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Original Article

Effectiveness of modified periodontally accelerated osteogenic orthodontics in skeletal class II malocclusion treated by a camouflage approach

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Abstract: Skeletal Class II malocclusion is a complex orofacial condition. Here, we translated the single clinical problem to a multidisciplinary approach that combined the periodontal surgery, biomaterial implantation, and orthodontics to treat this condition. This study aimed to explore the clinical effectiveness of modified periodontally accelerated osteogenic orthodontics (PAOO) in adult patients with skeletal Class II discrepancy via a camouflage orthodontic approach. This clinical trial has been registered in the Chinese Clinical Trial Registry (trial number: ChiCTR2100052638, trial URL: http://www.chictr.org.cn/showproj.aspx?proj=135827). A total of 26 adult female patients with similar skeletal Class II malocclusions and similar dental and skeletal discrepancies were enrolled. A total of 13 patients in the experimental group received modified PAOO characterized by vertical incisions in interradicular areas and random punching made by a piezoelectric device, whereas 13 patients in the control group received orthodontic treatment only. All patients underwent extraction of four premolars and orthodontic treatment with the sliding MBT straight-wire technique. Treatment courses were recorded and changes in dental and skeletal parameters were evaluated by cephalometric analysis and translated into upper digital cast for further measurements. The results showed that the durations of the alignment and leveling stage (4.51±1.53 mos versus 9.41±1.46 mos. $P<0.01$), space closing stage (13.56±2.57 mos versus 17.09±3.50 mos. $P<0.05$) and total treatment course (24.43±2.53 mos versus 31.16±4.17 mos. $P<0.01$) in the PAOO group were significantly shorter than in the control. The modified PAOO accelerated orthodontic tooth movement in adult extraction cases with skeletal Class II discrepancy and convex profile; the modified PAOO achieved dual goals of periodontal health and long-term stability of orthodontics. Ultimately, this multidisciplinary approach and the use of translational 3D measurements constitute powerful tools that can be used to solve complex clinical problems.

Keywords: Adult treatment, PAOO, skeletal class II malocclusion, multidisciplinary consideration, 3D measurement

Introduction

Skeletal Class II malocclusion is a complex condition characterized by protrusive maxilla and/or a retrusive mandible, resulting in a convex profile and upright upper incisors [1-3]. A routine method of intervention for such condition involves extraction, torque control of the anterior teeth, anchorage design, and sagittal and vertical control in the treatment of camouflage orthodontic treatment. The orthodontic treatment is time consuming. Corticotomy-assisted orthodontics have been reported to shorten the treatment duration without severe root resorption [4]. Accelerated tooth movement depends on the regional acceleratory phenomenon (RAP) [5], which is a localized osteoporosis state after surgical procedures [6].

Periodontally accelerated osteogenic orthodontics (PAOO) combines selective corticotomy and alveolar bone augmentation, which was first introduced by Wilcko et al. in 2001 [7]. PAOO is used to accelerate orthodontic tooth movement and augment supporting alveolar bones during the orthodontic process [8]. Its effective-

Table 1. Comparison of the skeletal and dental index between the two groups

	PAOO	Control	P*
Female	13	13	
Age (y)	22.66±2.85	24.19±4.25	0.29
Crowding-upper (mm)	2.00±1.35	2.88±2.50	0.35
Crowding-lower (mm)	3.62±2.26	3.42±2.22	0.83
Overjet (mm)	4.99±2.75	4.71±2.43	0.79
Overbite (mm)	2.86±2.43	2.47±1.68	0.63
ANB (°)	7.02±1.83	6.36±1.87	0.38
MP/SN (°)	41.72±7.85	40.45±6.81	0.66
Z angle (°)	54.05±9.63	54.39±10.08	0.95

y, years; ANB angle determined by points Subspinale, Nasion and Supramentale; MP/SN, angle between the lines Sella-Nasion and mandibular plane; Z angle, the posterior lower angle determined by the Frankfort horizontal plane and a line connecting the soft tissue pogonion and most protrusive lip. *Statistically significant at $P<0.05$.

ness has been assessed in several clinical trials and retrospective studies, which usually focus on the management of bimaxillary dentoalveolar protrusion [9], canine retraction for routine extraction cases [10], severe crowding and tooth decompensation before orthognathic surgery [11, 12]. However, no systematic studies have evaluated the application and effectiveness of PAOO in adult extraction cases with skeletal class II discrepancy. Piezocision can minimize the trauma of periodontal surgery, but the deviations in flapless incision may damage important anatomical structures and result in permanent scars [13, 14]. Thus, a modified PAOO is expected to improve RAP activation and reduce the risk of surgical trauma and root injury.

The present study hypothesized that modified PAOO could accelerate tooth movement in adults with skeletal Class II malocclusion treated via a camouflage strategy. The effectiveness of this procedure was evaluated through cephalometric analysis and 3D dental cast analyses before and after treatment.

Material and methods

Subjects

This non-randomized controlled clinical trial (NCCT) was approved by the Ethics Committee of Peking University School and Hospital of Stomatology (approval number: IRB00001052-08061). Twenty-six female individuals were enrolled in this study. The patients that requested orthodontic treatment in the Department of Orthodontics, Peking University School and Hospital of Stomatology between September 2008 and September 2012. The patients in the PAOO group received modified PAOO combined with orthodontic treatment, whereas the patients in the control group received orthodontic treatment only. The patients in both groups were matched in terms of age, primary dental, and skeletal index (**Table 1**).

