Original Article

Changes in glenoid fossa of adult female patients with Class II division 1 malocclusion during premolar extraction treatment and mini-implant anchorage: a cone-beam computed tomography study

Xiao-Chuan Fan[a]; Lin-Sha Ma[b]; Marco Aoqi Rausch[c]; Li Chen[d]; Qing Zhang[e]; Diwakar Singh[f]; Xiaohui Rausch-Fan[g]; Xiao-Feng Huang[h]

ABSTRACT

Objectives: To evaluate changes in glenoid fossa morphology before, during, and after orthodontic treatment with extractions.

Materials and Methods: Eighty-four cone-beam computed tomograms from 28 adult female patients with Angle Class II, division 1 malocclusion, who underwent orthodontic treatment involving premolar extraction and mini-implant insertion, were collected at three time points: before treatment (T0), during treatment (just before extraction space closure, T1), and after treatment (T2). Changes in the morphology of the glenoid fossa and the relationship of the anterior teeth among T0, T1, and T2 were recorded.

Results: Inclination of the articular eminence (AEI-BFL and AEI-TRL) increased from T1 to T2 and from T0 to T2, whereas the width of the glenoid fossa (GFW) decreased from T1 to T2 and from T0 to T2. Changes in depth of the glenoid fossa (GFD) and the ratio of GFW to GFD were observed only in T0–T2. The height of the articular eminence (AEH) showed no significant differences among the three time points. Except for incisor overbite, which decreased from T0 to T1 and then to T2, all other dental parameters showed differences only in T1–T2 and T0–T2.

Conclusions: Orthodontic treatment with extractions can induce adaptive morphological changes in the glenoid fossa, primarily during the stage of extraction space closure. These changes are mainly characterized by a steeper AEI and a reduction in GFW. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Articular eminence; Cone-beam computed tomography; Glenoid fossa; Mini-implant; Premolar extraction

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INTRODUCTION

There are a large number of direct and indirect factors that may affect temporomandibular joint (TMJ) morphology, including tooth inclination, dental arch morphology, occlusion changes, TMJ osteoarthritis, internal derangements, posterior tooth loss, and variations in muscle activity.[1–3] Among these, occlusion is frequently cited as one of the major etiological factors.[4]

Orthodontic treatment, especially with fixed appliances, is a common clinical method for changing occlusion and has a potential role in the possible recovery consequent

[a] Associate Chief Physician and Lecturer, Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, Beijing, PR China.
[b] Attending Doctor and Lecturer, Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, Beijing, PR China.
[c] Resident and PhD Candidate, Division of Orthodontics, University Clinic of Dentistry, Medical University of Vienna, Wien, Austria.
[d] Associate Professor, Department of Orthodontics, Beijing Stomatological Hospital & School of Stomatology, Capital Medical University, Beijing, PR China.
[e] Radiologic Technologist, Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, Beijing, PR China.
[f] PhD Candidate, Center for Clinical Research, University Clinic of Dentistry, Medical University of Vienna, Wien, Austria.
[g] Professor and Head, Center for Clinical Research, Division of Periodontology and Conservative Dentistry, University Clinic of Dentistry, Medical University of Vienna, Wien, Austria.
[h] Professor and Head, Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, Beijing, PR China.
Corresponding author: Dr Xiao-Feng Huang, Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, No.95 Yong'an Road, Xicheng District, Beijing 100050, PR China
(e-mail: huangxf1998@163.com)

