Original Article

Effect of occlusal plane control procedure on hyoid bone position and pharyngeal airway of hyperdivergent skeletal Class II patients

Xiaolong Li[a]; Qing Zhao[b]; Rui Zhao[a]; Meiya Gao[a]; Xiaolei Gao[a]; Wenli Lai[c]

ABSTRACT

Objective: To evaluate the effect of occlusal plane control on the hyoid bone position and pharyngeal airway of hyperdivergent skeletal Class II patients during orthodontic treatment.

Materials and Methods: Cephalograms of 47 hyperdivergent skeletal Class II subjects with occlusal plane control (OPC), and another 50 subjects without occlusal plane control (NOPC) were selected to compare the effects of the occlusal plane control procedure. Lateral cephalograms before treatment (T1), immediately after treatment (T2), and an average of 12 months after treatment (T3) were obtained, and 17 measurements were analyzed in each group and compared between groups.

Results: With respect to the T2–T1 changes, the sagittal discrepancies in both groups were alleviated. In the OPC group, both the occlusal and mandibular plane angles decreased, accompanied by anterior and superior movement and counterclockwise rotation of the hyoid bone. The overall changes from T3 to T1 in each group exhibited trends similar to that induced by treatment. As for pharyngeal airway space alterations, no significant difference in OPC group was presented throughout treatment or retention periods.

Conclusions: The customized occlusal plane control procedure was effective for hyperdivergent skeletal Class II patients: The occlusal plane rotated counterclockwise, followed by a counterclockwise rotation of the mandibular plane. The hyoid bone moved anteriorly and superiorly, accompanied by its counterclockwise rotation. However, this procedure did not induce significant alteration of the pharyngeal airway space. (*Angle Orthod.* 2017;87:293–299)

KEY WORDS: Occlusal plane control; Hyoid bone; Pharyngeal airway; Hyperdivergent skeletal Class II malocclusion

INTRODUCTION

Hyperdivergent skeletal Class II malocclusion has always been an intractable challenge for orthodontic practitioners because it presents with both sagittal and vertical discrepancies.[1] To get these discrepancies corrected, favorable mandibular counterclockwise rotation during treatment is required. Many studies have pointed out that mandibular rotation is closely related to alteration of the occlusal plane; continuous horizontalization of the occlusal plane is accompanied by simultaneous reduction in its cant during growth and development.[2] Although the occlusal plane is a horizontal plane, its control is literally under the control of the vertical dimensions of dental arches.[1] The fact that the vertical molar height should be strictly limited to avoid unfavorable backward rotation of mandible has been widely accepted.[3] In addition, this unfavorable mandibular rotation in hyperdivergent cases could lead to a lower hyoid bone position, with subsequent reduction of the pharyngeal airway space and eventual occurrence of the obstructive sleep apnea/hypopnea syndrome (OSAHS).[4] Therefore, occlusal plane control (and subsequently the hyoid bone) has received increasing attention among orthodontic practitioners, especially when correcting hyperdivergent Class II malocclusion.

[a] Graduate Student, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, Chengdu, China.

[b] Associate Professor, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, Chengdu, China.

[c] Professor, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, Chengdu, China.

Corresponding author: Dr Wenli Lai, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, Ren Min South Road, No.14, Section 3, Chengdu 610041, China
(e-mail: wenlilai@scu.edu.cn)

Accepted: July 2016. Submitted: April 2016.
Published Online: October 7, 2016

The hyoid bone is unique in that it has no bony articulation, but is suspended by the muscles, ligaments, and connective tissues of the mandible, pharynx, and cranium.[5] Therefore, the position of hyoid bone is determined mainly by the conjoint action of the suprahyoid and infrahyoid muscles, as well as various oral functions in close conjunction with tongue activity.[6] Current evidence has suggested that tongue position and its effect on the airway can be measured more accurately by evaluating the hyoid bone position.[7] In addition, a steeper mandibular plane angle, a shorter mandibular body length, and a lower hyoid bone position are consistently reported by most investigations.[8] Therefore, the position of the hyoid bone can be considered a sensitive indicator of pharyngeal airway space and mandibular rotation.[9]

Therefore, the aim of this retrospective, controlled study is to evaluate the effect of the occlusal plane control procedure in hyperdivergent skeletal Class II cases on hyoid bone position and pharyngeal airway space.

Figure 1. Customized occlusal plane control procedure.