All patients had similar malocclusion and were diagnosed with skeletal Class II discrepancy with Angle's I or II molar relationship. The inclusion criteria were as follows: 1) age between 18-40 years; 2) skeletal Class II (ANB 4.7°-8°); 3) crowding degree of 1-7 mm; 4) extraction of four premolars (the upper first premolars and the lower second premolars or the first four premolars); and 5) healthy oral status as assessed by a professional periodontist and endodontist (i.e., no untreated periodontal disease, no untreated caries or pulpitis). The exclusion criteria were as follows: 1) serious skeletal discrepancy (ANB>9°) that required orthognathic surgery; 2) temporomandibular joint disorders; 3) aggressive periodontitis; 4) subjects with systemic diseases, oral mucosal diseases, and oral cancer. A comparison of detailed malocclusions between the two groups is shown in **Table 1**.

Sample size calculation

In this study, the effective size for primary outcome (the duration of the alignment and leveling stage) was expected to be 7.33. This value was the average change of duration for the alignment and leveling stage between the two groups (with or without PAOO) we obtained in our preliminary study. The calculation was carried out using ware G*power 3.0.10 software. Based on these parameters, the calculated sample size for the paired samples required to achieve at least 80% power with a type II error rate β of 0.2 while maintaining an α of 5% was estimated to be n=13.

Orthodontic treatment procedures

All subjects received systematic periodontal and endodontic examinations and treatment before orthodontic treatment. The orthodontic

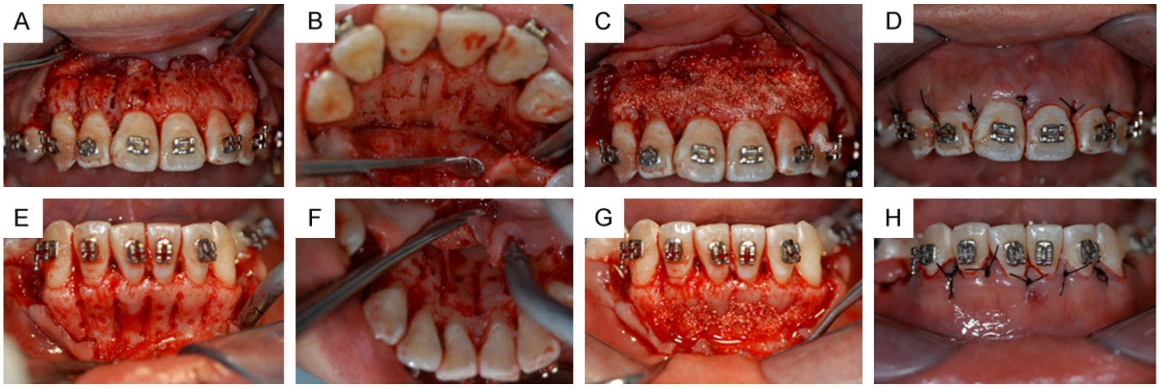

Figure 1. Periodontal surgery procedure. A-D. Surgical reigon for teeth 14-24; E-H. Surgical reigon for teeth 34-44; A, E. Labial view of vertical incisions and randomly perforation in the interradicular spaces from 2 mm below the top of the alveolar ridge to the apical 1/3; B, F. Lingual view; C, G. Bio-Oss spongious bone substitute was grafted; D, H. The periodontal flaps were sutured in situ.

treatment implemented was the MBT straight-wire technique after the extraction of the four premolars. The braces and archwires were obtained from TP Orthodontics (La Porte, IN, USA). In order to ensure comparability between the two groups, the follow-up interval for the alignment and leveling stages was two weeks for both groups. For the space-closing stage, a classic sliding mechanism with a 0.019×0.025 in. stainless steel archwire and an elastic tie-back was used to close the space in both arches. Accordingly, a month of recovery was necessary prior to follow-up for both groups. The alignment and leveling stages began with bracket bonding and ended with a 0.019×0.025 in. stainless steel archwire after using 0.014 in. NiTi, 0.016 in. NiTi, 0.016 in. *0.022 in. NiTi, 0.019 in. *0.025 in. NiTi archwires. The space-closing stage began with a classic sliding mechanism with a 0.019×0.025 in. stainless steel archwire and ended with no space left in the premolar region. The detailing stage started from the end of the space-closing stage and ended with debonding. In this study, miniscrews (diameter: 1.5 mm; length: 7 mm; Zhongbang Medical Treatment Appliance, Xi'an, China) were inserted into the buccal alveolar bone of the maxillary posterior segment between the second premolar and the first molar on both sides under local infiltration anesthesia to enhance maxillary anchorage. An elastic tieback with a single unit of power-chain was tied from the miniscrew to the hook between the lateral incisors and canines. The anchorage was moderate in the lower arch.

Modified PAOO procedure

Patients in the modified PAOO group signed an informed consent before the operation and underwent a modified PAOO within 1 month after the bonding of brackets. The modified PAOO involved vertical incisions in interradicular areas and random punching without subapical corticotomy using piezoelectric devices. The surgical procedure was performed by the same senior periodontist under local anesthesia, and the operation area covered the upper and lower anterior teeth and extraction sockets (14-24, 34-44). After the full-thickness labial and palatal/lingual flaps were elevated, vertical incisions in the interradicular spaces were made using a piezoelectric device from 2 mm below the top of the alveolar ridge to the apical 1/3. The cortical bone around the surface of each tooth was randomly drilled. A Bio-Oss spongious bone substitute (Geistlich, Switzerland) was grafted onto the alveolar bone surface, and the periodontal flaps were sutured *in situ* to reduce the risk of postoperative alveolar bone absorption and gingival recession. A representative PAOO procedure is shown in **Figure 1**.