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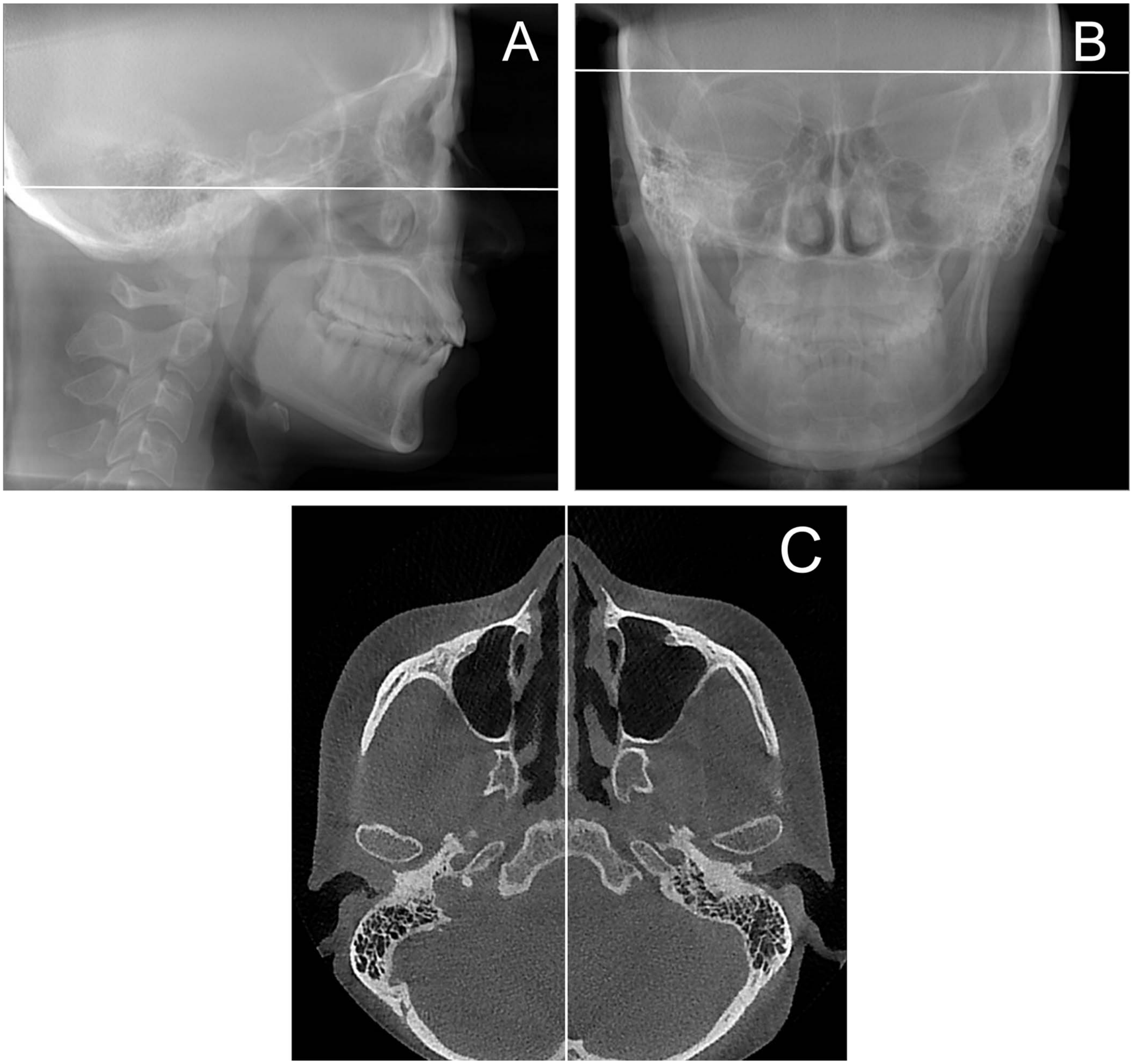

Figure 1. (A) Horizontal plane; (B) Transverse plane; (C) Anteroposterior plane.

to the correction of malocclusion. Recently, interest in the relationship among occlusal factors, orthodontic treatment, and the TMJ has grown, and the question about whether orthodontic treatment can promote adaptive modification of the TMJ has been addressed in many current research studies.[5] As early as 1977, Mongini[6] proposed that changes in occlusal relationships may lead to adaptive anatomical remodeling of TMJ morphology. The study by Shi et al.[7] investigated morphological changes of the condylar bone after fixed orthodontic treatment. Enami et al.[8] described the changes in condylar position and morphology that occurred in Class III patients after orthognathic surgery. Additionally, some studies have reported condylar remodeling after functional appliance therapy.[9–11]

After reviewing the previous research, it is revealed that only a few studies to date have focused on the glenoid fossa. Nevertheless, the glenoid fossa plays a fundamental role in functional movement, as the condyle slides toward the articular eminence of the temporal bone. The inclination of the articular eminence (AEI) has a significant influence on the dynamic path and form of the mandible and is, therefore, considered as the functional component of the glenoid fossa.[12] However, it is surprising that studies dealing with adaptive morphological remodeling of the glenoid fossa are rare; changes during the

