THIN-PLATE SPLINE GRAPHICAL ANALYSIS OF THE MANDIBLE IN MANDIBULAR PROGNATHISM

Hsin-Fu Chang, Hong-Po Chang, Pao-Hsin Liu, and Chih-Han Chang

Abstract: The chin cup has been used to treat skeletal mandibular prognathism in growing patients for 200 years. The pull on the orthopedic-force chin cup is oriented along a line from the mandibular symphysis to the mandibular condyle. Various levels of success have been reported with this restraining device. The vertical chin cup produces strong vertical compression stress on the maxillary molar regions when the direction of traction is 20° more vertical than the chin-condyle line. This treatment strategy may prevent relapse due to counter-clockwise rotation of the mandible. In this report, we describe a new strategy for using chin-cup therapy involving thin-plate spline (TPS) analysis of lateral cephalometric roentgenograms to visualize transformation of the mandible. The actual sites of mandibular skeletal change are not detectable with conventional cephalometric analysis. A case of mandibular prognathism treated with a chin cup and a case of dental Class III malocclusion without orthodontic treatment are described. The case analysis illustrates that specific patterns of mandibular transformation are associated with Class III malocclusion with or without orthopedic therapy, and that visualization of these deformations is feasible using TPS graphical analysis.

Conventional roentgenographic cephalometrics, based on angular, linear and ratio measurements, have shown an increasing number of limitations [1, 2]. The actual sites of putative mandibular skeletal change are insufficiently visible in traditional cephalometric analysis [1], and conventional cephalometrics cannot analyze size and shape changes of complex anatomical forms such as the mandible [1]. Bookstein introduced a new morphometric method for shape comparisons called thin-plate spline (TPS) analysis [3, 4]. TPS analysis facilitates the construction and display of transformation grids that capture the shape change between forms. This conceptually simple maneuver quickly shows the location and extent of deformation.

A relatively high prevalence of Class III malocclusion has been observed in Asian populations [5–8]. Class III malocclusion is a common clinical problem in orthodontic patients. Studies suggest that skeletal Class III malocclusion presents in 63 to 72% of patients with Class III malocclusion [5, 6]. Mandibular prognathism or Class III malocclusion with a prognathic mandible has long been viewed as one of the most severe facial deformities [9]. A number of treatment protocols have been used to address skeletal Class III malocclusion. The chin cup is recommended in growing patients who have a moderately protrusive mandible and a relatively normal anteroposterior position and maxilla size [10]. However, treatment of skeletal Class III malocclusion in growing children is one of the most challenging problems confronting the practicing orthodontist. Relapse after treatment is occasionally an embarrassing situation for the orthodontist, the patient, and the parents.

The aim of this study was to apply TPS to mandibular configurations on lateral cephalographs and to determine the local form differences between initial
and final cephalographs in subjects with Class III malocclusion, with or without orthodontic treatment.

Case Reports

Case 1
Two patients were selected for study. The first patient was a boy, aged 7 years, who was referred to us with Class III malocclusion in early mixed dentition. Dental Class III with a Class III deciduous molar and Class III deciduous canine relationships were noted. He had a Class I permanent molar on the left side and a Class III permanent molar on the other side. He also had an anterior crossbite (Fig. 1A). He received no treatment and was followed up regularly. The anterior cross-bite corrected itself and the molar occlusion became a Class I relationship at the age of 9 years 7 months (Fig. 1B).

Case 2
The second patient was a girl, aged 8 years and 8 months, who came to the orthodontic clinic with Class III malocclusion in early mixed dentition. Skeletal Class III malocclusion with Class III deciduous canine and Class III molar relationships and an incisal edge-to-edge bite were noted (Fig. 2A). Chin cup treatment was given for 2 years, which corrected the incisal edge-to-edge bite to a normal overbite. However, the bite was not deep enough to provide sufficient anterior guidance and there was still a Class III molar relationship (Fig. 2B). Severe skeletal Class III malocclusion with super Class III molar and Class III canine relationships, anterior cross-bite, and anterior open-bite developed at the age of 16 years 1 month (Fig. 2C). Orthognathic surgical treatment combined with orthodontic therapy was performed to correct the problem after completion of growth when she moved to the USA. The posttreatment result was stable.