Cephalometric measurements

Dental and skeletal parameters were evaluated by cepahlomatric analysis. All lateral cephalometric radiographs were acquired using a digital cephalometer ORTHOPANTOMOGRAPH® OP200 (Instrumentarium, Finland) and analyzed using Dolphin 11.8 Premium software. The observer was blinded to sample informa-

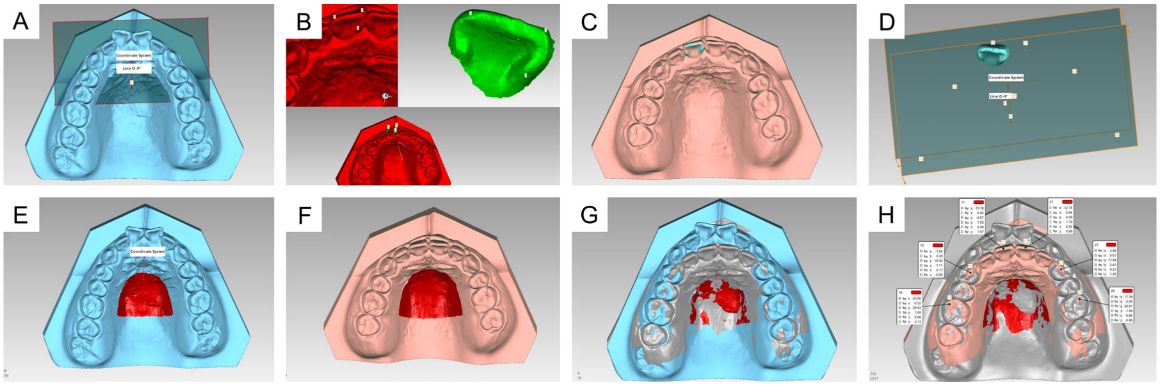

Figure 2. The 3D measurement of tooth movement between pre-treatment and post-treatment digital models. A. Coordinate system was created on the pre-treatment model; B-D. Feature points were defined on pre-treatment model and copied to post-treatment model by overlapping the models locally; E-G. Models were aligned by overlapping the maxillary stable zone; H. The spatial changes of teeth were quantified.

tion and repeated the procedure twice in 1 week intervals. All tracings and measurements were performed following the same routine method and the average of two measurements was obtained. Time 1 (T1) and time 2 (T2) represent the timepoints before and after the treatment, respectively.

Upper dental cast analysis

Upper dental casts before and after orthodontic treatment were scanned using a 3DTALK Discover scanner (scanning accuracy, 0.05 mm; 3DTALK, Jiangsu, China). Laser-scanned images were imported into the Geomagic Qualify 2013 software (Geomagic, America) and reverse engineering was used to analysis the three-dimensional movement of teeth. The color-coded map of the digital models are shown in **Figure 2**. The facial axis of the clinical crown was transferred from pretreatment teeth to posttreatment teeth via three-dimensional imaging registration. Surface-based superimposition of the models before and after treatment was performed using the stable structures of the hard palate [15, 16]. The medial two thirds of the third ruga and the regional palatal vault dorsal associated with it were used as stable structures for 3D digital model superimposition to evaluate orthodontic tooth movement as previously described by Chen et al. [17]. The 3D Euclidean distances of the two superimposed surfaces were measured, and the results were evaluated on the basis of a color-coded map. A three-dimensional coordinate system was established using the anatomic occlusal plane in which the mark points on the teeth surface of the post-treatment model were transferred and measured on the pre-treatement occlusal plane. The three-dimensional movement of teeth in the saggital (X), vertical (Y), and horizontal (Z) directions of the upper central incisor, canine, and first molars were measured. The width between upper canines and the upper first molars were recorded [17], with positive directions defined as distal, buccal and occlusal. We measured the movement of bilateral teeth and took the average value of both sides for statistical analysis.

Statistical analysis

The SPSS16.0 software package (IBM Corp, Armonk, NY) was used for data analysis and to determine intraclass correlation coefficients (ICC), which served as a measure of the examiner's reliability. The data conformed to normal distribution. A paired t-test was then used to analyze treatment duration in each group and the cephalometric results before and after orthodontic treatment. $P<0.05$ indicates statistical significance.

Results

Patient characteristics before orthodontic treatment

The intra-observer reliability of dental and skeletal changes in the two groups was high for the observer (ICC: 0.915-0.973). The intra-observer reproducibility of measurements was high

Table 2. Comparison of the treatment duration between the two groups

	PAOO	Control	P
Alignment (month)	4.51±1.53	9.41±1.46	0.00**
Space closing (month)	13.56±2.57	17.09±3.50	0.01*
Detailing (month)	6.36±1.66	4.66±2.34	0.06
Total duration (month)	24.43±2.53	31.16±4.17	0.00**

*Statistically significant at $P<0.05$, **$P<0.01$.

(all ICC>0.8). No systematic errors were detected when paired t-test was applied.