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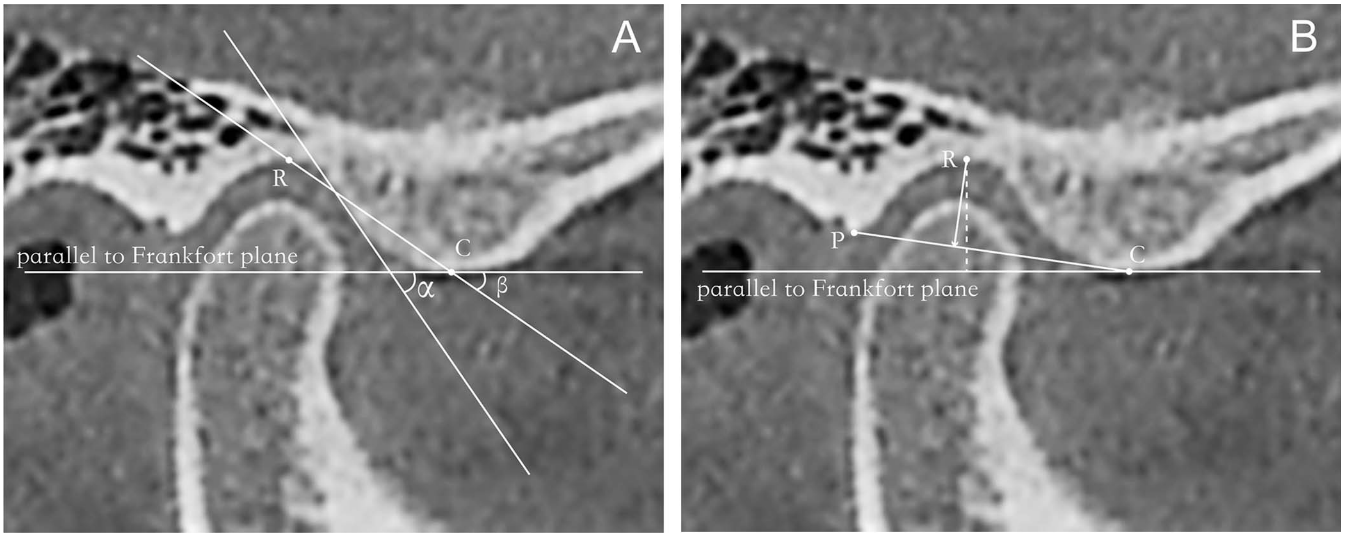

Figure 2. (A) Articular eminence inclination measured with the best-fit line method (α) and the top-roof line method (β); (B) Width of the glenoid fossa (GFW, line P-C); Depth of the glenoid fossa (GFD, arrow); Height of the articular eminence (AEH, dotted line).

different stages of fixed orthodontics have not been sufficiently analyzed.

Therefore, the purpose of this study was to evaluate changes in the glenoid fossa before, during, and after fixed orthodontic treatment with first premolar extraction and mini-implant anchorage in adult female patients with Angle Class II, division 1 malocclusion, using cone-beam computed tomography (CBCT). The findings of this study might provide the necessary reference for a possible association between orthodontic treatment, malocclusion, and the TMJ.

MATERIALS AND METHODS

Data Collection

This study was conducted at the Department of Stomatology, Beijing Friendship Hospital, Capital Medical University, and it received approval from the Ethical Committee of Beijing Friendship Hospital (approval number: 2021-P2-008-01). CBCT data were collected from January 2016 to December 2020 from patients diagnosed with Angle Class II, division 1 malocclusion who underwent orthodontic treatment along with upper and lower first premolar extraction and mini-implant insertion at the infrazygomatic crest to retract the upper anterior teeth under absolute anchorage in the Department of Stomatology, Beijing Friendship Hospital, Capital Medical University. All patients were treated by orthodontists with over 10 years of experience, and the entire treatment process followed standard orthodontic treatment procedures.

To ensure that the tubercle and the fossa were fully developed,[13,14] the inclusion criteria were as follows: (1) participants were at least 20 years old and female; (2) Angle Class II, division 1 malocclusion; (3) complete permanent dentition, except for third molars; (4) whole-cranial CBCT scans were obtained at the first visit (T0), just after mini-implant insertion and full alignment of the teeth (T1), and at the completion of orthodontic treatment (T2); (5) sufficient image sharpness and contrast to visualize the structures. The exclusion criteria included: (1) temporomandibular disorders based on DC/TMD; (2) pathology in the region evaluated in the CBCT examinations; (3) craniofacial anomalies or systemic diseases; (4) severe crowding of the dental arch; (5) anterior open bite and posterior crossbite or locked bite. After applying the

Table 1. Measurement Parameters of the Glenoid Fossa

Measurement Parameters	Abbreviations	Definition
Articular eminence inclination with best-fit line method	AEI-BFL	The angle between the tangent line to the posterior slope of the articular eminence and a line parallel to the FH plane
Articular eminence inclination with top-roof line method	AEI-TRL	The angle between the line connecting the crest of the articular eminence to the roof of the glenoid fossa and a line parallel to the FH plane
Width of the glenoid fossa	GFW	The distance between the crest of the articular eminence and the posterior aspect of the glenoid process
Depth of the glenoid fossa	GFD	The perpendicular distance from the highest point of the glenoid fossa to the GFW line
Ratio of GFW to GFD	GFW/GFD	The arithmetic ratio of the GFW to the GFD
Height of articular eminence	AEH	The vertical distance between the highest point of the glenoid fossa and the line parallel to the FH plane passing through the crest of the articular eminence

