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RESEARCH ARTICLE

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A quantitative analysis of facial changes after orthodontic treatment with vertical control in patients with idiopathic condylar resorption

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Abstract

Objective: This study aimed to investigate temporomandibular joint (TMJ) stability and three-dimensional (3D) facial changes in class II hyperdivergent patients with stable idiopathic condylar resorption (ICR) after orthodontic camouflage treatment with vertical control by using temporary anchorage devises (TADs).

Methods: Nineteen skeletal class II hyperdivergent patients who were diagnosed with stable ICR underwent bicuspid extraction orthodontic treatment with vertical control via TADs were enrolled. TMJ was evaluated with the cone beam computerized tomography (CBCT) and clinical records before and after treatment. Changes in dental and skeletal parameters were evaluated with cephalometric and dental cast measurements. The 3D morphable model (3DMM) method was performed with the MeshMonk toolbox for the 3D facial analysis. After the reposition and landmark setting process, 3D facial heatmaps were used to illustrate facial changes, and the 3D deviations of landmarks were calculated.

Results: Both the imaging evaluation and clinical examination proved that TMJs remained stable after treatment. The retrusion of the upper and lower incisors reached 6.63 ± 0.79 mm and 3.78 ± 1.49 mm. The intrusion of the upper first molar reached 2.65 ± 0.75 mm, with a $2.27 \pm 0.82°$ counterclockwise rotation of the mandibular plane. An upward shift of the soft tissue pogonion (2.34 ± 2.03 mm) and protrusion of Po-NB (0.82 ± 0.70 mm) was gained. Larger intrusion was found in the lower lip (3.29 ± 0.80 mm) than in the upper lip (2.20 ± 0.69 mm).

Conclusion: Camouflage orthodontic treatment with TAD for vertical control is acceptable for skeletal class II hyperdivergent patients with ICR, which can improve the facial profile.

KEYWORDS
3D morphable model, camouflage orthodontic treatment, class II hyperdivergent patient, idiopathic condylar resorption

Bochun Mao and Yajing Tian contributed equally to this work.

1 | INTRODUCTION

Idiopathic condylar resorption (ICR) is a progressive degenerative disease of the temporomandibular joint (TMJ). This condition leads to the loss of condylar bone mass, the decrease of mandibular ramal height, steep mandibular and occlusal plane angles, and an anterior open bite, which is often accompanied by a skeletal class II hyperdivergent pattern.[1] Together, these sagittal and vertical inharmonious statuses always cause retrusive and clockwise rotated mandibles that lead to convex facial profiles with excessively lower facial heights. Skeletal class II hyperdivergent patients, who are often assumed to be one of the most difficult cases for orthodontists, are regularly persuaded to undergo orthognathic treatment for the best prognosis. However, it has been reported that orthognathic surgery may be an iatrogenic cause of progressive condylar resorption for some patients with ICR, and the incidence of resorption is 2–5% for all orthognathic surgery patients; however, the incidence of resorption is 20–30% for patients with a class II hyperdivergent pattern.[2] Due to reasons such as the high cost of the surgery or the fear of surgery, many adult patients still choose camouflage orthodontic treatment for eclectic treatment outcomes.

Profile improvement has been one of the most common chief complaints of class II hyperdivergent patients, due to the shift of concern that has been placed on the soft tissue profile by both patients and orthodontists. For these patients, anchorage control in both the sagittal and vertical directions is essential to improve treatment outcomes. Within these two decades, temporary anchorage devices (TADs) have been widely used as maximum anchorages, especially to reinforce vertical anchorages. For patients with stable ICR, orthodontic treatment is a conservative treatment option in addition to orthognathic surgery, and the treatment goal includes the improvement of occlusal status, the prevention of the progression of ICR, and the improvement of facial aesthetics.[3]

Most of the methods that are currently used for three-dimensional (3D) facial measurement are based on landmarks that are manually set. However, landmarks such as soft tissue gonion or zygoma cannot be precisely displaced, and relatively flat areas (such as the frontal part and cheek) are also difficult to measure.[4] The 3D morphable model (3DMM), which is also known as the anthropometric mask, has been demonstrated as being optimal for 3D face analysis in recent years.[5] During the procedure, 3DMM ensures a vertex-level corresponding relationship between the mask and the target face. Moreover, it has been proven that more accurate landmarks can be set with 3DMM compared with the conventional manual setting, and more information can be gained with this vertex-level pairing.[5,6] Currently, a few studies have used 3DMM for facial measurements in the field, such as for orthognathic surgery, growth and development, and facial asymmetry.[6–8]

However, there is a question as to whether vertical control with TAD is acceptable for class II hyperdivergent patients with ICR. Additionally, how much facial improvement can be gained with TAD-assisted camouflage orthodontic treatment for class II hyperdivergent patients with ICR is unknown. Thus far, no studies have been able to answer these 2 questions. Therefore, this retrospective study aimed to investigate the 3D facial changes in class II hyperdivergent patients with ICR after orthodontic camouflage treatment by using the 3DMM method; additionally, TMJ status was also investigated.