Patients in both the modified PAOO group (aged 22.66±2.85 years, age range: 18.92-26.25 years) and control group (aged 24.19±4.25 years, age range: 18.75-34.67 years) consisted of 13 female adults. Space analyses were performed on the study modes. The results showed crowding at 2.00±1.35 mm in the experimental group and 2.88±2.50 mm in the control group in the maxilla. The crowding of the lower arch for the two groups was observed at 3.62±2.26 and 3.42±2.22 mm, respectively. Relevant dental and skeletal items were measured and analyzed via cephalometry before orthodontic treatment. All patients in both groups were diagnosed with skeletal Class II malocclusion. The two groups were statistically homogeneous in terms of SNA angle, SNB angle, ANB angle, MP/SN, U1/SN, U1-NA, L1/MP, L1-NB, and Z angle. No significant differences were observed between the two groups with regard to skeletal and dental malocclusions before treatment ($P>0.05$). The results are shown in **Table 1**. All the patients underwent the full process of orthodontic treatment.

Treatment course of the experimental group and control group

The entire treatment course and durations of alignment and leveling stage, space-closing stage, and detailing stages for both groups can be found in **Table 2**.

In the experimental group, the durations of the leveling stage, space-closing stage, and detailing stages were 24.43±2.53, 4.51±1.53, 13.56±2.57, and 6.36±1.66 months, respectively; in the control group, the durations were 31.16±4.17, 9.41±1.46, 17.09±3.50, and 4.66±2.34 months, respectively. Differences in the entire treatment course and durations of alignment and leveling duration, and space-closing stages between the two groups were statistically significant ($P<0.01$, $P<0.01$, $P<0.05$, respectively). However, the difference in durations of detailing stage between the two groups was not statistically significant ($P>0.05$).

Clinical outcomes of modified PAOO-assisted orthodontic treatment-Results of cephalometric analysis

The results of the cephalometric analysis before and after orthodontic treatment are shown in **Table 3**.

The ANB angle decreased by 1.59°±0.99° (PAOO group) versus 1.48°±1.01° (control group). The U1/SN angle representing anterior teeth inclination decreased by 10.47°±3.05° (PAOO group) versus 7.46°±7.45° (control group). The mandibular plane angle MP/SN decreased by 1.08°±2.39° (PAOO group) versus 0.97°±2.41° (control group). Based on photographs of the patients, the treatment resulted in alignment of the upper and lower arches, neutral molar relationship, normal overbite and overjet, and a good profile. However, the differences in changes in cephalometric measurements before and after the treatment between both groups were not statistically significant ($P>0.05$).

Clinical outcomes of modified PAOO-assisted orthodontic treatment-results of upper cast analysis

The upper dental casts were also overlapped and measured before and after the treatment (**Table 4**). Three-dimensional movements in the saggital, horizontal, and vertical planes of the upper central incisors, canines, and first molars were measured. The width between the upper canines and the upper first molars were recorded. Results showed that the upper central incisors and canines were obviously retracted. The first molars showed slight movement mesially. The 3-3 width marginally increased, whereas the 6-6 width decreased. Additionally, both the overjet and overbite obviously decreased. However, no significant difference was found between the two groups according to the results of the upper model analysis ($P>0.05$).

Typical case

A 26-year-old female patient presented with complaints of irregular teeth and a protrusive mouth.

Table 3. Comparison of the treatment changes (post- and pre-treatment) of cephalometric analysis between the two groups

Variable	PAOO	PAOO	P	Control	Control	P	PAOO	Control	P*
	Pre-Tx	Post-Tx		Pre-Tx	Post-Tx		post-pre	post-pre	
SNA (°)	83.65±3.32	81.50±3.43	0.00**	82.44±4.89	81.07±4.17	0.00**	-2.15±2.12	-1.37±1.17	0.25
SNB (°)	76.65±3.99	76.05±4.02	0.24	76.05±4.37	76.19±4.41	0.68	-0.59±1.71	0.15±1.25	0.22
ANB (°)	7.02±1.83	5.42±1.71	0.00**	6.36±1.87	4.89±1.59	0.00**	-1.59±0.99	-1.48±1.01	0.77
MP/SN (°)	41.72±7.85	40.63±6.76	0.13	40.45±6.81	39.48±6.94	0.17	-1.08±2.39	-0.97±2.41	0.9
U1/SN (°)	108.08±6.52	97.61±6.36	0.00**	106.71±8.67	99.25±7.42	0.00**	-10.47±3.05	-7.46±7.45	0.19
U1-NA (mm)	5.85±1.94	1.81±1.64	0.00**	5.75±2.95	1.65±1.82	0.00**	-4.05±1.24	-4.11±2.99	0.95
L1/MP (°)	97.55±7.77	93.69±8.04	0.10	100.62±4.18	92.58±7.61	0.00**	-3.85±7.84	-8.04±7.39	0.17
L1-NB (mm)	10.05±2.51	6.35±1.96	0.00**	9.79±2.41	5.43±2.28	0.00**	-3.70±2.69	-4.36±2.98	0.57
Z angle (°)	54.05±9.63	67.10±9.01	0.00**	54.39±10.08	67.82±9.42	0.00**	13.05±6.20	13.42±7.19	0.89
Overjet (mm)	4.99±2.75	1.90±0.51	0.00**	4.71±2.43	1.89±0.31	0.00**	-3.08±2.44	-2.82±2.43	0.78
Overbite (mm)	2.86±2.43	1.21±0.61	0.02*	2.47±1.68	1.26±0.72	0.02*	-1.65±2.31	-1.21±1.64	0.58

