portion of the mandible as indicated by the vectors in Figure 4 approximates the direction of the Class III elastics used in the BAMP protocol. Therefore, the morphometric display revealed the dentoskeletal changes along the line of force of the elastics.

In the untreated Class III controls, the morphological analysis revealed both mandibular lengthening and maxillary retrusion along with growth. These data confirm previous indications of the literature regarding the lack of self-improvement of the facial skeletal unbalance in untreated Class III subjects at the circumpubertal ages (Baccetti *et al.*, 2007).

Previous investigations used TPS analysis for the evaluation of craniofacial deformations produced by either rapid maxillary expansion and face mask therapy (Baccetti *et al.*, 1999) or maxillary protraction in association with a chincup (Chang *et al.*, 2005). The maxillary expansion and protraction study (Baccetti *et al.*, 1999) showed less pronounced maxillary changes when compared with the effects of the BAMP protocol, whereas the use of the face mask was associated with a favourable upward and forward direction of growth in the mandibular condyle. This positive effect was reported also in the study by Chang *et al.*, (2005), which revealed marked dentoalveolar contributions to the general effect of therapy. The use of the bone anchors in the BAMP protocol allowed for a more evident amount of skeletal change.

The morphometric outcomes presented in this study are at the end of active therapy. Longitudinal observation after fixed appliances and the pubertal growth spurt will be needed to assess overall treatment changes at a longer term. The lateral cephalograms in this study were generated from three-dimensional (3D) CBCT reconstructions. Future 3D assessments will deliver a more comprehensive analysis of the modifications induced by the BAMP protocol.

Conclusions

TPS analysis allowed an appraisal of deformations in the craniofacial structures induced by BAMP independently from size changes. The morphometric evaluation of the therapeutical effects of the BAMP protocol in Class III growing patients revealed significant favourable deformations of both the maxillary and the mandibular structures that were associated with dimensional differences induced by treatment. No appreciable vertical deformation was associated with treatment. The maxillary effects were particularly pronounced.

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