2 | METHODS

This study was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (No. PKUSSIRB-201630096). All of the patients provided informed consent prior to participation. The sample size was calculated to detect a significant mean difference in upper incisor retraction before and after treatment with the standard deviations of the previous studies.[9,10] The statistical power was set at 90% with a 95% confidence interval (CI). It was determined that a minimum of 9 patients was needed. Thus, 19 adult female patients aged 22.82 ± 4.69-years-old who were diagnosed as being class II hyperdivergent with stable ICR and who refused combined surgical and orthodontic treatment were involved. The diagnosis of ICR can be made only when all local conditions (such as osteoarthritis, reactive arthritis, infection, traumatic injury) and systemic disorders (such as rheumatoid arthritis, scleroderma, systemic lupus erythematosus, and psoriatic arthritis) that can cause progressive condylar resorption have been excluded.[11,12]

All of these patients started and finished their camouflage orthodontic treatment with a fixed appliance in the Department of Orthodontics, Peking University School and Hospital of Stomatology, between April 2017 and June 2021. The average treatment duration was 34.19 ± 6.96 months. Additionally, their body mass index (BMI) before treatment was $18.62 \pm 1.88\,\text{kg/m}^2$, and no significant changes in BMI were observed after the treatment.

The inclusion criteria were as follows: (1) adult females of Chinese ethnicity who were diagnosed as class II hyperdivergent with cephalometric analysis (MP-SN $\geq 37.7°$, ANB $> 4.7°$); (2) a progressive mandibular retrusion or retrognathia of anterior teeth in the relevant medical history; (3) cone-beam computed tomography (CBCT) data indicating cortical continuity for both TMJs, which was thought to be a radiographically stable stage of ICR; (4) no obvious malocclusion factors, such as scissors bite, crossbite, point contact, and secondary occlusion disorders, were noted; (5) extraction of four bicuspids was designed; and (6) patients with obvious facial asymmetry, craniofacial anomalies, a previous history of orthodontic treatment, and defective dentitions were excluded.

The same orthodontist designed the treatment plan and performed the treatments. All of the patients were treated with straight-wire techniques. Alignments and levelling of the teeth were accomplished via sequential delivering wire as follows: 0.012- or 0.014-inch Ni-Ti, 0.016-inch Ni-Ti, 0.016×0.022-inch Ni-Ti, and 0.019×0.025-inch Ni-Ti. The space-closing stage began with a classic sliding mechanism with a 0.019×0.025-inch stainless steel arch wire and ended after finishing the detailing stage. For all the patients, TADs were implanted in both the bilateral buccal and lingual sides of the alveolar bone between the roots of the upper first molar and upper second molar, with or without the TADs inserted at the buccal alveolar bone between the roots of upper canines and lateral incisors to correct gummy smile. The average time for posterior active vertical control and anterior intrusion is about 29.30 ± 8.37 and 7.71 ± 1.14 months, during which no clinical symptom of contact between the teeth and TADs was noticed. The relevant treatment protocol was detailed in previous published 2 cases.[13,14]

Cone beam computerized tomography was taken before and after orthodontic treatments for all the patients. A chart containing the osseous changes, including subcortical cysts, surface erosions, generalized sclerosis, osteophytes, or condylar flattening,[15] for each joint was completed before and after the treatment by 2 surgeons from the Center for Temporomandibular Disorders and Orofacial Pain of our hospital after discussion. A score of 0–3 was given to each osseous change, according to the scoring system proposed by Gallagher et al.[16] (Table 1). Symptoms of TMD were also recorded after clinical examinations (≤6 months before and after the treatment) for comparison, which included (1) sounds: clicking, crepitation, or the combined; (2) orofacial pain: TMJ pain on palpation, or muscular pain on palpation; and (3) TMJ function: maximal incisor opening. All the indicators of the symptoms were recorded as "Better", "Steady", or "Worsen" by comparing each indicator before and after the treatment.