TPS analysis
For TPS analysis in these two patients, 12 homologous landmarks were determined for the mandible on the lateral cephalograph: condyion, anterior border of ramus, lower incisor lingual bony contact, infracartilaginous, supramentale, protuberance menti, pogonion, gnathion, menton, gonion, posterior border of ramus, and articulare. The anterior border of ramus is the intersection of the functional occlusal plane with the anterior border of the ramus, and the posterior border of ramus is the intersection of the functional occlusal plane with the posterior border of the ramus (Figs. 1C and 2D; Table). TPS graphical analysis showed the shape difference or deformation, which appeared as vertical compression/extension and/or horizontal compression/extension of the grids on the graphical displays when the pre- and post-treatment lateral cephalographs were superimposed and the landmark configurations compared. TPS software was used as previously described [11]. A more detailed review of the theoretical basis and calculation procedures of TPS morphometrics can be found in Bookstein [3, 4] and Dryden and Mardia [12].

Results

TPS analysis of the lateral cephalographs in Case 1 without orthodontic treatment showed a slight clockwise rotation of the mandibular condyle and ascending ramus, a compression in the region of the antero-inferior portion of the mandibular symphysis, and a slight counter-clockwise rotation of the mandibular body (Fig. 1D).

After chin cup therapy, TPS analysis of the lateral cephalographs in Case 2 revealed a slight forward compression of the mandibular condyle, an extension in the region of the anterior portion of the mandibular symphysis, and a counter-clockwise rotation of the inferior portion of the mandibular symphysis (Fig. 2E). TPS analysis of the follow-up cephalograph showed a posterior extension of the mandibular condyle and ascending ramus and an extension in the region of the anterior portion of the mandibular symphysis (Fig. 2F).

Discussion

This study used TPS analysis to visualize transformations and to provide insight into the localization of actual anatomic deformations of the mandible in two patients with Class III malocclusion. The TPS function fits the differences in the positions of the landmarks in one form relative to their positions in another [3, 4, 12]. This method models shape differences as a deformation between landmarks. The interpolation function used in spline analysis can be described by a physical metaphor in which the landmarks of one form located on an infinitely thin metal plate are deformed, so that the height over each landmark is equal to the coordinates of the corresponding point in the other form [3, 4]. While TPS analysis is also suitable for three-dimensional studies, in this study we only used two-dimensional data derived from lateral cephalographs.

The use of the chin cup in the treatment of mandibular prognathism was first reported in the early 1800s [13]. Cellier in France and Fox, Kinsley and Farrar in the USA designed appliances that resemble today’s chin cup. While chin-cup therapy for mandibular prognathism has been used for a long time, varying levels of success have been reported. Differences in these findings may be causally related to the duration of treatment, level of force utilized in the appliance, and/or the age of the patient being treated. This orthopedic appliance is effective for mandibular
Fig. 1. Case I. Class III malocclusion in a boy without orthodontic treatment. A) Initial cephalometric roentgenogram. B) Final cephalometric roentgenogram. C) Graphical display of initial mandibular configuration is untransformed (see the Table for description of abbreviated terms). D) Graphical display of final mandibular configuration showing mandibular shape changes as total spline.

Table. Homologous mandibular landmarks used in this study

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Definition</th>
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<tr>
<td>Condylion (Cd)</td>
<td>Most superior point on mandibular condyle</td>
</tr>
<tr>
<td>Anterior border of ramus (Ab)</td>
<td>Intersection of functional occlusal plane with anterior border of ramus</td>
</tr>
<tr>
<td>Lower incisor lingual bony contact (Lib)</td>
<td>Lingual contact of alveolar bone with mandibular central incisor</td>
</tr>
<tr>
<td>Infradentale (Id)</td>
<td>Most anterosuperior point on labial aspect of mandibular alveolus</td>
</tr>
<tr>
<td>B point or supramentale (B)</td>
<td>Deepest point on mandibular alveolus</td>
</tr>
<tr>
<td>Protuberance menti or suprapogonion (Pm)</td>
<td>Most superoposterior point on mandibular symphysis changes from concave to convex</td>
</tr>
<tr>
<td>Pogonion (Pog)</td>
<td>Most anterior point on mandibular symphysis</td>
</tr>
<tr>
<td>Gnathion (Gn)</td>
<td>Most anteroinferior point on mandibular symphysis</td>
</tr>
<tr>
<td>Menton (Me)</td>
<td>Most inferior point on mandibular symphysis</td>
</tr>
<tr>
<td>Gonion (Go)</td>
<td>Midpoint of mandibular or gonial angle</td>
</tr>
<tr>
<td>Posterior border of ramus (Pb)</td>
<td>Intersection of functional occlusal plane with posterior border of ramus</td>
</tr>
<tr>
<td>Articulare (Ar)</td>
<td>Posterior intersection of condylar head and posterior cranial base</td>
</tr>
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prognathic patients in late deciduous dentition or early mixed dentition [10]. The girl in this report began treatment with 150 to 300 g of force per side of the chin cup. This force was increased to a minimum of 450 g per side over a 2-month period. She was instructed to wear the chin cup for a period of 10 to 12 hours per day. In cases of more severe malocclusion or uncooperative patients, the period of requested wear is increased to 12 to 16 hours daily. After resolution of the intermaxillary skeletal imbalance, both the amount of chin-cup force and the duration of wear are reduced. The appliance is then used as a retainer for the remainder of the treatment period. The appliance is fabricated so that the pull on the chin cup is oriented along a line from the mandibular symphysis (chin) to the mandibular condyle.

