The Morphometric Analysis of Maxillopalatal and Mandibular Changes of Skeletal Class III Malocclusion Treated with Orthopedic Therapy

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Abstract

The purpose of this study was to investigate the treatment effects on the maxillopalatal mandibular configuration by occipito-mental anchorage (OMA) (maxillary protraction) combined with chin cup appliance (CCA) therapy among growing children. The assessment of geometric morphometric, using Procrustes analysis, thin plate spline analysis, and growth-trended vectors, was applied and integrated to evaluate treatment effects on the maxillopalatal mandibular configuration of 22 children with skeletal Class III malocclusion. Taiwanese children (12 males and 10 females; 22 untreated stage of Class III subjects as pre-treated group; 22 treated stage of Class III subjects as post-treated group) were traced, and 9 landmarks digitized. Thin-plate spline analysis (TPSA) and growth-trended vectors (GTVs) of geometric morphometric technique were integrated and utilized to investigate the morphological differences of dentofacial growth and local effects of orthopedic treatment. Goodall’s analysis of morphometric statistics established statistical difference (p < 0.01) between the mean configurations of the pre-treated and post-treated groups. Significant morphological changes on the maxillopalatal mandibular configuration were detected that the skeletal Class III subjects following orthopedic therapy included the growth of forward extension on the maxillopalatal configuration and the growth of backward compression on the mandible. In addition, the mandible treated with the CCA therapy appeared to have a tendency of clockwise rotation. Median and transverse palatine sutures seem to play an important role to produce the antero-superior elongation on the maxillopalatal configuration when orthopedic force was applied. The results indicated that the therapy of the OMA+CCA was efficient for correcting developing Class III malocclusion. Moreover, the morphometric techniques of the TPSA and GTVs are efficient methods to investigate growth change and treatment effect for craniofacial studies.

Keywords: Class III malocclusion, Thin plate spline analysis (TPSA), Occipito-mental anchorage (OMA), Geometric morphometry, Growth-trended vectors (GTVs)

1. Introduction

The anteroposterior relationship between the maxilla and mandible has been evaluated and used in the evaluation of malocclusion [1]. Mandibular prognathism or skeletal Class III malocclusion with a prognathic mandible has long been viewed as one of the most severe maxillofacial deformities [2]. A skeletal Class III malocclusion can exhibit mandibular protrusion, maxillary retrusion, or some combination of the two. According to dental relationship of occlusion, a normal Class I occlusion is defined by the anteroposterior relationship of the maxillary and mandibular first permanent molars being correct. Similarly, a Class II malocclusion is defined when the mandibular first permanent molar is distal to normal in its relationship with the maxillary first molar. And a Class III malocclusion is defined as the mandibular first permanent molar being mesial to normal in its relationship with the maxillary first molar [3]. Chang reported that the prevalence of Class III malocclusion in Taiwanese children was 9.9% to 16.8% [4]. On the other hand, many studies demonstrated that the incidence of Caucasian population afflicted with Class III malocclusion was below 5% [5,6]. In clinics, various types of jaw relationship have been found in patients with Class III malocclusion. Sanborn indicated that 45.2% of the evaluated Class III subjects showed mandibular protrusion with normal maxilla; moreover, the maxillary retrusion without mandibular...
protrusion was 33%, and the subjects with both maxillary retrusion and mandibular protrusion were 9.5% [1,7]. Jacobson et al. reported that the most common of the jaw types in adult Class III malocclusion was mandibular protrusion with normal maxilla (49%), and the next was patients who had maxillary retrusion with a normal mandible (26%) [6]. In addition, Ellis and McNamara found that 30% of the Class III subjects had maxillary retrusion and mandibular prognathism, and furthermore, patients with maxillary retrusion with normal mandible and mandibular protrusion with normal maxilla were 19.5% and 19.1%, respectively [8]. Clinically using an occipito-mental anchorage combined with chin cap appliance (OMA+CCA) was efficient to correct skeletal Class III malocclusion for growing children [9] because this appliance can protract the retrognathic maxilla and retard the protrusive mandible [10].

The conventional cephalometric technique, which mainly employs angular and linear measurements to represent the morphologic changes, shows limitation to determine the localized growth effects of size and shape changes after orthopedic treatment [11]. Recently, some new geometric morphometric approaches, e.g. thin-plate spline analysis (TPSA), have been developed for measuring the size and shape changes as well as the quantification of morphologic differences for growth evaluation [12,13]. TPSA can be used to compare the deformation of craniofacial configuration of orthopedic treatment between the starting and final stage to present in terms of the isolated features of skeletal morphology or the ontogeny of individual skeletal parts [14]. Therefore, the differences between two configurations can be expressed as a continuous deformation by visualizing biorthogonal grids [15]. For investigating morphological changes in skeletal Class III malocclusion, TPSA was utilized to evaluate the morphological differences in the areas of cranial base, midfacial complex, and mandible [16-19].