3D face models before (T1) and after (T2) treatment were acquired with the 3D optical FaceSCAN3D system (3D-Shape) for 10 of the patients, according to the filming standard.[17] For the 3DMM method (Figure 1), each 3D face model was imported into the IDAV Landmark Editor v.3.0.0.6 (University of California) to mark 5 anchoring points as follows: exocanthus points, pronasale point, and cheilion points. Subsequently, the models with corresponding anchoring points were imported into MATLAB (MATLAB R2018b, MathWorks) with the MeshMonk toolbox for 3DMM mapping,[18] which resulted in deformed 3DMMs with 7160 quasi-landmarks that captured the facial region of interest of each mask. The deformed 3DMMs were exported in STL format and imported into Geomagic Studio 12.0 (Geomagic) along with the corresponding face models of T1 and T2 for further analysis. The repositioning of the T1 face model was conducted, as a previous study demonstrated that by lining up the left and right tragus points as rotation axes, the Camper's plane inclined at −7.5° on the sagittal plane to serve as the horizontal plane, and the subnasal point was set as the origin of the coordinates.[19] Area fitting with the forehead and upper nasal dorsum was performed to align the T2 face models with those of T1.[20] Afterwards, the deformed 3DMMs were repositioned by using best fitting with the corresponding face models. The geomorph package version 3.2.1 in R was used to gain the average face models of T1 and T2 and to quantify the pairwise differences in variance of facial shapes between the 2 average faces. Moreover, 3D facial heatmaps were used for the visualization of the study findings.[21] The changes in the facial area that were larger than 2 mm were assumed to have clinical significance and were also marked.[22] Moreover, the upper lip (the area marked by left/right Chelion, Stomion Superius, and Subnasale), lower lip (the area marked by left/right Chelion, Stomion Superius, and Sublabial), and chin (the area marked by the perpendicular line passing through left/right Chelion, Soft Tissue Menton, and Sublabial) were extracted and displayed separately via heatmaps.

As shown in Figure 2, with the 3D deviation analysis function in conventional 3D processing software (such as Geomagic Studio), nonanatomical mapping based on the iterative closest point (ICP) was performed. The conventional ICP aims for the best fitting of the whole model, which neglects the corresponding relationship of the topical region, and the results can sometimes be misleading. In contrast, the 3DMM method was based on the vertex-level pairing of the two models, which can illustrate the corresponding relationship of each anatomical structure.

3DMM was also imported into MeshLab for landmark setting. Eight commonly used facial landmarks were determined (Table 2, Figure 3) on the initial mask, and the index of the points was recorded to obtain the 3D coordinate value of those points in the average face models. The 3D deviations of the points were then calculated. During 3DMM mapping, non-rigid fitting eliminated the potential manual error during the previous rigid fitting process. Moreover, the landmarks were set on the initial mask, and the index number of landmarks were extracted to gain all landmark coordinate values for all deformed 3DMM. Thus, no repeated measurement or blinded fashion was needed for 3DMM.

For the cephalometric analysis, the skeletal measurements included 6 angular dimensions, and the dental measurements included 7 angular dimensions and 3 linear dimensions (Table 3).

Digital working casts were obtained via optical scanning (D900, 3Shape). Within Geomagic Studio, pre- and posttreatment casts

TABLE 1 The scoring system of idiopathic condylar resorption

	Imaging features				
Score	Subchondral cyst	Erosion	Sclerosis	Osteophyte	Flatten
0	Not visualized	Not visualized	Not visualized	Not visualized	Not visualized
1	1–2 small cysts	Mild	Mild	Mild/small size	Mild
2	3–4 small or 1–2 medium cysts	Moderate	Moderate	Moderate/medium size	Moderate
3	≥5 cysts or large cysts	Severe	Severe	Severe/large size	Severe