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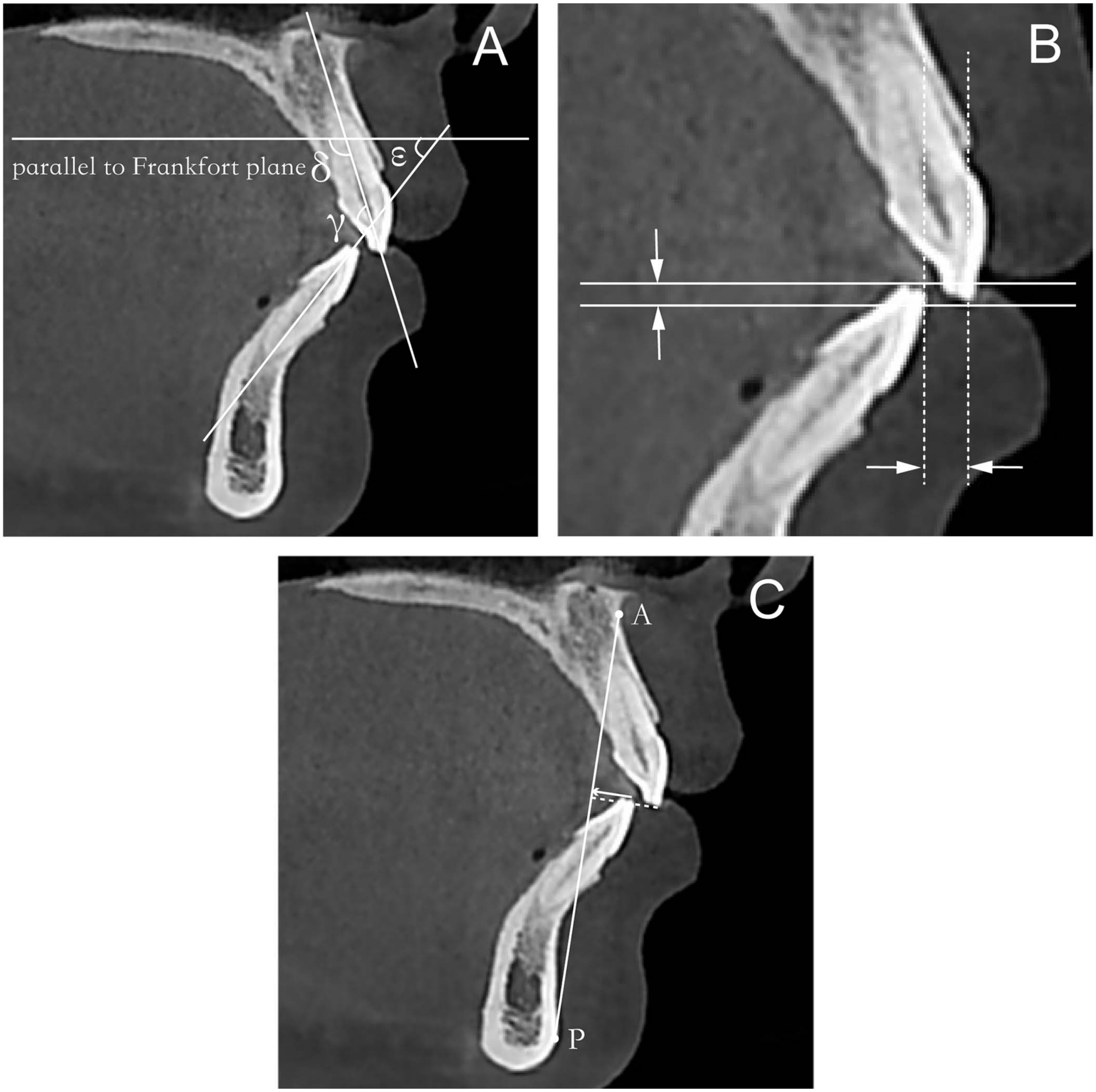

Figure 3. (A) U1 axis to FH plane (U1-FH, δ); L1 axis to FH plane (L1-FH, ε); Inter-incisal angle (U1-L1, γ). (B) Incisor overbite (OB, between the solid line), Incisor overjet (OJ, between the dotted line); (C) U1 to AP plane (U1-AP, dotted line); L1 to AP plane (L1-AP, arrow).

inclusion and exclusion criteria, 28 patients were included in the study.

Acquisition of CBCT Images

CBCT scans were taken with a New Tom 5G version FP (Quantitative Radiology, Verona, Italy) by the same experienced radiologist using a standardized scanning protocol: 110 kV and 5 mAs with an exposure time of 3.6 s, and the axial pitch was 0.15 mm.

The QR-NNT Viewer version 5.6 was used to reconstruct and evaluate the CBCT data. The Frankfort plane (FH plane), the supraorbital line, and the anterior-posterior nasal spine were used as reference planes to standardize the measurements and minimize errors (Figure 1).