Pre-Tx, before orthodontic treatment; Post-Tx, after orthodontic treatment; post-pre, the value after treatment minus the value before treatment; SNA, angle determined by points Sella, Nasion and Subspinale; SNB, angle determined by points Sella, Nasion and Supramentale; ANB angle determined by points Subspinale, Nasion and Supramentale; MP/SN, angle between the lines Sella-Nasion and mandibular plane; U1/SN, angle between the line Sella-Nasion and a line connecting Maxillary incisor apex and tip; U1-NA: distance between the incisal edge of the maxillary incisor and Nasion-Subspinale line; L1/MP, angle between the line connecting Mandibular incisor apex and tip and the mandibular plane; L1-NB: distance between the incisal edge of the mandibular incisor and the Nasion-Supramentale line; Z angle, the posterior lower angle determined by the Frankfort horizontal plane and a line connecting the soft tissue pogonion and most protrusive lip. *Statistically significant at $P<0.05$, $^{**}P<0.01$.

Table 4. Comparison of the treatment changes (post- and pre-treatment) of upper dental casts analysis between the two groups

Variable	PAOO	Control	P*
1-X (mm)	6.70±1.68	6.93±1.58	0.73
1-Y (mm)	0.20±0.98	-0.47±1.29	0.55
1-Z (mm)	0.31±1.94	-0.29±1.41	0.37
3-X (mm)	5.56±1.84	6.55±1.20	0.12
3-Y (mm)	-0.41±1.04	-0.53±0.98	0.77
3-Z (mm)	0.16±1.88	-0.62±1.23	0.22
6-X (mm)	-1.71±1.38	-0.81±0.87	0.06
6-Y (mm)	-0.05±0.95	0.16±0.77	0.54
6-Z (mm)	-0.37±1.46	-0.93±1.59	0.36
3-3 W (mm)	1.69±1.51	1.06±2.35	0.43
6-6 W (mm)	-2.14±1.10	-1.38±1.97	0.23

1, upper central incisor; X, sagittal axis; Y, vertical axis; Z, horizontal axis; 3, upper canine; 6, upper first molar; 3-3 W, the width between the upper canines; 6-6 W, the width between the upper first molars.

A clinical examination found the following: permanent dentition; bilaterally neutral molar relationship; slightly anterior deep overbite and deep overjet; mild crowding in the upper and lower arches. The patient showed a convex profile with maxillary protrusion, mandibular retraction, and gingival smile.

X-rays showed that the patient was a skeletal Class II high-angle case. Photographs and X-rays before treatment are shown in **Figure 3**.

Four first premolars were extracted from this patient, and a standard MBT straight wire technique was performed. Modified PAOO operations were performed on the upper and lower anterior teeth two weeks after the bonding of the orthodontic appliances (**Figure 4**). The sequential archwire used for the aligning and leveling stages were generally 0.014 in. NiTi, 0.016 in. NiTi, 0.016×0.022 in. NiTi, and finally 0.019×0.025 in. NiTi. The appointment interval of the aligning and leveling stages was 2 weeks. The upper and lower arches were rapidly aligned after 2.5 months. Photographs of the treatment progress at 12 and 18 months are shown in **Figure 2**. The entire treatment ended after 21 months. Closed space, normal anterior overbite and overjet, and greatly improved profile were observed (**Figure 5**).

After 6 years of follow-up (**Figure 5**), the patient presented with maintained alignment of upper and lower arches, neutral molar and canine relationship, normal anterior overbite and overjet, and a good profile.

Discussion

Modified PAOO can accelerate orthodontic tooth movement in adult extraction cases, especially in the early stages after surgery

Most studies recommended the shortening of the interval between visits and immediate com-

Figure 3. Photographs and X-rays of the typical case before treatment.

Figure 4. The photographs of corticotomy operation and 12 and 18 months of treatment progress for the typical case.