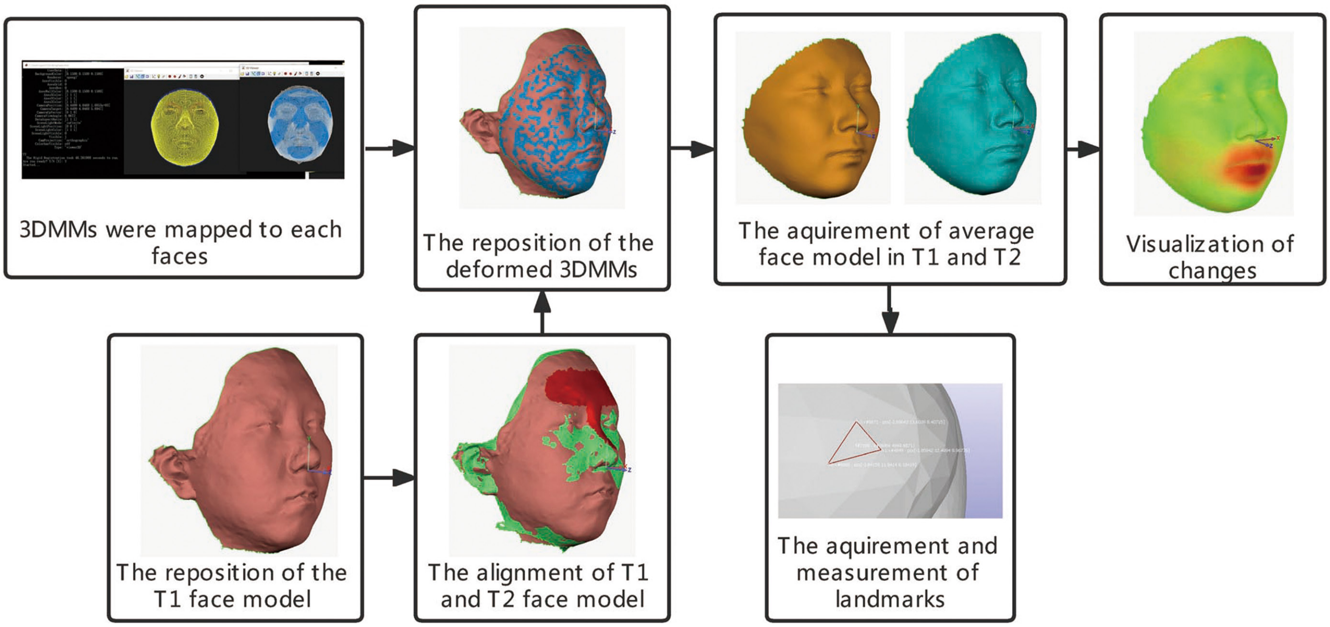

FIGURE 1 Flow diagram of the facial measurements using the 3D morphable model (3DMM) method

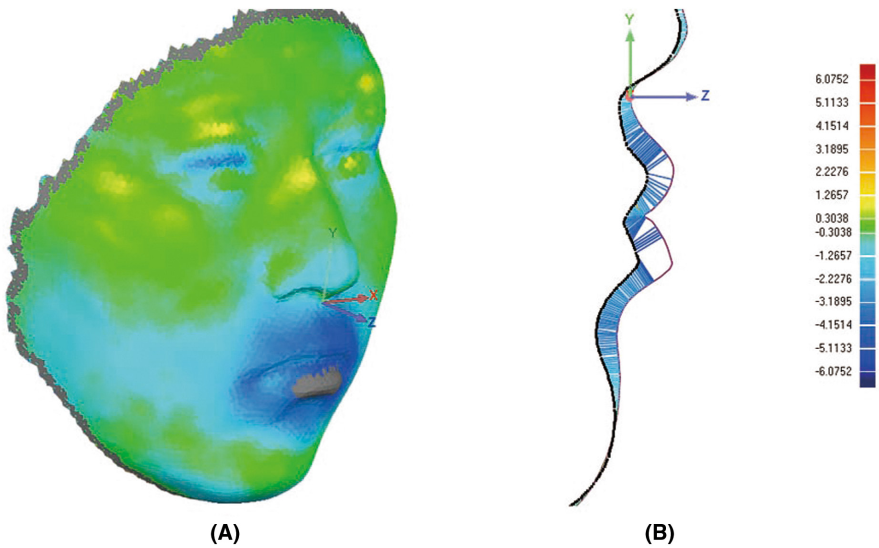

FIGURE 2 The results of the 3D deviation analysis comparing the face before and after the treatment of a patient involved in this study with conventional 3D processing software (Geomagic Studio). A, Note the grey area without 3D deviation results at the lower lip area; B, the 2D profile showed that the lower lip area was not mapped

were aligned and measured per our previous study.[23] The retrusion of the upper first incisors was measured. In addition, the vertical change of the upper first molar was determined by measuring the distance between the occlusion plane at T1 and the mesial buccal tips of U6s at T2.

The operator was blinded to the patients' identity during the cephalometric measurement and dental cast measurement, and the operations were repeated 1 week after the first time. The intrarater reliability of measurements were assessed using 2-way absolute agreement intraclass correlation coefficient (ICC) on a mean of measurements. The ICC for the intrarater reliability was above 0.87 for all measurements. Data were exported to SPSS 19.0 (IBM) for the statistical analysis. Paired T tests were used to determine the differences among deviation values. For all the comparisons, $P < .05$ indicated a statistical significance.

