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Chincup treatment modifies the mandibular shape in children with prognathism

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Introduction: Although chincups are the preferred treatment for growing children with mandibular prognathism, the mechanism by which chincups improve this condition remains unclear. The aim of this study was to use geometric morphometrics to evaluate changes in the shape of the mandible of prognathic children treated with a chincup. **Methods:** Geometric morphometrics were used to evaluate the short-term mandibular shape changes in 50 prognathic children treated with chincups compared with 40 untreated matched controls. Twenty-one 2-dimensional mandibular landmarks from cephalograms taken before and after 36 months of treatment or observation were analyzed by Procrustes superimposition and thin plate spline. **Results:** Permutation tests of the treated patients showed highly significant differences in the mandibular shapes before and after treatment, and compared with the control group after the observation period. The thin plate spline grid deformations indicated more rectangular mandibular configuration, forward condyle orientation, condyle neck compression, gonial area compression, and symphysis narrowing. **Conclusions:** Early chincup treatment widely modifies the mandibular shape of prognathic children to improve Class III malocclusion. (Am J Orthod Dentofacial Orthop 2011;140:38-43)

Mandibular prognathism is responsible for about 20% of skeletal Class III malocclusions and originates from imbalances in mandibular size, form, and position with respect to the maxilla or the cranial base.[1-3] Malocclusions are not self-correcting and actually worsen during growth and development, because of excessive forward mandibular growth.[4,5] Early treatment is recommended, since the morphologic pattern of the prognathic face associated with excessive forward mandibular growth is most likely established early in life.[2,5,6]

The chincup is the preferred orthopedic appliance for growing children with mandibular prognathism and a normal maxilla. Studies evaluating the skeletal and dental effects of chincups by conventional cephalometric analyses indicate that they improve Class III malocclusions by redirecting mandibular growth backward or downward, repositioning the mandible backward, closing the gonial angle, retarding mandibular growth, remodeling the mandible and temporomandibular joint, and retroclining the mandibular incisors.[3,4,6-9] Nevertheless, the mechanisms by which this treatment improves prognathism remain unclear. One hypothesis is that the chincup directly applies orthopedic forces that modify the mandibular shape, thereby improving skeletal Class III malocclusion.

Conventional cephalometrics measure linear distances or angles but do not relate distance or angle changes to whole form changes, leading to certain limitations for shape assessment.[10,11] Geometric morphometric methods, including Procrustes superimposition and thin plate spline (TPS), are being increasingly used in orthodontics to study shape changes.[12-17] Only a few clinical studies have used these methods to determine changes in mandibular shape after orthopedic functional treatment with the Twin-block,[18] Fränkel,[19,20] and Teuscher[21] appliances; after maxillary protraction combined with chincup appliances[22]; or after removable mandibular retractor appliances.[23] Only 1 investigation attempted to evaluate changes in mandibular shape after chincup treatment, but it was a pilot study with only few clinical cases.[14]

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To elucidate the short-term treatment response mechanisms of the mandible after early chincup treatment, we performed a retrospective longitudinal study using geometric morphometrics to evaluate mandibular shape changes in treated and untreated prognathic children.

MATERIAL AND METHODS

A group of 50 consecutive children (25 boys, 25 girls) with skeletal Class III malocclusions due to mandibular prognathism treated solely with chincups, with mean ages of 8.5 ± 0.5 years at the first observation (immediately before treatment) and 11.4 ± 0.6 years at the second observation (after treatment), were recruited from the Orthodontic Clinic of the School of Dentistry, University Complutense, Madrid, Spain. Because chincup device usage was indispensable, restrictive criteria were applied; the children were chosen from a sample of 110 treated patients only if they had mandibular symphysis narrowing (pretreatment symphysis-pogonion distance > posttreatment symphysis-pogonion distance) as a sure sign of cooperation.[24] Forty untreated children (20 boys, 20 girls), with mean ages of 8.6 ± 0.4 years at the first observation and 11.7 ± 0.5 years at the second observation, matched by age, skeletal maturity, sex, and observation period, with skeletal Class III malocclusions caused by mandibular prognathism and similar pretreatment dentoskeletal morphologies, comprised the control group. The availability of a sample of children with untreated skeletal Class III malocclusion was because many parents refused chincup treatment at the first observation (after orthodontic diagnosis and treatment planning) but came for a second visit at a later age.

Parents gave written informed consent for their children to participate in the study, which was approved by the ethics committee of University Complutense.