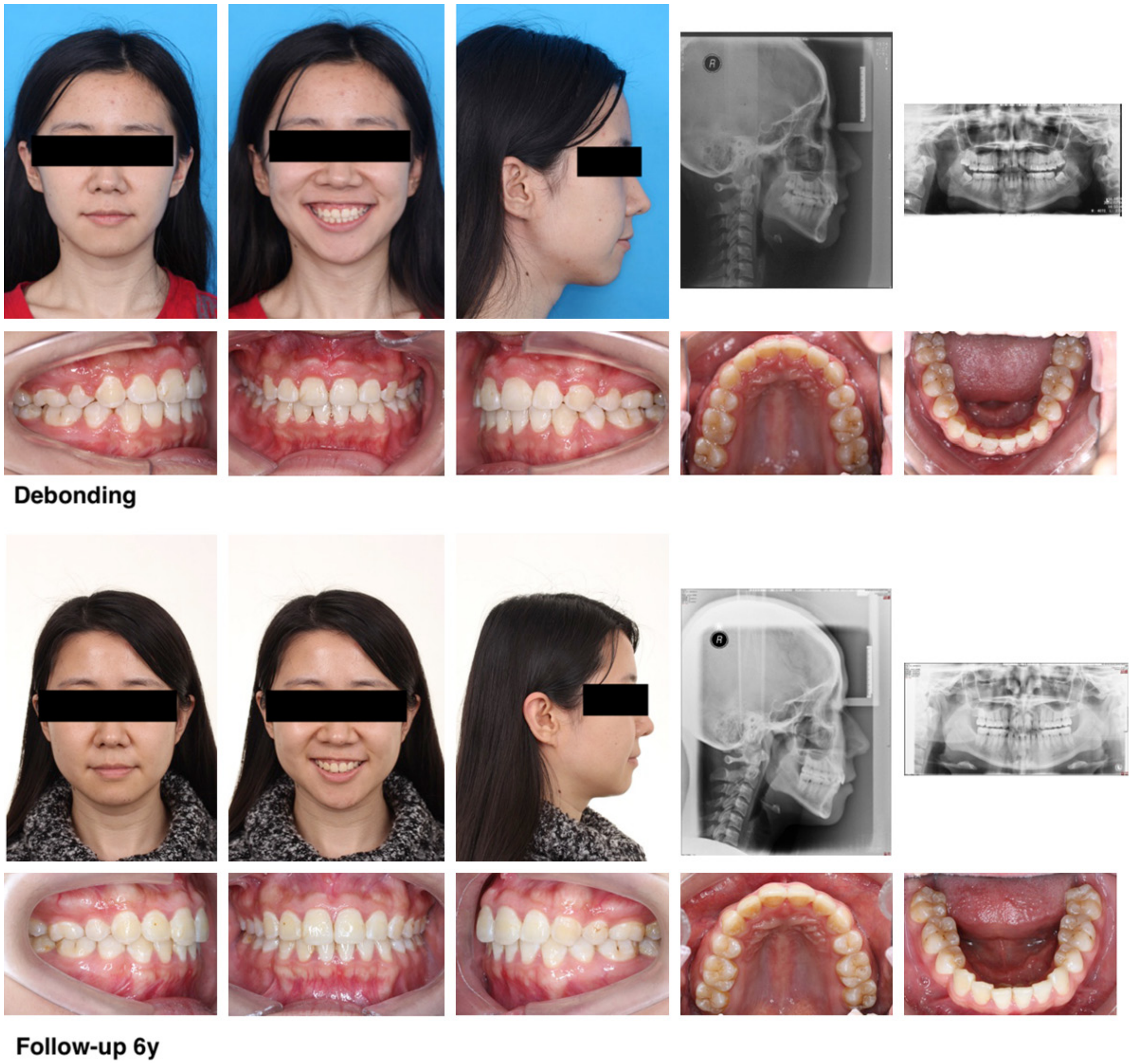

Figure 5. The photographs of the typical case after treatment and 6 years follow up.

pletion of active tooth movement after PAOO [18]. In the present study, cortical bone incision was conducted within 1 month after appliance bonding, and light force was applied during orthodontic treatment. In order to reduce the surgical trauma, minimize the risk of damaging the root, and maintaining stimulation to the alveolar bone, we performed a modified PAOO. The vertical groove in the interradicular alveola bone was maintained. The cortical bone around the surface of each tooth was randomly drilled in the modified PAOO, the RAP effect on bone was not weakened.

Obvious tooth movement was observed at an early stage after surgery. Results showed significant differences during the initial stages of alignment and leveling, space closing, and total duration. The alignment and leveling stage was considered to be completed when the stainless steel archwire was able to slide into the slot without resistance. Therefore, the alignment and leveling stage in the control group required a relatively long duration.

We did not observe noticeable advantages in shortening the course of detailing course in this study, unlike previous study [14]. Charavet et al. reported that cumulative time substantially decreased as each archwire was changed in the piezocision group compared with the control group. A possible reason for this observation was that relatively minor dentomaxilla discrepancy was included in their randomized control trial. The findings of the present study may be explained by the complexity of malocclusion for skeletal adult patients with various controls and adjustments. Besides, the detailing stage was longer in the PAOO group than in the control group, although the difference in length was not statistically significant. The underlying reason for longer detailing stage in the PAOO group may be that the mean MP/SN was larger in the PAOO group than in the control group without showing statistical difference. Five patients in the PAOO group showed severe high angles, and we performed vertical control to rotate the mandible counterclockwise to improve the profile. Thus, this procedure led to the partial open bite of the posterior teeth and a relatively long duration for the detailing stage to adjust the occlusion. These results suggest that the timing of operation for the modified PAOO should be based on individual requirements. For example, the operation should be performed immediately for cases with severe crowding. However, the operation may be delayed for the space closing stage in patients with mild crowding and protrusive profiles.

Corticomy combined with extraction orthodontics in adults exhibited good results.

In this study, both groups achieved good camouflage treatment results. Although the PAOO group showed no greater advantage in the items examined, it obtained obvious anterior teeth retraction and sufficient torque control in a shorter treatment duration than the control group.

We evaluated the torque of the upper and lower anterior teeth and the retraction of the upper anterior teeth by cephalometric analysis and model analysis. Although cephalometric and dental cast analyses revealed no significant differences between the two groups, the treatment outcomes in both groups were satisfactory and indicated significant anterior retraction effect, good dentition alignment, occlusions, and profiles. Besides, the course of treatment in the PAOO group was significantly shorter than in the control group, which might indicate the PAOO procedure facilitates tooth movement and torque control for adult skeletal Class II malocclusions. Although the reduction of treatment course was not as significant as reported in other studies, treatment times may be related to the difficulty of treatment in patients with an adult skeletal Class II discrepancy. The treatment of skeletal Class II malocclusion has distinct characteristics and difficulties. The difficulty lies in the improvement of patients' facial aesthetic and torque control during the retraction of anterior teeth. In this study, we used TAD to enhance anchorage and achieve good treatment effects with significantly improved profiles (Z Angle increased by 13.05±6.20°) and occlusions.