Many treatments have been utilized to correct skeletal Class III malocclusion using a combination of maxillary retrognathism and mandibular prognathism during the growth period. Orthognathic surgery was proposed for treating severe Class III skeletal disharmony [20,21]. However, such surgery is still an invasive treatment. Orthopedic appliances such as OMA+CCA seem to be more desirable for the treatment of skeletal Class III malocclusion [22-24]. Chang et al. [25] used TPSA to evaluate the treatment effects of the OMA+CCA. The study found that the significant results were a forward advancement of the maxillary complex with negligible rotation of the palatal plane and a forward direction of growth of the mandibular condyle associated with a restriction in sagittal advancement of the chin [25]. Geometric morphometric integration by TPSA and growth-trended vectors (GTVs) has not been investigated extensively on the maxilla and/or mandible when OMA+CCA therapy has been undertaken. GTVs were developed to present the growth changes of craniofacial landmarks by two indexes of vectors, magnitude and direction. Hence, the effects of treatment or growth on the continuum of landmarks may be visualized as growth behavior. The purpose of this study was to investigate the morphological changes of the palatomandibular configuration using OMA+CCA therapy in subjects with skeletal Class III malocclusion by geometric morphometric technique. The technique of geometric morphometric assessments was utilized for evaluating growth transformation by TPSA and GTVs.

2. Materials and methods

Twenty-two Taiwanese patients (12 males and 10 females) who received the OMA+CCA therapy were examined. The mean ages of pre-treatment and post-treatment in the Class III subjects were 9 years, 8 months and 11 years, 3 months, respectively. The OMA appliance of maxillary protraction combined with chin cap was semifixed with bands on the first molars. The entire maxillary base is pulled forward with elastics from buccal hooks of the first molars to the horns extending from the chin cap. Patients treated with the OMA+CCA were instructed to wear the appliance for 10-12 hours per day. The force for maxillary protraction of 200 to 250 gm was applied on each side. Moreover, total force of 400 to 500 gm between headgear and chin cap was used to inhibit overgrowth of the mandible. The OMA appliance assembly consisted of three parts, a head cap, a maxillary intraoral appliance, and a chin cup. In detail, the maxillary intraoral appliance was composed of a palatal wire frame, a palatal plate, and bands fixed on the molars (Fig. 1). All subjects had no history of airway problem. No subjects had received orthodontic and/or orthopedic treatment before the initial cephalographs were taken. Stopping criteria of the treatment was that the Class III molar relationships and the anterior crossbite were corrected.

Figure 1. The lateral view of the occipito-mental anchorage combined with chin cap appliance therapy (left). Intraoral photograph of OMA appliance (right).

Lateral cephalograms of the Class III subjects were taken from beginning (pre-treatment stage) and finishing (post-treatment stage) of orthopedic treatment for each subject. The magnification of each cephalogram was standardized to a 10% enlargement factor. Nine points on the palatomandibular structure of cephalograms were identified and digitized by a geometric morphometric digitizer that was created using software Matlab 7.1 (Table 1, Fig. 2). All landmarks with x- and y-coordinate digitizing in this study that demonstrated an inconsistency of >2% on duplication were repudiated and redigitized in accordance with error criteria. To prevent errors of duplication, digitization and error evaluation were performed by a single investigator who conducted both digitization and error
evaluation. The mean configurations of the palatomandibular landmarks were generated from the subjects of the pre-treated and post-treated group using the Procrustes superimposition approach [26]. The pre- and post-treated mean shapes were taken as the initial and final geometries of TPSA, respectively [27]. The TPSA was conducted to map points within the palatomandibular landmarks from the mean shapes of initial and final geometries. The TPSA was incorporated with the GTVs to obtain and display shape changes and redirected growth of the palatomandibular landmarks after orthopedic treatment.

Figure 2. Nine homologous landmarks of maxillopalatal mandibular configuration were selected and derived line segments as bone structures used for TPSA.

Table 1. Landmarks definition of maxillopalatal mandibular configuration

<table>
<thead>
<tr>
<th>Designation</th>
<th>Interpretation</th>
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<tr>
<td>Co</td>
<td>Condylion</td>
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<tr>
<td>Ar</td>
<td>Articulare</td>
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<tr>
<td>Go</td>
<td>Gonion</td>
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<td>Gn</td>
<td>Gnathion</td>
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<tr>
<td>B</td>
<td>Supramentale</td>
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<tr>
<td>A</td>
<td>Subspinale</td>
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<tr>
<td>ANS</td>
<td>Anterior nasal spine</td>
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<tr>
<td>MPP</td>
<td>Midpalatal point</td>
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<tr>
<td>PNS</td>
<td>Posterior nasal spine</td>
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Fundamentally, a growing or treated craniofacial bone is usually considered as a growing continuum that is evaluated by calculating a displacement of landmark to understand how morphological configuration changes. In the GTV analysis of one patient, the original locations of landmarks are associated with the pre-treatment state, and the displacements of the landmarks, as a result of treatment, are regarded as associated with the post-treatment state. The changes are specified by the length and direction of the growth vectors between the two states of the landmark. The vertical and horizontal grid deformations presenting from the TPSA show the contraction or expansion of the palatomandibular complex due to the orthopedic treatment. The mean shapes of the palatomandibular complex of the pre-treatment and the post-treatment groups were statistically compared using Goodall’s $F$-test method to determine whether morphological differences existed between the two groups [28]. The mean shapes of the pre-treated and post-treated group were obtained using a Procrustes analysis. The null hypothesis of this study between the pre- and post-treated average geometries was not different. Probability and $F$ value were computed to compare treatment effects by OMA+CCA appliance. Judging from the above, statistical significant differences were confirmable for the samples independently with and without the orthopedic treatment. Hence, further geometric morphometric analysis using TPSA would be approved.