Inclusion criteria for both groups included diagnosis of skeletal Class III malocclusion (ANB angle, $<0°$; Wits appraisal, <-2 mm) caused by mandibular prognathism (SNB angle, $>82°$) with a normal maxilla (SNA angle, 82° ± 2°), permanent first molar relationship of at least a half cusp Class III, anterior crossbite or edge-to-edge incisal relationship, accentuated mesial-step relationship of the deciduous second molars, and white race. Exclusion criteria included congenitally missing, supernumerary, or extracted teeth; craniofacial anomalies; temporomandibular joint dysfunction; and previous or current orthopedic or orthodontic treatment.

The treated children were given an occipital chincup (Dentaurum, Ispringen, Germany) by the same operator (J.A.A.) using the same treatment protocol. Force (about 300 g per chin side) applied to the chin center was oriented along a line from gnathion to sella turcica, so that the vector force was in the direction of the condyle. The patients were instructed to wear the chincup for 14 hours daily. All children started and finished treatment or observation before the pubertal growth spurt and had cervical stage 1 (CS1) at the beginning and cervical stage 3 (CS3) at the end of the study, according to the cervical vertebral maturation method.[25]

Lateral cephalograms were obtained with the teeth in centric occlusion in all subjects before (T1) and after (T2) a mean 36 months of chincup treatment (treatment group) or observation (control group). The same x-ray device (Orthotomograph-10, Trophy OPX/105, Trophy Radiologie, Marne la Vallée, France; 90 kV, 10-15 mA), technician, focus-median (150 cm), and film median (10 cm) plane distances were used. Film magnifications were standardized to 8%. At T1, conventional cephalometrics were used to evaluate the malocclusion type and dentoskeletal morphology (Table).[26-29]

To asses errors in cephalometric tracing and digitizing, 25 randomly selected lateral cephalograms were retraced and redigitized after an interval of 10 days. Errors according to Dahlberg's formula[30] varied between 0.15 and 0.56 mm, and 0.21° and 0.54°.

Cephalograms were imported into tpsDIG software (tpsSeries, J. F. Rohlf, Department of Ecology and Evolution, State University of New York at Stony Brook; free download at: http://life.bio.sunysb.edu/morph/) to digitize 21 landmarks (2-dimensional) representing mandibular morphology[31] (Fig 1). All measurements and landmark localizations were performed by a blinded examiner (J.A.A.). Measurement errors were evaluated by multivariate analysis of variance (MANOVA) by using repeated data recordings of 10 randomly selected subjects on 4 different days. No significant differences were found between the repeated samples (Wilks lambda = 0.00; F = 1.69; $df_{1,2}$ = 138, 6, 47; $P = 0.2$), indicating that the measurement errors were smaller than the sample variations.

The landmark data were then analyzed by geometric morphometric standard procedures (Procrustes superimposition and TPS).[32,33] At the core of these techniques is the definition of shape by Kendall,[34] who considered the geometric information that remains when location, orientation, and scale have been filtered out of an object defined by its landmark configurations. Landmarks are points of correspondence between different objects that match between and in populations,[35] and have both coordinates and biological significance.[33] The Procrustes technique uses the least squares method to superimpose a structure (target) at corresponding landmarks by translation, rotation, and scaling onto

Table. Cephalometric comparison of groups at T1

Cephalometric measurement	Control group n = 40 Mean	SD	Treated group n = 50 Mean	SD	t test
Cranial base					
S-N (mm)	65.1	1.7	64.5	1.2	NS
N-S-Ba (°)	129.5	2.3	130.3	2.5	NS
Po-PtV (mm)	−37.3	2.5	−36.6	1.1	NS
FH/Ba-N (°)	28.0	1.9	27.7	1.3	NS
Maxillary skeletal					
SNA (°)	81.0	0.9	80.8	0.7	NS
Co-Pt A (mm)	75.9	2.6	74.8	2.2	NS
ANS-PNS (mm)	48.1	2.4	47.3	1.8	NS
Mandibular skeletal					
SNB (°)	82.6	0.5	82.8	0.7	NS
Co-Gn (mm)	103.8	4.9	102.4	3.8	NS
Symphysis-pogonion (mm)	14.8	1.0	14.3	0.6	NS
Facial angle (°)	89.8	3.7	90.9	2.7	NS
Maxillary/mandibular					
ANB (°)	−1.4	0.7	−1.5	0.5	NS
Wits (mm)	−6.5	2.2	−7.5	2.1	NS
Maxillomandibular difference (mm)	27.9	3.0	27.6	3.5	NS
Vertical skeletal					
N-ANS (mm)	47.0	3.3	46.7	2.4	NS
S-Go (mm)	62.9	4.1	63.9	3.3	NS
N-Me (mm)	104.6	7.0	104.9	5.8	NS
(S-Go/N-Me) × 100 (%)	60.4	3.9	60.9	3.2	NS
FH to palatal plane (°)	1.0	1.2	−0.4	1.9	NS
Ar-Go-Me (°)	130.9	6.1	132.7	5.1	NS
Dental					
Molar relationship (mm)	−4.3	1.7	−4.5	2.1	NS
Overjet (mm)	−1.3	0.8	−1.8	0.8	NS
Overbite (mm)	1.0	1.3	0.9	1.5	NS
Interincisal angle (°)	140.4	7.1	145.2	8.8	NS
U1 to S-N (°)	97.9	7.6	97.4	6.8	NS
L1 to mandibular plane (°)	86.9	6.8	84.3	7.5	NS