MATERIALS AND METHODS

This study was approved by the Bioethics Committee of the university. The included subjects were consecutively finished and selected from the orthodontic department of West China Hospital of Stomatology. Inclusion criteria of selected subjects were as follows: (1) nongrowing patients at the beginning of treatment, namely after cervical vertebral maturation stage V[10]; (2) hyperdivergent Class II skeletal pattern (ANB angle $>$ 4°, SN-MP angle $>$ 36°); (3) treated with four-premolar (maxillary first premolars and mandibular second premolars) extraction; (4) no history of orthodontic treatment; (5) no history of upper respiratory disease; (6) no complaints of temporomandibular problems before or after treatment.

The sample size was calculated by a biostatistician based on the primary outcomes of a previous study by Orhan,[5] which was actually based on comparing H-FH changes between early (–0.40 $\pm$ 0.35) and long-term (–0.22 $\pm$ 0.19) postoperative data, with an $\alpha = 0.05$ and power of 80%; therefore, a minimum of 30 samples in each group was required.

Considering the possible dropout of included subjects, a larger sample of 97 hyperdivergent skeletal Class II patients was finally included in the study.

All the patients were treated with 0.022 $\times$ 0.028-inch preadjusted brackets (Damon Q, Ormco, Orange, Calif) by postgraduate students using a generally identical treatment protocol under the same supervisor. Originally, 50 subjects were selected for the occlusal plane control (OPC) group, then three were excluded for inadequate cephalometric records. The mean age of the 47 patients was 18.6 $\pm$ 1.3 years before treatment (T1) and 20.8 $\pm$ 1.5 years immediately after treatment (T2). The average treatment (T2–T1) interval was 2.2 $\pm$ 0.3 years, while the average posttreatment interval (T3) was 1.1 $\pm$ 0.1 years. The occlusal plane control procedure was carried out through the high-pull J-hook headgear and a reverse curve of Spee in both arches, combined with proper interarch elastics. Specifically, a reverse curve was bent into 0.019 $\times$ 0.025-inch stainless steel archwires (ClassOne Orthodontics, Carlsbad, Calif) and were maintained 5 mm gingivally to the center of the anterior bracket slots each time when engaged into the brackets. Additionally, two types of interarch elastics were applied. Class II elastics (5/16-inch, 3.5-ounce, Ormco) were connected from a hook between the maxillary canine and lateral incisor to the buccal tube of the mandibular second molar, while anterior vertical elastics (1/8-inch, 3.5-ounce, Ormco) connected a hook between the maxillary central and lateral incisors and a hook between the mandibular canine and lateral incisor on 0.019 $\times$ 0.025-inch stainless steel archwires. The high-pull J-hook headgear was attached to hooks that were fixed on the archwire between the maxillary central and lateral incisors (Figure 1).

The control group (ie, no occlusal plane control [NOPC]) group, consisted of 50 hyperdivergent Class II patients. Their mean age was 18.8 $\pm$ 1.1 years at T1 and 21.1 $\pm$ 1.6 at T2. The T2–T1interval was 2.3 $\pm$ 0.2 years, and the T3 interval was 1.0 $\pm$0.1 years. No occlusal plane control procedure was applied in this group; however, to correct the Class II malocclusion,

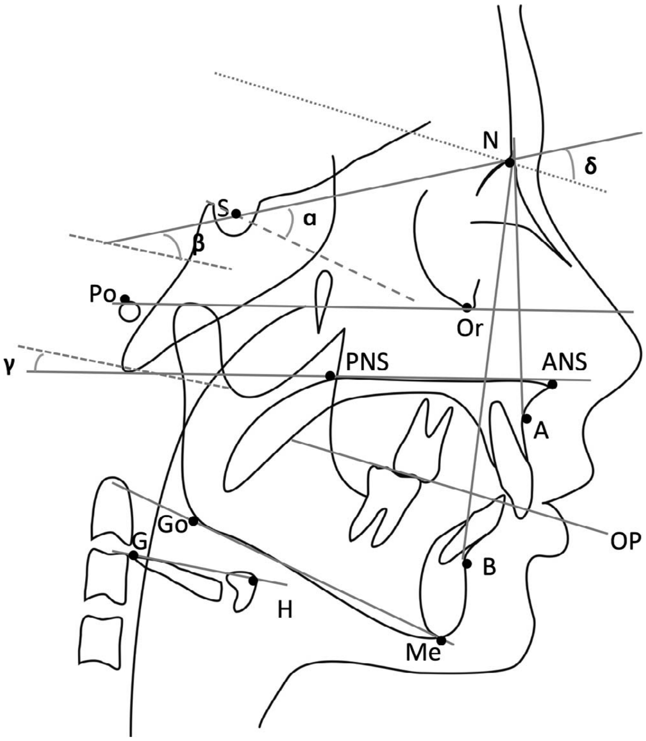

Figure 2. Measurements of the angular variables. Skeletal landmarks: S, sella; N, nasion; ANS, anterior nasal spine; PNS, posterior nasal spine; A, subspinale; B, supramentale; Me, menton; Go, gonion; Po, porion; Or, orbitale; H, most superior anterior point on the body of the hyoid bone; G, most posterior point on the greater horn of the hyoid bone. Reference planes: SN, PP, ANS-PNS, OP (average occlusal points of U1–U6), MP (Go-Me), FH (Po-Or), HP (hyoid plane, the line that connects points Go and H). Angular measurements: SNA, SNB, ANB, α (MP-SN), β (HP-SN), γ (HP-PP), δ (OP-SN), HP-MP.