Corticotomy or PAOO-assisted orthodontic treatment is effective for severe crowding or incisor retraction [19, 20]. However, associated reports are often limited to case reports, non-extraction treatments, or the period of space-closing for extraction treatment. All 26 patients enrolled in this study showed skeletal Class II discrepancy before treatment. In general, the modified PAOO combined with extraction orthodontics generally achieved good treatment effects with good occlusion relationships and profiles. The patients were instructed to wear a conventional retainer for at least 2 years.

The PAOO procedure can increase the stability of orthodontic treatment because periodontal surgery can increase alveolar bone turnover rate and separate periodontal ligament fibers, which are responsible for tooth movement from the surface of the tooth root. Thus, the physical memory of the original position is changed, and the probability of relapse is reduced [7, 21]. An increase in the amount of alveolar bone after surgery contributes to a decrease in risk of relapse after orthodontic treatment. PAOO associated bone grafting increases bone mass, thus substantially increasing the thickness of attached gingiva and reducing alveolar bone fenestration [22, 23]. In a retrospective study, Brugnami F et al. found that bone grafting can increase the limit of orthodontic tooth movement when compared with corticotomy without bone graft. However, the issue of whether the modified PAOO can increase the stability of orthodontic treatment remains to be determined.

Limitations and prospects of the modified PAOO combined with extraction orthodontics in adults

Root resorption, alveolar bone fenestration, and gingival recession are the most significant complications associated with adult orthodontic treatment. The risks are mainly related to the long distance of tooth movement, intrusive force, and possible torque control [24]. Recently, the use of flapless tools, including piezoelectric devices, and flapless strategies, including micro-osteoperforations and piezocision, have been proposed to reduce surgery trauma in periodontal tissues [25-27]. However, performing these techniques without grafting cannot reduce the risk of bone dehiscences and fenestrations over vital root surfaces. Bhattacharya P et al. proposed combining corticotomy with bone grafting in the upper anterior teeth to increase the thickness of supporting alveolar bone. Additionally, a randomized controlled clinical trial studied the effect of corticotomy on the labial side of the lower anterior teeth with moderate crowding for the treatment of adult patients. This study suggests that corticotomy can effectively shorten the course of treatment and reduce root resorption. In addition, it was found that the use of bovine-derived Xenografts can effectively increase bone density [28]. Despite the high accuracy of computer-guided piezocision, deviations remain in the entry point and cutting depth between the planned and actual cutting. The modified PAOO applied in our study can minimize the risks associated with grafting.

The panoramic X-rays of the patients showed that root resorption occurred after orthodontic treatment in both groups (data not shown). However, most of the resorption degrees were mild, a result consistent with previous studies on corticotomy or PAOO combined with orthodontics [29, 30]. However, cone beam CT is required to determine whether this procedure can reduce root resorption in the anterior teeth during extraction orthodontics in adults.

In addition, this study is not a randomized controlled trial and the sample size is small. Hence, a more rigorous randomized controlled study with a larger sample is needed to confirm the current results. Nevertheless, the two groups in this study were matched in terms of age, gender, malocclusion type, and orthodontic processes. The results indicate the advantages of modified PAOO in facilitating orthodontic tooth movement for adult patients with skeletal class II malocclusion. Moreover, the results suggest that periodontally accelerating techniques should be used at appropriate times and within approximately 6 month period after surgery to promote orthodontic tooth movement.

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Disclosure of conflict of interest

None.

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References

[1] Ishida Y and Ono T. Nonsurgical treatment of an adult with a skeletal class II gummy smile using zygomatic temporary anchorage devices and improved superelastic nickel-titanium alloy wires. Am J Orthod Dentofacial Orthop 2017; 152: 693-705.
[2] Wang XD, Zhang JN, Liu DW, Lei FF, Liu WT, Song Y and Zhou YH. Nonsurgical correction using miniscrew-assisted vertical control of a severe high angle with mandibular retrusion and gummy smile in an adult. Am J Orthod Dentofacial Orthop 2017; 151: 978-988.
[3] Wang X, Li X, Chen K and Hu J. Treatment of skeletal Class II malocclusion by orthodontic and surgical means. Hua Xi Kou Qiang Yi Xue Za Zhi 2000; 18: 37-39.
[4] Kole H. Surgical operations on the alveolar ridge to correct occlusal abnormalities. Oral Surg Oral Med Oral Pathol 1959; 12: 413-420 contd.
[5] Frost HM. The regional acceleratory phenomenon: a review. Henry Ford Hosp Med J 1983; 31: 3-9.