NS, Not significant.

a reference structure. In the extension of this method, the generalized Procrustes analysis, all specimens (many targets) are aligned to their mean shape (reference).[32] The results are scatters of corresponding landmarks (Procrustes shape coordinates) around their mean. The shape of a generalized Procrustes analysis superimposed landmark configuration is defined by the entirety of its shape coordinates. The metric in this shape space is called "Procrustes distance: d" (the sum of squares of homologue interlandmark distances between Procrustes superimposed specimens).[33]

TPS can be used to interpolate between 2 or more superimposed landmark configurations with the generalized Procrustes analysis and to visualize their differences in shape as transformations of 1 shape into the other.[33] This visualization has the advantage that shape differences are resumed in 1 transformation (TPS) grid.

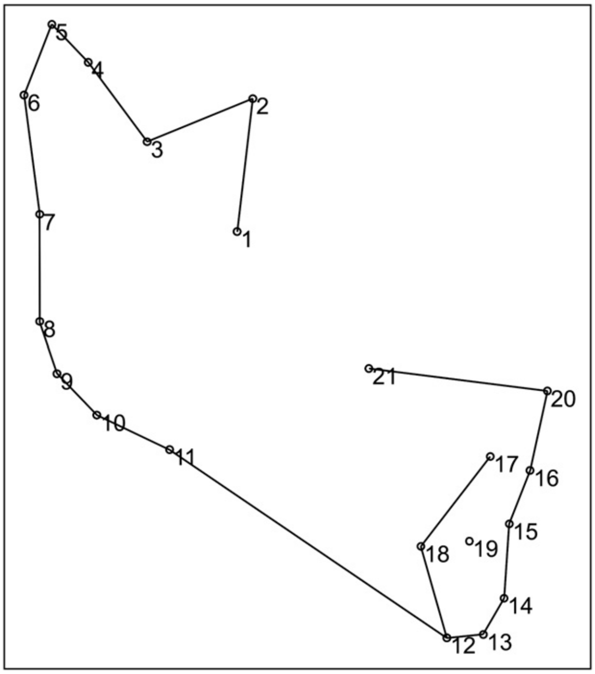

Fig 1. Twenty-one 2-dimensional landmarks on the mean shape (consensus of full sample): *1*, anterior ramus point (most posterior point on the anterior border of the ramus); *2*, coronoid tip; *3*, sigmoid notch; *4*, articulare anterior (anterior intersection of the condylar head and the posterior cranial base); *5*, condylion; *6*, articulare posterior (posterior intersection of the condylar head and the posterior cranial base); *7*, posterior ramus point (point of deepest concavity on the posterior border of the ramus); *8*, superior gonion (most superior aspect of the gonial curve); *9*, gonion; *10*, inferior gonion (most inferior aspect of the gonial curve); *11*, antegonial notch; *12*, menton; 13, gnathion; *14*, pogonion; *15*, B-point; *16*, infradentale; *17*, internal infradentale (most anterosuperior point on the lingual aspect of the mandibular alveolus); *18*, symphysis; *19*, mandibular incisor apex; *20*, L1 (incisal edge of the most prominent mandibular incisor); and *21*, mandibular molar mesial cusp tip.

The smoothing effect of the TPS also gives some idea of shape changes in regions between landmarks. A further, major advantage is that the spline provides a set of orthonormal shape variables (TPS coefficients, partial warps, and uniform component scores) that can be used in common statistical tests.[33,35,36]

Statistical analysis

Descriptive statistics of the cephalometric variables in both groups at T1 were calculated by using SPSS software (version 1.0, SPSS, Chicago, Ill). Mean parameters were subjected to independent samples *t* tests to determine differences between the groups and test for homogeneity. Significance was set at $P \leq 0.05$.