Measurements

Standardized lateral cephalograms were reconstructed and output by QR-NNT Viewer based on CBCT data

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Table 2. Measurement Parameters of the Anterior Teeth

Measurement Parameters	Abbreviations	Definition
U1 axis to FH plane	U1-FH	The angle between the long axis of the upper central incisors and a line parallel to the FH plane
L1 axis to FH plane	L1-FH	The angle between the long axis of the lower central incisors and a line parallel to the FH plane
inter-incisal angle	U1-L1	The angle between the long axes of the upper and lower central incisors
incisal overbite	OB	The vertical distance between the two lines, each passing through the cutting-edge points of the upper and lower central incisors and parallel to the FH plane
incisal overjet	OJ	The horizontal distance between the two lines, each passing through the cutting-edge points of the upper and lower central incisors and perpendicular to the FH plane
U1 to AP plane	U1-AP	The perpendicular distance between the cutting-edge point of the upper central incisor and the line passing through the subspinale (A point) and the pogonion (P point)
L1 to AP plane	L1-AP	The perpendicular distance between the cutting-edge point of the lower central incisor and the line passing through the subspinale (A point) and the pogonion (P point)

from all subjects at T0, T1, and T2 automatically. Using computerized cephalometric analysis, five skeletal angular measurements were calculated: SNA, SNB, ANB, FH-MP, and SN-GnGo. In quantitative evaluation of the TMJ, the axial section in which the condylar processes showed the widest mediolateral diameter on both sides of the TMJ was chosen as the reference view for secondary reconstruction of the sagittal slices[12]. The sagittal section of the TMJ was performed perpendicular to the reference line and passed through its midpoint. Five measurement parameters of the glenoid fossa based on previous studies[15,16], were evaluated on the central sagittal section (Figure 2), and their definitions are listed in Table 1. For reconstruction of the front teeth, the maximum cross-section of the long axis of the central incisors on the ipsilateral side and the section connecting the midpoint of the incisal edge of central incisors on the ipsilateral side were chosen for evaluation. The schematic diagram and definitions of linear and angular measurements used for dental evaluation are shown in Figure 3 and Table 2.

Measurement Precision

Twelve joints were randomly selected using an online tool (www.randomizer.org). The measurements were repeated after one week by the same operators (X-C.F. and L-S.M.). A paired *t*-test and intraclass correlation coefficient (ICC) were used to assess systematic and random errors, respectively.

Statistical Analysis

Statistical analyses were performed using SPSS 20.0 (IBM, New York, USA). Quantitative data with a normal distribution for comparison among three detection time points were evaluated using Mauchly's test of sphericity. Parameters with equal variance-covariance matrices were evaluated using one-way analysis of variance. For those with unequal variance-covariance matrices, the Greenhouse-Geisser method ($\varepsilon < 0.75$) and the Huynh-Feldt method ($\varepsilon \geq 0.75$) were used according to ε index. The Bonferroni test was used to assess the intergroup differences further. Similarly, Friedman's two-way analysis of variance was applied to determine intergroup differences for parameters with non-normal distribution. The correlation between the glenoid fossa and the anterior teeth was evaluated by canonical correlation analysis (CCA). The predetermined level of statistical difference was $P < .05$.

Table 3. Age and Skeletal Measurements Before, During, and After Treatment

		Mean ± SD			*P* Value[b]		
Measurement Parameters	n	T0[a]	T1[a]	T2[a]	T0–T1	T1–T2	T0–T2
Age[c] (month)	28	311.79 ± 51.09	323.75 ± 50.96	334.50 ± 50.26	.001**	.001**	<.001**
SNA[d] (°)	28	83.58 ± 2.59	83.66 ± 2.68	83.64 ± 2.50	1.000	1.000	1.000
ANB[d] (°)	28	5.19 ± 1.57	5.23 ± 1.56	5.15 ± 1.51	1.000	.196	1.000
SNB[d] (°)	28	78.39 ± 2.46	78.43 ± 2.52	78.48 ± 2.30	1.000	1.000	1.000
FH-MP[d] (°)	28	27.78 ± 3.76	28.10 ± 3.82	27.47 ± 3.62	.234	.035*	.556
SN-GnGo[d] (°)	28	35.73 ± 4.29	35.90 ± 4.16	35.25 ± 4.05	1.000	.031*	.085

[a] T0 indicates before treatment; T1, during treatment (after the teeth aligned and mini-implant inserted); T2, after treatment.
[b] *P* value has adjusted with the level of $\alpha = .05$ for multiple comparison.
[c] statistical analysis with Friedman's two-way analysis of variance by ranks.
[d] statistical analysis with one-way analysis of variance.
* statistical difference ($P < .05$); ** significant difference ($P < .01$).

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Table 4. Arithmetic Differences of Age and Skeletal Variables Before, During, and After Treatment[a]

Variables	Mean ± SD		
	T1–T0[b]	T2–T1[b]	T2–T0[b]
ΔAge (month)	11.96 ± 1.86	10.75 ± 1.67	22.71 ± 2.54
ΔSNA (°)	0.08 ± 0.89	−0.02 ± 0.88	0.06 ± 1.08
ΔANB (°)	0.04 ± 0.21	−0.08 ± 0.21	−0.04 ± 0.25
ΔSNB (°)	0.04 ± 0.98	0.05 ± 0.90	0.10 ± 1.14
ΔFH-MP (°)	0.33 ± 0.94	−0.64 ± 1.24	−0.31 ± 1.21
ΔSN-GnGo (°)	0.18 ± 1.04	−0.65 ± 1.25	−0.48 ± 1.09

[a] Δ indicates arithmetic difference of variables.
[b] T0, before treatment; T1, during treatment (after the teeth aligned and mini-implant inserted); T2, after treatment.