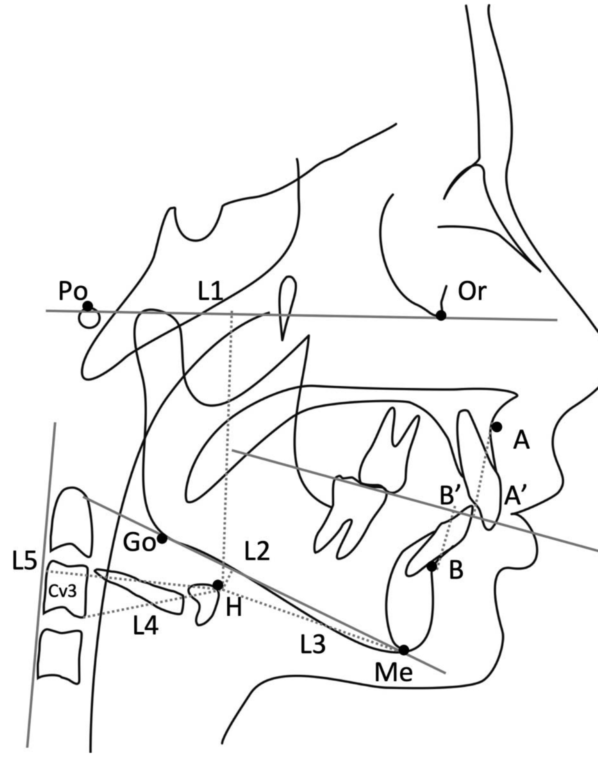

Figure 3. Measurements of the linear variables: Wits appraisal, A'B', erecting perpendiculars from points A and B to the occlusal plane; L1, H-FH, perpendicular distance from hyoid bone to FH plane; L2, H-MP, perpendicular distance from hyoid bone to mandibular plane; L3, H-Me, distance from hyoid bone to menton; L4, H-Cv3, distance from hyoid bone to the most anteroinferior point of the third vertebra; L5, H-Cv2Cv4, perpendicular distance from hyoid bone to the cervical vertebral tangents of second and fourth cervical vertebrae.

Class II elastics (5/16-inch, 3.5-ounce, Ormco) were also used on this group.

Cephalometric radiographs of all patients with the head in the natural head position and teeth in centric occlusion were taken using standard cephalometric procedures. Cephalogram exposures were recorded on the same machine with the same exposure parameters at the end of patients' expiration phase without swallowing, speaking, or chewing. Lateral cephalograms of all subjects were available at T1, T2, and T3. All the cephalograms were input into Wincep 7.0 software (Rise Corp, Tokyo, Japan) after being collected. Then a customized cephalometric analysis based on previous studies in this field[8] (consisting of 17 variables—8 angular and 9 linear for each tracing), was performed after specific cephalometric landmarks were determined as described in Figures 2–4. Specifically, all the cephalograms were traced and measured by the same operator within 2 weeks for consistency of landmark identification and were then checked by a second operator. Both operators were blinded as to group assignment of the cephalograms.

Statistical Analysis

Statistical analysis was performed using SPSS 18.0 (IBM Corp, Somers, NY), and descriptive statistics (means and standard deviations, with 95% confidence interval) were calculated. A *t*-test was applied for comparing the OPC group with the NOPC group at T1, while the angular and linear changes occurring during treatment (T2–T1), during retention (T3–T2), and across the whole period (T3–T1) were evaluated through a paired *t*-test, as were intergroup differences of changes.