The null hypothesis (ie, no effect by treatment) was tested by mean shape comparisons of mandibular landmarks before and after treatment compared with the control group. Permutation tests (n = 999) were used to compare mean shapes, in which the group membership became permuted repeatedly, and the observed Procrustes distance was compared with the distribution of Procrustes distances obtained by the permutated group comparisons. It was evaluated how often a Procrustes distance equal to or larger than that observed is obtained by pure chance, providing an estimate of the statistical significance of the observed difference. These tests were carried out with software (Morpheus et al, D. E. Slice, Department of Ecology and Evolution, State University of New York at Stony Brook; free download at: http://www.morphometrics.org/morpheus.html).

The mean shapes were then displayed by using TPS grid transformations to analyze visually and demonstrate the shape features at the landmarks that corresponded to the statistical results. These were performed by tpsSPLINE software (tpsSeries).

RESULTS

No cephalometric differences between the treatment and control groups were found at T1 (Table). Permutation tests showed significant differences in mandibular shape before and after chincup treatment in Procrustes distance (d = 0.035; $P < 0.001$), whereas no significant shape differences were obtained for the same interval in the control group (d = 0.015; $P = 0.7$). Similarly, the control and treated groups were significantly different in terms of their mean shapes after the treatment or observation period (d = 0.04; $P < 0.001$). These results imply that the chincup significantly affected the mandibular shape and that the null hypothesis should be rejected.

Details of the shape changes in the treatment group are depicted in the TPS grid deformations (Fig 2) and indicate that the chincup had strong effects on overall mandibular geometry. Several shape features could be identified as treatment effects: more rectangular relationship between the corpus and the ramus, anteroposterior compression of the relative distance between the condyle (landmark [lm] 5) and coronoid process (lm 2), relative vertical compression at the posterior ramus (between lms 5, 6, and 7), and gonial area compression (lms 8-10) that decreased the gonial angle and accentuated the preangular notch profile (lm 11). Thus, the inferior basal border became curved in the treatment group compared with the control group. Further changes include an increase of the relative height of the symphysis and a relative narrowing of the anteroposterior diameter of the symphysis (lms 18, 14). Finally, the relative distance between lms 20 and 21 was reduced, reflecting dental changes.

DISCUSSION

Mandibular landmarks from the cephalograms before and after a mean of 36 months of treatment or observation were analyzed by Procrustes superimposition and TPS. Treated patients had significant differences in their mandibular shapes before and after treatment compared with the controls. The TPS grid deformations indicated more rectangular mandibular configuration, forward condyle orientation, gonial area compression, and symphysis narrowing.

Prognathic patients started chincup treatment at CS1, the skeletal maturity stage when the best orthopedic results are typically obtained.[6,37] Class III prognathic children with similar dentoskeletal morphologies as the treated group were chosen as controls; no cephalometric differences were observed between the groups at T1 (Table). Control matching enabled separation of growth and chincup treatment effects. Control Class III prognathic children grew differently from Class I normocclusive subjects and were therefore preferred.[4-6] Sexual dimorphism was not accounted for, beyond matching for sex. Although there are some sex differences in the skeletal maturation stages of CS1, CS2, and CS3, such as a shorter anterior cranial base (S-N) in girls than in boys, most dentofacial parameters (including the mandible) do not show significant sexual dimorphism until age 13 (ie, the circumpubertal period onward).[38]

Procrustes analysis demonstrated significant mandibular shape changes in the prognathic patients after treatment, whereas no significant differences were found in the control group. The treated and control groups exhibited different mandibular configurations after the treatment or observation period, and the mandibular shape of patients in the control group did not change during the evaluation period. Thus, early chincup treatment widely modified the mandibular shape in growing prognathic patients.

The TPS findings also provided evidence on how the chincup alters the mandibular shape, indicating that the overall mandibular geometry is strongly affected in a manner that greatly improves the skeletal profile. Many specific shape changes were identified, including anteroposterior compression of the relative distance between the condyle and the coronoid process, and a relatively vertical compression at the posterior ramus. This can be interpreted as a change of mandibular condyle