RESULTS

ICC analyses revealed excellent intraoperator agreement of measurements (X-C.F.: r = 0.976–0.991; L-S.M.: r = 0.880–0.912) and interoperator agreement of measurements (r = 0.869–0.902), indicating good reliability.

Tables 3 and 4 show age, basic skeletal measurements, and differences before, during, and after treatment. The sagittal and vertical skeletal measurements included in this study showed no statistically significant differences ($P > .05$) from before to after treatment.

Tables 5 and 6 show the means and differences of the linear and angular measurement parameters of the glenoid fossa and the anterior teeth before, during, and after treatment. Except for OB, all other variables of the anterior teeth showed significant differences between T1-T2 and between T0-T2 ($P < .01$). For the parameters related to the glenoid fossa, multiple comparison analysis showed that the two indicators of articular eminence inclination increased sequentially from pre-treatment (T0), through treatment (T1), to after treatment (T2). The two variables reflecting the sagittal morphology of the glenoid fossa, GFW and GFD, exhibited opposite trends of change.

Table 7 shows the correlation coefficients of the variations in glenoid fossa parameters and dental parameters. At the level of $\alpha = 0.05$, only the first pair of canonical correlation variables for the T2-T1 stage reached a significant level ($P < .01$). The standardized canonical correlation coefficients of the variations in all fossa and dental parameters for each pair of canonical correlation variables during the T2-T1 stage are listed in Table 8.

DISCUSSION

Miles et al.[17] found that approximately 20% of patients who received fixed orthodontic treatment were treated with extraction. However, this proportion is as high as 55.31%–56.6% in the Chinese population due to racial disparities and facial type discrepancies.[18] The extraction of four premolars is most commonly used in camouflage orthodontic treatment for adult patients. Recently, mini-implant anchorage has been used more widely in orthodontic practice. In combination with premolar extraction treatment, it can provide stable anchorage and sustained loading force independently, without relying on the teeth. To avoid the possible biases caused by different extraction patterns, the level of anchorage, amount of growth, and gender factors on the research results, the present study selected adult female patients with Angle Class II, division 1 malocclusion who underwent four first premolar extraction treatment and had infrazygomatic crest mini-implants inserted for strengthening anchorage as the research sample.

Currently, the principle that function affects structure is widely accepted in the field of orthodontics, and a

Table 5. Measurement Parameters of the Glenoid Fossa and the Anterior Teeth Before, During, and After Treatment

Measurement Parameters	n	Mean ± SD			*P* Value[b]		
		T0[a]	T1[a]	T2[a]	T0–T1[a]	T1–T2[a]	T0–T2[a]
AEI-BFL[d] (°)	56	57.49 ± 9.05	58.20 ± 9.05	61.79 ± 9.96	<.001**	<.001**	<.001**
AEI-TRL[d] (°)	56	41.78 ± 7.34	41.85 ± 7.41	43.40 ± 8.25	1.000	<.001**	<.001**
GFW[d] (mm)	56	17.04 ± 1.93	16.99 ± 1.89	16.67 ± 1.98	1.000	.001**	<.001**
GFD[d] (mm)	56	6.15 ± 1.06	6.19 ± 1.04	6.28 ± 1.08	1.000	.147	.045*
GFW/GFD[c]	56	2.83 ± 0.47	2.79 ± 0.49	2.73 ± 0.46	1.000	.113	.018*
AEH[d] (mm)	56	7.53 ± 1.16	7.52 ± 1.08	7.60 ± 1.12	1.000	.300	.598
U1-FH[d] (°)	56	116.41 ± 6.59	117.05 ± 6.85	108.10 ± 7.77	1.000	<.001**	<.001**
L1-FH[d] (°)	56	49.83 ± 5.99	50.05 ± 6.46	57.10 ± 6.98	1.000	<.001**	<.001**
U1-L1[d] (°)	56	113.41 ± 8.58	113.00 ± 10.12	129.00 ± 10.49	1.000	<.001**	<.001**
OB[d] (mm)	56	3.69 ± 1.42	3.23 ± 1.41	2.58 ± 1.06	.012*	.002**	<.001**
OJ[d] (mm)	56	5.04 ± 1.98	4.84 ± 1.96	3.12 ± 0.75	.885	<.001**	<.001**
U1-AP[d] (mm)	56	12.29 ± 2.21	12.20 ± 2.02	6.91 ± 1.13	.908	<.001**	<.001**
L1-AP[d] (mm)	56	7.04 ± 1.91	7.07 ± 1.40	3.72 ± 0.98	1.000	<.001**	<.001**

[a] T0 indicates before treatment; T1, during treatment (after the teeth aligned and mini-implant inserted); T2, after treatment.
[b] *P* value has adjusted with the level of $\alpha = .05$ for multiple comparison.
[c] statistical analysis with Friedman's two-way analysis of variance by ranks.
[d] statistical analysis with one-way analysis of variance.
* statistical difference ($P < .05$); *** significant difference ($P < .01$).