RESULTS

At T1, no significant difference was found between the OPC group and NOPC group for any of the variables (Table 1). As for variables of T2–T1 skeletal changes, the SNB angle in both groups increased by 3.64°and 2.28°, leading to a reduction of the ANB angle

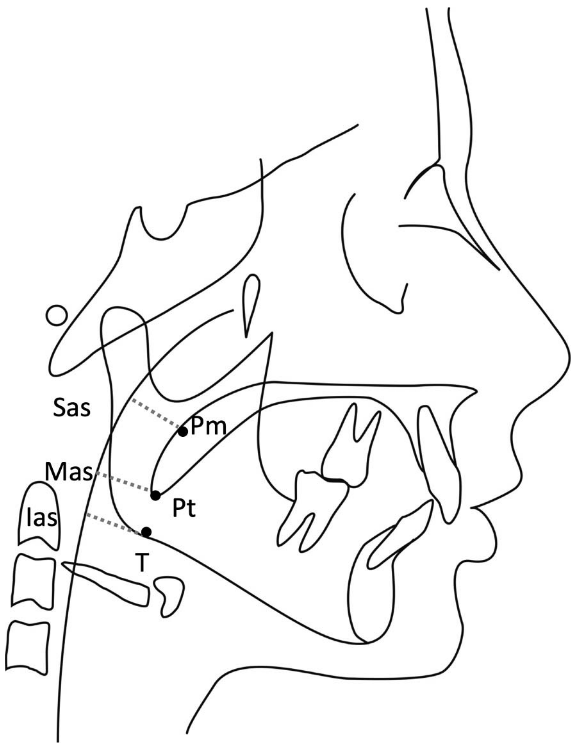

Figure 4. Measurements of pharyngeal airway space: SAS, superior airway space, distance from midpoint of the soft palate (Pm), to the point on the posterior pharyngeal wall where the distance to Pm is the shortest; MAS, middle airway space, distance from the tip of the soft palate (Pt) to the point on the posterior pharyngeal wall where the distance to Pt is the shortest; IAS, inferior airway space, distance from the point on the tongue along the mandibular lower border (T) to the point on the posterior pharyngeal wall where the distance to T is the shortest.

of 3.87°and 2.77°, respectively. The OPC group also exhibited significant decreases in the SN-MP and SN-OP angles of 2.15°and 5.46° respectively, while, interestingly, only the NOPC group followed a 1.06-mm improvement in the Wits appraisal with statistical significance (Tables 2 and 3).

With respect to the T2–T1 hyoid bone position change, this customized occlusal plane control procedure induced statistically significant decreases in the HP-SN and HP-PP angles of 3.29°and 4.05°, respectively. In terms of linear variables, H-FH was reduced by 3.51 mm in the OPC group, while the H-Cv2Cv4 and H-Cv3 distance increased 3.4 mm and 3.99 mm, respectively (Table 2).

For changes in pharyngeal airway spaces, neither the OPC nor the NOPC group showed any statistically significant differences before or immediately after treatment (Tables 2 and 3).

Similar trends were found in the overall changes (T3–T1) within both groups and between groups (Figure 5), indicating that, despite some relapse during the retention period, it was not significant enough to alter treatment outcomes.

DISCUSSION

The treatment difficulty of some orthodontic cases and their adverse effects are challenges for practitioners.[11,12] Particularly, the skeletal feature of hyperdivergent skeletal Class II malocclusion is generally characterized by a clockwise rotation of mandible, which usually leads to both vertical and sagittal problems.[1] Therefore, counterclockwise rotation of the

Table 1. Comparisons Between OPC and NOPC Groups Before Treatment (T1)

	NOPC group (n = 50)		OPC group (n = 47)		Statistical Comparison, OPC vs NOPC			
Measurements	Mean	SD	Mean	SD	Diff	*P* value	CI 95%	
Skeletal Relationship								
SNA (°)	81.09	1.62	82.21	2.49	1.12	.119	−0.29	2.51
SNB (°)	75.86	2.24	76.88	2.71	1.02	.237	−0.65	2.70
ANB (°)	5.24	1.29	5.32	1.29	0.08	.759	−0.79	0.97
Wits (mm)	1.75	1.11	2.31	1.11	0.56	.738	−0.20	1.32
SN-MP (°)	40.97	2.29	41.12	3.35	0.15	.111	−1.77	2.06
SN-OP (°)	20.38	2.86	23.92	2.98	3.54	.755	1.55	5.53
Hyoid Bone Position								
HP-SN (°)	34.93	3.82	32.52	5.28	−2.41	.112	−5.49	0.67
HP-PP (°)	23.97	3.12	22.77	5.76	−1.20	.610	−4.24	1.86
HP-MP (°)	5.98	2.13	8.57	2.02	2.59	.089	−0.85	6.03
H-FH (mm)	89.35	7.26	81.52	8.07	−7.83	.348	−13.76	−1.90
H-MP (mm)	16.41	4.59	15.11	4.19	−1.30	.685	−4.31	1.71
H-Cv2Cv4 (mm)	53.35	4.53	49.46	4.76	−3.89	.143	−8.48	0.70
H-Me (mm)	42.81	5.97	39.21	5.56	−3.60	.908	−7.54	0.36
H-Cv3 (mm)	38.31	4.51	33.97	5.36	−4.34	.659	−7.68	−1.00
Pharyngeal Airway Space								
SAS (mm)	12.08	2.46	14.02	3.35	1.94	.311	−0.03	3.91
MAS (mm)	8.85	1.46	9.95	1.79	1.10	.545	0.00	2.20
IAS (mm)	6.99	1.22	7.75	1.82	0.76	.191	−0.28	1.79