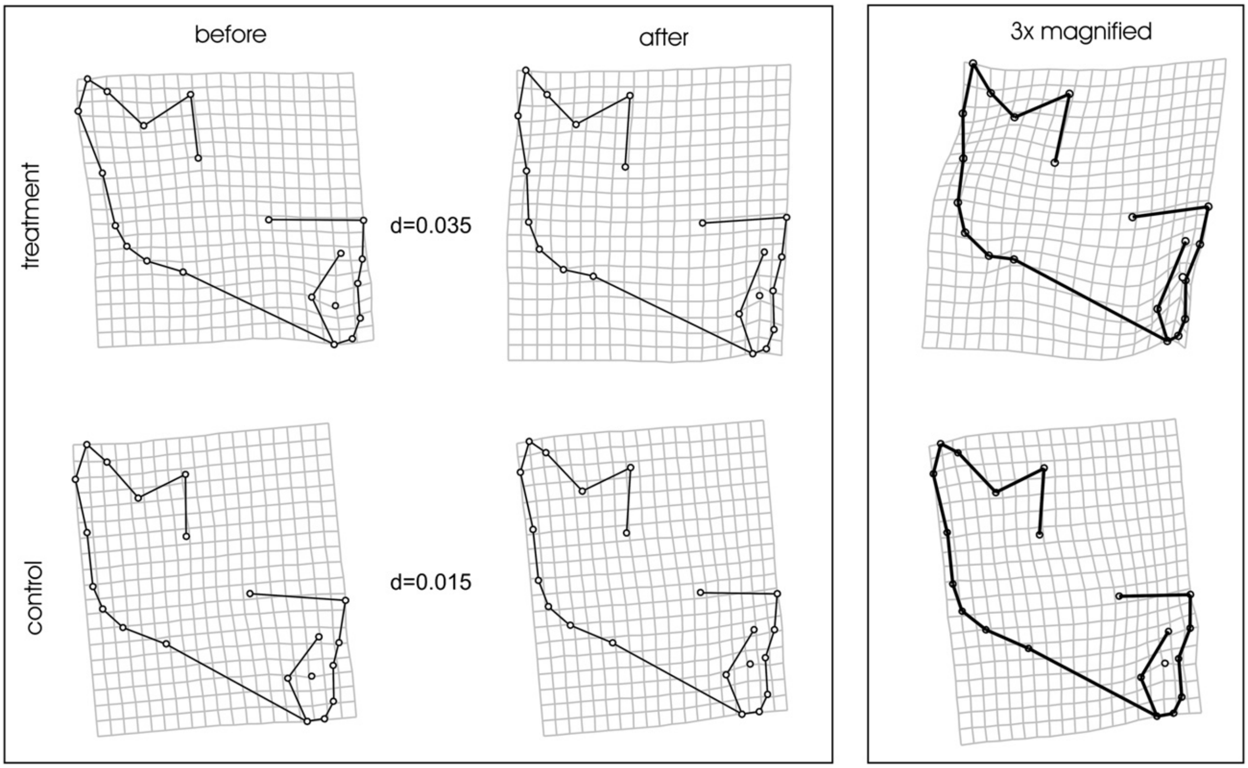

Fig 2. Mean shape differences. The left box shows the observed range of shape differences. The TPS grid illustrates the deformation of the sample average into the mean shape before and after chincup treatment, or before and after spontaneous growth (control). The right box shows the ontogenetic transformations (treatment and control) magnified by 3 times. *d*, Procrustes distance.

orientation from backward and upward before treatment to forward and upward after treatment. Condyle neck compression was also produced; consequently, mandibular growth was not expressed along the total mandibular length, improving the malocclusion. In the untreated children, the condyle continued to grow backward and upward, and mandibular growth occurred along the total mandibular length, worsening the malocclusion.

The gonial area (lms 8-10) was also compressed, thereby closing the gonial angle, in the treated group but not in the control group. This produced a more rectangular relationship between the corpus and the ramus. Additionally, the inferior portion of the symphysis (lms 14-18) was narrowed, probably due to the direct application of chincup forces that compressed the mandibular symphysis and limited its spontaneous forward growth. Thus, the sagittal mandibular advance was restricted. Direct force on the symphysis also reduced the relative distance between dental lms 20 and 21, reflecting retroclination of the mandibular incisors. Chincup treatment improved the Class III malocclusion through some dentoalveolar effects achieved by mandibular incisor retroclination, which contributed to overjet correction. Taken together, these effects (forward reorientation of condyle growth, compression of the gonial area, and symphysis narrowing) shortened the total mandibular length (condylion-gnathion distance) and improved the Class III malocclusion (Fig 2).

The results of this morphometric study broadly complement the information provided by cephalometric analyses.[4,6-9] Geometric morphometrics are advantageous to cephalometrics because they detail the pattern and localization of mandibular anatomic changes, clarifying the origin of prognathic improvement. Three-dimensional morphometric studies would provide more specific information.

CONCLUSIONS

Our findings support the claim that early chincup treatment widely modifies the mandibular shape in prognathic children in a way that improves Class III malocclusion in the short term. Follow-up studies are needed to determine the extent to which these mandibular shape changes are maintained.

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