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Table 6. Arithmetic Difference of the Glenoid Fossa and the Anterior Tooth Variables Before, During, and After Treatment[a]

Variables	Mean ± SD		
	T1–T0	T2–T1	T2–T0
ΔAEI-BFL (°)	0.71 ± 1.13	3.59 ± 2.26	4.30 ± 2.65
ΔAEI-TRL (°)	0.08 ± 0.79	1.55 ± 2.21	1.62 ± 2.33
ΔGFW (mm)	−0.04 ± 0.41	−0.32 ± 0.60	−0.37 ± 0.67
ΔGFD (mm)	0.08 ± 0.31	0.09 ± 0.35	0.13 ± 0.38
ΔGFW/GFD	−0.04 ± 0.17	−0.06 ± 0.17	−0.10 ± 0.19
ΔAEH (mm)	−0.02 ± 0.28	0.09 ± 0.39	0.07 ± 0.41
ΔU1-FH (°)	0.64 ± 5.40	−8.95 ± 6.43	−8.31 ± 8.77
ΔL1-FH (°)	0.22 ± 7.16	7.04 ± 7.76	7.27 ± 8.15
ΔU1-L1 (°)	−0.41 ± 9.16	16.00 ± 9.99	15.59 ± 11.41
ΔOB (mm)	−0.46 ± 1.15	−0.65 ± 1.36	−1.11 ± 1.71
ΔOJ (mm)	−0.21 ± 1.47	−1.71 ± 1.89	−1.92 ± 2.10
ΔU1-AP (mm)	−0.09 ± 0.67	−5.29 ± 1.90	−5.38 ± 2.08
ΔL1-AP (mm)	−0.87 ± 2.02	−2.89 ± 1.60	−2.88 ± 2.09

[a] T0 indicates before treatment; T1, during treatment (after the teeth aligned and mini-implant inserted); T2, after treatment; Δ, arithmetic difference of variables.

Table 7. Canonical Correlation Analysis of the Variations of the Glenoid Fossa and the Anterior Tooth Parameters[a]

	T1–T0		T2–T1		T2–T0	
	CCC	*P* Value	CCC	*P* Value	CCC	*P* Value
1{U_1, V_1}	0.621	.066	0.703	.001**	0.553	.438
2{U_2, V_2}	0.396	.723	0.424	.290	0.312	.965
3{U_3, V_3}	0.227	.919	0.388	.457	0.178	.986
4{U_4, V_4}	0.138	.866	0.104	.950	0.109	.950
5{U_5, V_5}	0.079	.576	0.059	.678	0.050	.726

[a] CCC indicates canonical correlation coefficient.
** significant difference ($P < .01$).

large number of previous studies have shown that functional appliances can promote remodeling of the TMJ.[9–11] However, about 90% of patients receive fixed orthodontic treatment, which can also significantly change the occlusal relationship, especially in those cases involving extractions.[17] According to previous research,[4] the morphology of the condyle and glenoid fossa may be closely related to different types of dental malocclusion and skeletal deformities. Previously, some scholars even considered orthodontic treatment with extractions to be one of the possible pathological factors for TMD.[19] In recent years, some literature has reported the structural changes in the glenoid fossa before and after fixed orthodontic treatment, but the results have been inconsistent. Yan et al.[20] analyzed the TMJs of 40 non-extraction adult patients with a high angle and Class II malocclusion and believed that orthodontic treatment had no adverse effect on the structure and function of the glenoid fossa. However, in the present study, the functional AEI (AEI-BFL) and anatomical AEI (AEI-TRL) increased significantly by 4.30 ± 2.65° and 1.62 ± 2.33° during treatment ($P < .05$). Koide et al.[21] conducted a similar study on adult patients with fixed appliances using TMJ laminography. The results suggested that both functional and anatomical AEI increased ($P < .01$), which was consistent with current study. The present study also measured the shape of the glenoid fossa and revealed that the GFW decreased while GFD increased after treatment. The opposite trend of GFW and GFD led to a decrease in their ratio (GFW/GFD) during treatment ($P < .05$). The AEH, which not only describes the anatomical morphology of the articular eminence but also reflects the longitudinal depth of the condylar head sliding along the glenoid fossa in natural head position, showed no significant changes during treatment ($P > .05$). This was in agreement with the MRI observation by Liu et al.[22] However, a prospective study by Carlton and Nanda[23] showed that the AEH increased after orthodontic treatment, possibly because the study included both extraction and nonextraction patients as subjects.