Table 2. Changes in NOPC Group During Treatment (T2–T1), During Retention (T3–T2), and Across the Whole Period (T3–T1)

	NOPC group														
	T2−T1					T3−T2					T3−T1				
Measurements	Mean	SD	*P*	CI 95%		Mean	SD	*P*	CI 95%		Mean	SD	*P*	CI 95%	
Skeletal Relationship															
SNA (°)	−0.49	0.69	.055	−0.82	−0.17	0.12	1.07	.061	−0.79	1.03	−0.37	2.04	.070	−1.39	0.65
SNB (°)	2.28	1.05	.014*	1.79	2.77	−0.19	1.48	.193	−1.12	0.74	2.09	1.80	.022*	1.27	2.91
ANB (°)	−2.77	0.95	.017*	−3.29	−2.25	0.24	1.23	.287	−0.83	1.31	−2.53	1.20	.019*	−3.12	−1.94
Wits (mm)	−1.06	1.00	.023*	−1.93	−0.19	0.10	1.51	.193	−0.98	1.18	−0.96	1.92	.024*	−1.77	−0.15
SN-MP (°)	−0.56	1.28	.066	−1.16	0.04	0.21	2.16	.079	−1.19	1.61	−0.35	1.53	.276	−0.87	0.17
SN-OP (°)	−0.73	2.19	.155	−1.75	0.30	0.18	1.90	.348	−0.77	1.13	−0.55	2.07	.137	−1.43	0.33
Hyoid Bone Position															
HP-SN (°)	−2.11	2.71	.058	−3.38	0.84	0.25	2.12	.072	−1.58	2.08	−1.86	2.23	.087	−3.11	−0.61
HP-PP (°)	−1.50	3.44	.066	−3.12	0.77	0.44	3.46	.118	−1.49	2.37	−1.06	3.49	.342	−2.82	0.70
HP-MP (°)	1.94	2.70	.074	0.68	3.21	−0.36	2.73	.349	−1.32	0.60	1.58	2.86	.903	0.11	3.05
H-FH (mm)	3.16	5.42	.138	0.61	5.71	−0.80	3.37	.069	−1.91	0.31	2.36	4.27	.309	−1.06	5.78
H-MP (mm)	0.47	4.61	.657	−1.69	2.62	0.21	5.74	.516	−0.86	1.28	0.68	5.16	.304	−1.27	2.63
H-Cv2Cv4 (mm)	0.41	5.10	.723	−1.98	2.80	−0.14	3.26	.387	−1.03	0.75	0.27	2.95	.520	−1.44	1.98
H-Me (mm)	1.15	4.32	.248	−0.87	3.17	−0.36	5.93	.074	−1.99	1.27	0.79	3.27	.144	−0.19	1.77
H-Cv3 (mm)	0.79	2.80	.223	−0.52	2.10	0.11	2.14	.393	−1.87	2.09	0.90	2.14	.081	−0.26	2.06
Pharyngeal Airway Space															
SAS (mm)	−0.13	1.13	.625	−0.66	0.40	−0.10	1.30	.438	−1.72	1.92	−0.23	2.59	.201	−1.07	0.61
MAS (mm)	0.28	1.27	.343	−0.32	0.87	−0.11	2.05	.650	−1.64	1.86	0.17	1.38	.415	−0.53	0.87
IAS (mm)	−0.16	0.98	.484	−0.61	0.30	0.31	1.14	.162	−0.92	1.54	0.15	2.52	.372	0.18	0.12

*indicates $P<0.05$.

mandible during orthodontic treatment would be favorable to alleviate these problems. Some studies point out that changes in the occlusal plane could influence the skeletal frame of the malocclusions.[2] Therefore, in this present study, a customized occlusal plane control procedure was applied, carried out through high-pull J-hook headgear and reverse curve of Spee in the archwire, combined with proper interarch elastics in the anterior segment based on the Tweed-Merrifield directional force philosophy.[13] The reverse curve was bent on 0.019 × 0.025-inch stainless steel archwires and maintained 5 mm gingival to the center of the anterior bracket slots each time when engaged into the brackets, which could intrude the anterior teeth

Table 3. Changes in OPC Group During Treatment (T2–T1), During Retention (T3–T2), and Across the Whole Period (T3–T1)