[6] Yaffe A, Fine N and Binderman I. Regional accelerated phenomenon in the mandible following mucoperiosteal flap surgery. J Periodontol 1994; 65: 79-83.
[7] Wilcko WM, Wilcko T, Bouquot JE and Ferguson DJ. Rapid orthodontics with alveolar reshaping: two case reports of decrowding. Int J Periodontics Restorative Dent 2001; 21: 9-19.
[8] Nowzari H, Yorita FK and Chang HC. Periodontally accelerated osteogenic orthodontics combined with autogenous bone grafting. Compend Contin Educ Dent 2008; 29: 200-206; quiz 207, 218.
[9] Singh S and Jayan B. Comparative evaluation of periodontally accelerated osteogenic orthodontics (PAOO) versus conventional orthodontic tooth movement in adult patients with bimaxillary dentoalveolar protrusion. Int J Periodontics Restorative Dent 2019; 39: 571-577.
[10] Thind SK, Chatterjee A, Arshad F, Sandhu PS, Thind MS and Nahin J. A clinical comparative evaluation of periodontally accelerated osteogenic orthodontics with piezo and surgical bur: an interdisciplinary approach. J Indian Soc Periodontol 2018; 22: 328-333.
[11] Wu J, Xu L, Liang C and Jiang J. Class III orthognathic surgical cases facilitated by accelerated osteogenic orthodontics: a preliminary report. Aust Orthod J 2015; 31: 226-235.
[12] Yu H, Jiao F, Wang B and Shen SG. Piezoelectric decortication applied in periodontally accelerated osteogenic orthodontics. J Craniofac Surg 2013; 24: 1750-1752.
[13] Cassetta M and Ivani M. The accuracy of computer-guided piezocision: a prospective clinical pilot study. Int J Oral Maxillofac Surg 2017; 46: 756-765.
[14] Charavet C, Lecloux G, Bruwier A, Rompen E, Maes N, Limme M and Lambert F. Localized piezoelectric alveolar decortication for orthodontic treatment in adults: a randomized controlled trial. J Dent Res 2016; 95: 1003-1009.
[15] Bailey LT, Esmailnejad A and Almeida MA. Stability of the palatal rugae as landmarks for analysis of dental casts in extraction and nonextraction cases. Angle Orthod 1996; 66: 73-78.
[16] Duran GS, Gorgulu S and Dindaroglu F. Three-dimensional analysis of tooth movements after palatal miniscrew-supported molar distalization. Am J Orthod Dentofacial Orthop 2016; 150: 188-197.
[17] Chen G, Chen S, Zhang XY, Jiang RP, Liu Y, Shi FH and Xu TM. Stable region for maxillary dental cast superimposition in adults, studied with the aid of stable miniscrews. Orthod Craniofac Res 2011; 14: 70-79.
[18] Aljhani AS and Zawawi KH. Nonextraction treatment of severe crowding with the aid of corticotomy-assisted orthodontics. Case Rep Dent 2012; 2012: 694527.
[19] Choo H, Heo HA, Yoon HJ, Chung KR and Kim SH. Treatment outcome analysis of speedy surgical orthodontics for adults with maxillary protrusion. Am J Orthod Dentofacial Orthop 2011; 140: e251-262.
[20] Murphy KG, Wilcko MT, Wilcko WM and Ferguson DJ. Periodontal accelerated osteogenic orthodontics: a description of the surgical technique. J Oral Maxillofac Surg 2009; 67: 2160-2166.
[21] Germec D, Giray B, Kocadereli I and Enacar A. Lower incisor retraction with a modified corticotomy. Angle Orthod 2006; 76: 882-890.
[22] Wu J, Jiang J, Xu L, Liang C, Li C and Xu X. Alveolar bone thickness and root length changes in the treatment of skeletal class III patients facilitated by improved corticotomy: a cone-beam CT analysis. Zhonghua Kou Qiang Yi Xue Za Zhi 2015; 50: 223-227.
[23] Agrawal AA, Kolte AP, Kolte RA, Vaswani V, Shenoy U and Rathi P. Comparative CBCT analysis of the changes in buccal bone morphology after corticotomy and micro-osteoperforations assisted orthodontic treatment-case series with a split mouth design. Saudi Dent J 2019; 31: 58-65.
[24] Kurol J and Owman-Moll P. Hyalinization and root resorption during early orthodontic tooth movement in adolescents. Angle Orthod 1998; 68: 161-165.
[25] Xu X, Xu L, Jiang J, Liang C, Wu J and Wang X. A clinical study of the effect of modified corticotomy on periodontium. Zhonghua Kou Qiang Yi Xue Za Zhi 2014; 49: 343-346.
[26] Yi J, Xiao J, Li Y, Li X and Zhao Z. Efficacy of piezocision on accelerating orthodontic tooth movement: a systematic review. Angle Orthod 2017; 87: 491-498.
[27] Alikhani M, Raptis M, Zoldan B, Sangsuwon C, Lee YB, Alyami B, Corpodian C, Barrera LM, Alansari S, Khoo E and Teixeira C. Effect of micro-osteoperforations on the rate of tooth movement. Am J Orthod Dentofacial Orthop 2013; 144: 639-648.
[28] Bahammam MA. Effectiveness of bovine-derived xenograft versus bioactive glass with periodontally accelerated osteogenic orthodontics in adults: a randomized, controlled clinical trial. BMC Oral Health 2016; 16: 126.
[29] Moon CH, Wee JU and Lee HS. Intrusion of overerupted molars by corticotomy and orthodontic skeletal anchorage. Angle Orthod 2007; 77: 1119-1125.
[30] Chung KR, Oh MY and Ko SJ. Corticotomy-assisted orthodontics. J Clin Orthod 2001; 35: 331-339.