In successfully treated cases, the generalized effect of chin-cup therapy on mandibular structures can be interpreted as a forward direction of condylar growth associated with a restriction in sagittal advancement of the symphysis [10, 14]. On the other hand, untreated progression of Class III growth presents as an overall deformation of the mandible with extension in the regions of the mandibular condyle and the antero-inferior portion of the mandibular symphysis [14]. In this study, TPS analysis demonstrated that the patient with untreated Class III malocclusion with self-correction of the original malocclusion (Case 1) showed a compression in the region of the antero-inferior portion of the mandibular symphysis, a counter-clockwise rotation of the mandibular body, and forward compression of the mandibular condyle and neck. This is similar to

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**Fig. 2.** Case 2. Mandibular prognathism in a girl receiving chin cup therapy. A) Pretreatment cephalometric roentgenogram. B) Posttreatment cephalometric roentgenogram. C) Follow-up cephalometric roentgenogram. D) Graphical display of pretreatment mandibular configuration is untransformed (see the Table for description of abbreviated terms). E) Graphical display of posttreatment mandibular configuration showing mandibular shape changes as total spline. F) Graphical display of follow-up mandibular configuration showing mandibular shape changes as total spline.
cases of successfully treated Class III malocclusion with chin-cup therapy [14]. Although there was a counterclockwise rotation of the inferior portion of the mandibular symphysis, the relapse of skeletal Class III malocclusion in this patient was treated with a chin cup, which revealed a forward extension in the region of the anterior portion of the mandibular symphysis. This result is the same as in a previously reported untreated growing case of Class III malocclusion [14]. The follow-up cephalograph in Case 2 with relapse showed a posterior extension of the mandibular condyle and ascending ramus, an extension in the region of the anterior portion of the mandibular symphysis, and clockwise rotation of the mandibular body as in the untreated case of growing Class III malocclusion. This explains why the girl developed severe skeletal Class III malocclusion. Clinically, this may be related to the duration of treatment, level of force used, wearing time of the appliance, and/or the age of the patient [9]. Thus, TPS graphical analysis demonstrated different shape changes in the mandibular configuration of children with Class III malocclusion with or without treatment and with or without correction of the original malocclusion.

The ultimate treatment goal for skeletal Class III patients should not only be the correction of the jaw relationship and negative incisal overjet related to mesial occlusion at that stage, but also the stabilization of the intermaxillary skeletal and dental relationships resulting from orthopedic appliance treatment. Thus, close observation and follow-up of mandibular growth during adolescence, particularly during the second or third stage of orthodontic treatment, is essential.

Using dried human skulls with strain gauges, Omatu and Kawamoto investigated the effects of a chin cup on the pediatric craniofacial skeleton [15]. This included consideration of different directions of traction force imparted by the chin cup. They found that when the direction of traction was 20° more vertical than the chin-condyle line, i.e., through the occlusal surfaces of the molars, the chin cup produced strong vertical compression stress on the maxillary molars, suggestive of induction of counter-clockwise rotation of the mandible. Therefore, this treatment strategy may prevent the relapse of treated skeletal Class III malocclusion. The effects of orthopedic force produced by a vertical chin cup are correlated with the cephalometric and histologic observations during use of this appliance in animal studies [16, 17].

In conclusion, TPS analysis may show the degree of transformation within the mandibular geometric configuration due to treatment effects and/or growth changes, as seen on lateral cephalometric roentgenograms. Further research into the growth changes and/or treatment effects of the vertical chin cup with the direction of traction of 20° more vertical than the chin-condyle line on a large number of patients with skeletal Class III malocclusion using TPS graphical analysis is warranted.

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References