3. Results and Discussion

The skeletal Class III malocclusions treated with the OMA+CCA were statistically significant ($p < 0.01$ and corresponding $F$ value was 1.873), meaning that significant differences between the morphological configurations of the pre- and post-treated groups were evidenced. Therefore, further morphometric analysis was performed by utilizing the TPSA and GTVs. The undeformed transformation grid was taken as pre-treatment group to compare with the result of the post-treatment group. The morphometric results demonstrate that the OMA caused forward extension of the maxillopalatal configuration (ANS and A) (Fig. 3). Furthermore, the transformation grid of the TPSA indicates that a backward retraction (compression) at the chin region (B and Gn) of the mandibular portion was caused by the orthopedic forces from the chin cap appliance to the adjusted elastic string in the occipital-mental direction (Fig. 3). In addition, the local differences of transformation grid showed evidence of forward growth of the mandibular condyle, affecting landmarks at the articulare (Ar) and the condylion (Co). Antero-inferior extension of the midpalatal point (MPP) was detected so that the tendency of forward protraction of the maxillopalatal configuration appeared to be significant. A slight effect of forward extension at the landmark of the posterior nasal spine (PNS) was also detected. The tendency of morphological change on the gonion landmark (Go) was displaced downward growth after orthopedic treatment. Correction of mandibular retraction accompanied with maxillary anterior protraction was demonstrated obviously by the morphometric representation of the TPSA and GTVs. The GTVs displays indicated that two trends of morphological change of the maxillopalatal landmarks mainly were both antero-inferior and antero-superior elongation. For orthopedic effects on the Class III mandible, the GTVs could present compressive tendency, backward compression at the mandibular chin area (B and Gn). Combination of the TPSA and GTVs provided further information regarding morphological change to understand relationship between the orthopedic treatment and craniofacial regrowth.

In this study, TPSA is a geometric morphometric technique that expresses the differences between two configurations as a continuous deformation. The morphological display of the GTVs effectively reveals the changes caused by orthopedic treatment or malocclusion development. The morphometric analysis of TPSA and GTVs
were utilized and conducted practicable for comparing morphological differences between the pre- and post-treated samples. This study apparently demonstrates that treatment with the OMA+CCA caused the forward movement of the maxillopalatal configuration. Furthermore, inhibition of protrusive growth of the mandible was also determined. Palatine suture plays an important role to produce the forward displacement of the whole maxilla/palate accompanied by sutural growth and bone remodeling [29]. Palatine suture, pressure-related growth sites, is a special tissue structure to provide the capacity for growth in a field of biomechanical/orthopedic force. Previous investigations of craniofacial growth and morphology addressed the transverse palatine suture to perform the role of growth site for palatal growth [30].

Figure 3. The graphical display of TPSA combined with GTV. (a) The orthogonal grid was as pre-treatment group (above), and (b) the deformation of the transformation grid was as post-treatment group (below). The vectors at the landmarks showed morphological changes on the maxillopalatal mandibular configuration between the two groups.

Quantitative expression of morphological differences in geometric display between different objects at diverse intervals is important to determine the complex etiology of morphological dissimilitude, and can help in diagnosis and treatment planning as well as prognosis for orthodontic treatment [14]. The method of TPSA combined with GTVs can be used to derive a graphic representation of morphologic differences between two forms. The method provided facilitated information of morphological change by deformed transformation grid and growth vectors to describe the treatment effects. The deformed transformation grid was related to localized differences, including treatment-induced and growth-induced morphogenetic effects on the maxillopalatal mandibular morphology [27]. The relationship between orthopedic force and forward displacement on the maxillopalatal configuration is confirmed significantly. Further investigation of orthopedic effect is going to be planned and undertaken, including increasing sample size for the skeletal Class III subjects and examination of gender and age. Comparing treated subjects of Class III malocclusion with age-matched untreated subjects (a control group to eliminate native mal-growth effect) will be further investigated to obtain a force-induced change of orthopedic treatment using strain tensor analysis.

4. Conclusions

OMA+CCA treatment was used to correct skeletal Class III malocclusion due to maxillary retardation (undergrowth) combined with mandibular protrusion (overgrowth). The results of the orthopedic treatment were evaluated using morphometric techniques (TPSA and GTVs), which was thus verified to be efficacious. Forward extension of the maxillopalatal configuration and backward compression on the mandible were observed. The displacement and direction-related regrowth of the maxillopalatal mandibular landmarks importantly provides more detailed information than conventional cephalometric study on craniofacial changes that are caused by orthopedic treatment.

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