	OPC group														
	T2−T1					T3−T2					T3−T1				
Measurements	Mean	SD	*P*	CI 95%		Mean	SD	*P*	CI 95%		Mean	SD	*P*	CI 95%	
Skeletal Relationship															
SNA (°)	−0.23	1.08	.406	−0.81	0.34	0.11	1.34	.091	−0.08	0.30	−0.12	1.31	.305	−0.56	0.32
SNB (°)	3.64	1.58	.019*	2.79	4.48	−0.27	1.48	.073	−1.02	0.48	3.37	1.56	.023*	2.28	4.46
ANB (°)	−3.87	1.12	.001**	−4.46	−3.27	0.38	1.20	.082	−0.25	1.01	−3.49	0.98	.001**	−4.27	−2.71
Wits (mm)	−0.50	1.28	.141	−1.18	0.18	0.11	1.07	.183	−1.14	1.36	−0.39	1.02	.092	−1.02	1.80
SN-MP (°)	−2.15	1.98	.014*	−3.20	−1.10	0.21	0.94	.069	−0.27	0.69	−1.94	1.68	.013*	−2.91	−0.97
SN-OP (°)	−5.46	3.28	.000***	−7.21	−3.71	0.63	1.04	.089	−0.49	1.75	−4.83	2.87	.000***	−6.35	−3.31
Hyoid Bone Position															
HP-SN (°)	−3.29	4.00	.016*	−5.42	−1.16	0.14	1.06	.457	−0.36	0.64	−3.15	2.53	.010*	−5.06	−1.24
HP-PP (°)	−4.05	2.71	.000***	−5.49	−2.61	0.22	1.95	.069	−1.03	1.47	−3.83	1.37	.000***	−5.41	−2.25
HP-MP (°)	1.12	3.86	.263	−0.93	3.18	−0.08	2.01	.613	−1.18	1.02	1.04	2.04	.122	−0.84	2.92
H-FH (mm)	−3.51	3.19	.000***	−5.06	−1.96	0.13	1.42	.111	−0.78	1.04	−3.38	1.30	.000***	−4.87	−1.89
H-MP (mm)	−0.43	4.24	.689	−2.69	1.83	0.11	3.45	.064	−1.57	1.79	−0.32	3.07	.061	−2.33	1.69
H-Cv2Cv4 (mm)	3.40	4.32	.014*	1.10	5.71	−0.10	2.98	.453	−0.90	0.70	3.30	2.18	.018*	1.16	5.44
H-Me (mm)	1.88	6.02	.231	−1.33	5.09	−0.31	1.73	.759	−0.93	0.31	1.57	3.21	.457	−1.58	4.72
H-Cv3 (mm)	3.99	3.39	.023*	2.18	5.80	−0.24	2.76	.348	−1.87	1.39	3.75	2.90	.029*	2.11	5.39
Pharyngeal Airway Space															
SAS (mm)	−0.33	2.76	.639	−1.80	1.14	0.13	1.75	.548	−1.02	1.28	−0.20	2.72	.740	−1.51	1.11
MAS (mm)	0.69	1.62	.110	−0.18	1.55	0.17	3.34	.442	−1.24	1.58	0.86	1.52	.308	−0.10	1.82
IAS (mm)	0.94	1.88	.064	−0.06	1.94	−0.10	2.09	.169	−1.97	2.17	0.84	2.72	.781	−0.13	1.81

*indicates $P<0.05$, **for $P<0.01$, ***for $P<0.001$.

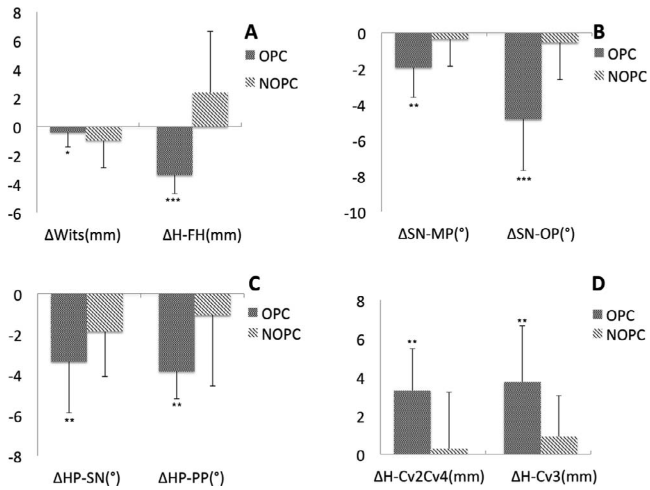

Figure 5. Comparisons of the overall changes (T3–T1) between the OPC and NOPC groups, which presented similar trends and demonstrated significant differences for Wits, H-FH (A); SN-MP, SN-OP (B); HP-SN, HP-PP (C); H-Cv2Cv4, and H-Cv3 (D). * $P < .05$; ** $P < .01$; *** $P < .001$.