The straight wire technique for extraction cases can be artificially divided into three stages: Stage 1: align the teeth and level the dental arch; Stage 2: closure of extraction space and correction of the molar and anterior tooth relationships; Stage 3: fine adjustment of occlusion. Except for the third stage, which involves only minimal movement, the movement characteristics and targets of teeth in the first two treatment stages are significantly different. Therefore, taking into account changes in the angulation and relative position of the anterior teeth at the different stages of orthodontic treatment may have a possible impact on morphology of the TMJ. Mini-implants were inserted at the time when the teeth had been fully aligned and prepared for retraction, and an intermediate CBCT scan was taken. The present study used this as a dividing point to investigate further the effect of different stages of orthodontic treatment on adaptive remodeling of the glenoid fossa. According to the results of the present study, except for the functional AEI, which increased slightly during the stage T0-T1, its changes, as well as the changes of anatomical AEI and GFW, mainly occurred in the T1-T2 stage ($P < .05$), which was accompanied by uprighting of the anterior teeth and a decrease in the overbite and overjet. Among them, the change in functional and anatomical AEI was manifested as an increase in angle, whereas the change in width of the glenoid fossa was represented as a decrease in length. Since the relative position of the mandible to the cranial base (SNA) and the maxilla (ANB) changed little during the different periods of treatment ($P > .05$), it was speculated that the reason for the structural changes in the TMJ, especially in the glenoid fossa, may have been due to the upper and lower incisors being retracted and uprighted continually during the T1-T2 stage. Anterior overbite and overjet decreased as the interincisal angle increased gradually, resulting in a change of anterior guidance, and then the

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Table 8. Canonical Correlation Coefficients of the Variations of the Glenoid Fossa and the Anterior Tooth Parameters During T2–T1 Stage[a]

Variables	1 $\{U_1, V_1\}$	2 $\{U_2, V_2\}$	3 $\{U_3, V_3\}$	4 $\{U_4, V_4\}$	5 $\{U_5, V_5\}$
Variations of glenoid fossa parameters					
ΔAEI-BFL	0.101	0.211	−0.075	−1.181	−0.166
ΔAEI-TRL	.0076	−0.492	0.591	0.232	−0.677
ΔGFW	–0.283	–0.003	0.849	–0.455	0.388
ΔGFD	–0.887	0.283	–0.056	0.573	–0.309
ΔAEH	0.524	0.817	0.138	0.282	–0.135
Variations of anterior teeth parameters					
ΔU1-FH	–90.320	18.655	20.808	–44.412	–6.246
ΔL1-FH	108.236	–23.551	–26.443	54.091	6.898
ΔU1-L1	–139.990	29.593	33.918	–68.692	–8.800
ΔOB	–0.300	0.084	–0.960	–0.008	0.544
ΔOJ	0.337	–0.424	0.607	–0.611	0.639

[a] Δ indicates arithmetic difference of variables.

path that the condyle slid along the glenoid fossa during functional movement changed accordingly, ultimately resulting in adaptive remodeling of the glenoid fossa. To clarify possible causation for remodeling of the glenoid fossa, more rigorously designed prospective functional studies are still needed for verification in the future. Considering that a large number of previous studies have mentioned that the excessively steep inclination of the articular eminence may be one of the potential factors inducing TMD,[3,4,16] it is recommended that, in orthodontic treatment, especially for cases that require tooth extraction and extensive retraction of the anterior teeth, practitioners should pay more attention to controlling the torque of the anterior teeth to avoid additional burden on the TMJ.

Unlike Pearson's correlation analysis, which can only be performed on a single indicator, the CCA proposed by Hotelling[24] is a highly versatile algorithmic procedure for decoding complex dependency structures in multivariate data and identifying groups of interacting variables. This allows it to better reflect the essential relationship between changes in the anterior teeth and variations of the glenoid fossa during different periods of orthodontic treatment. The results of the present study showed that the correlation between the two sets of parameters reached a significant level ($P < .01$) only during the T2-T1 period. In this pair of canonical correlation variables, the parameters with the highest absolute values were ΔGFD and ΔU1-L1, with values of 0.887 and 139.990, respectively. This suggests that the correlation was mainly caused by the GFD and U1-L1. Additionally, both coefficients were negative, implying a positive correlation between the two variables. However, this was only a preliminary finding, as there were many TMJ and dental parameters that changed as treatment progressed. Therefore, to clarify the relationship between the morphological variations of the TMJ and occlusion more systematically, more three-dimensional dynamic functional studies are needed for further investigation.

CONCLUSIONS

- On the basis of the present study, orthodontic treatment with premolar extractions can induce adaptive morphological remodeling of the glenoid fossa, which primarily occurred during the stage of extraction space closure.
- The changes mainly manifested as a steeper AEI and a decrease in GFW.

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