on both arches;[14] then 1/8-inch, 3.5-ounce elastics (Ormco) were applied in the anterior segment. Compared with the anterior teeth intrusion effect of a reverse curve of Spee, the elastics produced a more continuous force on the teeth.[15] Therefore, the combined effects of our mechanics were to extrude the incisors while producing intrusive forces and an uprighting effect on the molars.[16] However, extrusion of the maxillary anterior teeth should be controlled for a more horizontal occlusal plane, thus a high-pull J-hook headgear was applied to counteract the extrusive effect on the maxillary incisors.

As the occlusal plane control was in essence vertical control, tooth extraction would obviously facilitate vertical tooth movement, especially for tooth intrusion, and the overall tooth movement could subsequently contribute to altering the occlusal plane without interfering with the oropharyngeal airway volume, as reported by Valiathan et al.[17] Accordingly, subjects treated with four-premolar extraction were finally selected for this retrospective study.

In the present study, the favorable occlusal plane horizontalization was associated with a statistically significant decrease in the SN-OP angle at 5.46° in the OPC group, indicating that the customized occlusal plane control procedure was effective in producing a counterclockwise rotation of the occlusal plane. Simultaneously, this procedure also induced a favorable decrease of 2.15° in the SN-MP angle. These outcomes were similar to those reported by Ye,[1] who also found that reducing the occlusal plane angle was usually accompanied by mandibular counterclockwise rotation. As presented in Tables 2 and 3, the sagittal discrepancies in both groups were somewhat alleviated as the SNB angle in both groups increased by 3.64°and 2.28°, leading to a resultant reduction of ANB angle at 3.87°and 2.77°, respectively. Interestingly, in terms of the Wits appraisal, only the NOPC group exhibited a significant decrease of 1.06 mm. This could be explained by the fact that this appraisal is based on erecting perpendiculars from points A and B to the occlusal plane. Counterclockwise rotation of the occlusal plane in the OPC group probably counteracted the anterior advancement and counterclockwise rotation of the mandible, resulting in the statistically null alteration of the Wits appraisal in the OPC group.

The anteroposterior position of the hyoid bone in the OPC group was significantly forward after treatment, as both H-Cv2Cv4 and H-Cv3 increased by 3.4 and 3.99 mm, respectively. This observation supports the concept that when the mandible is rotated in an upward and forward direction, the suprahyoid muscles pull the hyoid bone into a more anterior position.[18] Interestingly, no statistically significant change was detected in terms of H-Me and H-MP in the OPC group, which could be partly attributed to the fact that, compared with the cervical vertebrae, both the hyoid bone and mandibular position are relatively changeable during orthodontic treatment, especially when accompanied by the customized occlusal plane control procedure.

The vertical position of the hyoid bone was determined by H-FH, which decreased by 3.51 mm in the OPC group and was significant at a statistical level. The superior movement of the hyoid bone might be its adaptation after the counterclockwise rotation of the mandible to prevent an encroachment of the tongue into the pharyngeal airway, thus maintaining the airway space.[19]

For the axial inclination of the hyoid bone, the statistically significant decreases in both the HP-SN and HP-PP angles of 3.29° and 4.05°, respectively, in the OPC group indicate that the hyoid bone rotated counterclockwise during treatment. This could be explained by the hyoid bone's being involved in overall rotational movement of the movable parts of the craniofacial complex; therefore, rotation of the hyoid bone was generally in concert with the mandibular rotation.

OSAHS, wherein significant constriction of the pharyngeal airway space takes place during sleep, is reported to affect 9% of males and 4% of females.[9] Numerous cephalometric studies have consistently reported that a steeper mandibular plane angle and a shorter mandibular body length are the discriminative characteristics of craniofacial morphology in OSAHS patients.[9] Thus, the present study assumed that the pharyngeal airway space would be narrow in hyperdivergent patients and that the occlusal plane control procedure might relieve the pharyngeal airway space constriction through the counterclockwise rotation of mandible. Thus this study evaluated the superior, middle, and inferior pharyngeal airway spaces; however, no significant change was found in the OPC group for any parameters throughout the overall period, indicating that our procedure did not alleviate the possible pharyngeal airway space constriction in hyperdivergent patients. Since many factors related to the oropharyngeal complex such as soft palate, tongue, and hyoid bone positions, associated tissues attached directly or indirectly to the maxilla and mandible, and movement of the jaws, can contribute to altering the pharyngeal area that it was difficult to determine the role that mandibular rotation plays in relation to the pharyngeal airway space changes.[20] Therefore, further study is required to directly evaluate the association between pharyngeal airway space and mandibular rotation.

CONCLUSIONS

- This customized occlusal plane control procedure was an effective alternative in controlling the occlusal plane: the counterclockwise rotation of the occlusal plane was closely followed by a corresponding rotation of the mandibular plane.
- Following treatment, the hyoid bone moved anteriorly and superiorly and rotated counterclockwise.
- No significant alteration of the pharyngeal airway was induced through this customized occlusal plane control procedure.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (81371113, 81571004, 81500884, and 81400549) and by the Orthodontic National Key Clinical Specialty Construction Program of China, West China Hospital of Stomatology, Sichuan University.

REFERENCES

1. Ye R, Li Y, Li X, et al. Occlusal plane canting reduction accompanies mandibular counterclockwise rotation in camouflaging treatment of hyperdivergent skeletal Class II malocclusion. *Angle Orthod*. 2013;83:758–765.
2. Eliana MT, Sadao S. Longitudinal alteration of the occlusal plane and development of different dentoskeletal frames during growth. *Am J Orthod Dentofacial Orthop*. 2008;134:602.e1–602.e11.
3. Proffit W, Fields H, Starver D. *Contemporary Orthodontics*. 4th ed. St Louis, MO: Mosby; 2007.
4. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. *Am J Orthod Dentofacial Orthop*. 2011; 139:e511–e521.
5. Orhan G, Umut S. Changes in pharyngeal airway space and hyoid bone positions after body ostectomies and sagittal split ramus osteotomies. *J Craniofac Surg*. 2005;16(1):23–30.
6. Spiro J, Rendell J, Gay T. Activation and coordination patterns of the suprahyoid muscles during swallowing. *Laryngoscope*. 1994;104:1376–1382.
7. Eggensperger N, Smolka W, Iizuka T. Long-term changes of hyoid bone position and pharyngeal airway size following mandibular setback by sagittal split ramus osteotomy. *J Cranio Maxillo Surg*. 2005;33:111–117.
8. Sheng CM, Lin LH, Su Y, Tsai HH. Developmental changes in pharyngeal airway depth and hyoid bone position from childhood to young adulthood. *Angle Orthod*. 2009;79:484–490.
9. Tangugsorn V, Krogstad O, Espeland L. Obstructive sleep apnea: a canonical correlation of cephalometric and selected demographic variables in obese and nonobese patients. *Angle Orthod*. 2001;71: 23–35.
10. Baccetti T, Franchi L, McNamara JA. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. *Angle Orthod*. 2002;2:316–323.
11. Long H, Wang Y, Jian F, Liao LN, Yang X, Lai WL. Current advances in orthodontic pain. *Int J Oral Sci*. 2016;8:67–75.
12. Liao ZY, Jian F, Long H, et al. Validity assessment and determination of the cutoff value for the Index of Complexity, Outcome and Need among 12–13-year-olds in Southern Chinese. *Int J Oral Sci*. 2012;4:88–93.
13. Jin YF, Chen WJ, Zhu Y. *Tweed-Merrifield Orientation Correction Technology Spectrum*. Vol 2. Chinese ed. Nanjing: Southeast University Press Pub; 2009.
14. Iosif S, Nikolaos P, Margarita M, Theodore E, Christoph B. A comparative assessment of the forces and moments generated at the maxillary incisors between conventional and self-ligating brackets using a reverse curve of Spee NiTi archwire. *Aust Orthod J*. 2010;26:127–133.
15. Pakhan K, Keith G. Calibration of force extension and force degradation characteristics of orthodontic latex elastics. *Am J Orthod Dentofacial Orthop*. 2000;118: 280–287.
16. Young C, Seong CM. Cephalometric evaluation of the anterior open bite treatment. *Am J Orthod Dentofacial Orthop*. 1999;115:29–38.
17. Valiathan M, El H, Hans MG, Palomo MJ. Effects of extraction versus non-extraction treatment on oropharyngeal airway volume. *Angle Orthod*. 2010;80:1068–1074.
18. Ashok KJ, Ritu D. Hyoid bone position in subjects with different vertical jaw dysplasias. *Angle Orthod*. 2011;81:81–85.
19. Tselnik M, Pogrel MA. Assessment of the pharyngeal airway space after mandibular setback surgery. *J Oral Maxillofac Surg*. 2000;58:282–285.
20. Halise A, Ufuk M, Hakan K. Pharyngeal airway space, hyoid bone position and head posture after orthognathic surgery in Class III patients. *Angle Orthod*. 2012;82:993–1000.