3 | RESULTS

3.1 | TMJs remain stable after orthodontic treatment

The radiographic evaluation at the condylar level indicated that the joint was stable after the treatment (Table 4). Subchondral cysts were not visible in most of the included condyles at pre- and post-treatment (32/38). Three condyles experienced a progression of erosion, whereas the erosion of the other condyles improved or remained steady. For sclerosis, osteophyte, and flatten, no more than 6% (2/38) of condyles were diagnosed as exhibiting an increase in severity, and most of the condyles remained steady after the treatment (81.58–86.84%). Figure 4 presents the CBCT of one of the patients who were involved in this study, whose condyles were

TABLE 2 Definition of the cephalometric measurements and soft tissue landmarks and measurements

Name	Definition
Cephalometric measurements	
SNA	Sella-Nasion-A point angle
SNB	Sella-Nasion-B point angle
ANB	A point-Nasion-B point angle
FH-NPo	The angle formed by the FH line and NPo line
NA-APo	The angle formed by the NA line and Apo line
MP/FH	The angle formed by the Frankfort horizontal plane and mandibular plane
SGn-FH	The angle formed by the SGN line and FH line
Mp-SN	The angle formed by the SN plane and mandibular plane
△Po-NB(mm)	The changes of vertical distance between Pogonion and NB line
△U1-NA(mm)	The changes of vertical distance between the maxillary central incisor and NA line
△U1-NA	The changes of angle formed by the NA line and maxillary central incisor
△L1-NB(mm)	The changes of vertical distance between the mandibular central incisor and NB line
△L1-NB	The changes of angle formed by the NB line and mandibular central incisor
△U1-L1	The changes of interincisal angle
△U1-SN	The changes of angle formed by the SN plane and maxillary central incisor
△IMPA	The changes of angle formed by the mandibular plane and mandibular central incisor
Soft tissue landmark	
Left/right cheekbone (L/R Chb)	Point of maximal convexity on the facial contour of the cheekbone region
Left/right chelion (L/R Chl)	Point marking the most lateral extent of the labial fissure
Left/right crista philtri (L/R CPh)	Point on each elevated margin of the philtrum at the vermilion border of the upper lip
Soft tissue gnathion(Gn')	The halfway point on the medial curve between Pg' and Me' under the chin
Left/right gonion (L/R Go)	The inferior aspect of the mandible at its most acute (mandibular angle) and lateral point
Glabella (Gl)	The most convex sagittal midline point on the forehead
Labrale inferius (Li)	The midline point on the lower vermilion border of the lower lip
Labrale superius (ls)	The midline point on the upper vermilion border of the upper lip
Soft tissue menton (Me')	The most inferior midline point of the chin.
Left/right mid-mandibular border(L/R Mid-Mb)	Point on the mandibular border, midway between Pg' and Go, along the jaw line.
Soft tissue pogonion (Pg')	The point of maximal curvature on the midline chin curve
Stomion superius (Sto)	Midline point on the lower margin of bottom of the upper lip
Sublabial (Sl)	The deepest point of the mentolabial sulcus
Subnasale (Sn)	The apex of the nasolabial angle in the midline, where the inferior border of the nasal septum merges with the upper cutaneous lip
Supralabial (Spl)	Midline point of maximal concavity on the facial contour between Sn and Ls
Columella (Cl)	Midpoint of the nasal columella crest intersecting a line between the two points at the tip of each nostril
Soft tissue measurement	
Lower lip height (LL H)	Distance between Li and Sl
Facial convexity (FC)	Angle at Sn subtended by Gl and Pg'
Lower vermilion height (L Verm H)	Distance between Li and Sto
Mandibular contour (Mand Cont)	Angle at Me' subtended by L/R Go projected to coronal plane
Nasolabial angle (Nasolabial A)	Angle at Sn subtended by Columella and Ls
Philtral length (Philtral L)	Distance between Sn and Ls
Philtral width (Philtral W)	Distance between L/R CPh
Upper lip height (ULH)	Distance between Sn and Sto
Upper vermilion height (U Verm H)	Distance between Ls and Sto
Labial fissure width	Distance between L/R Chl

severely flattened before treatment but remained steady after the treatment. Likewise, the clinical examination results also suggested stable joints and T2 (Table 5). Most of the clinical findings remained steady or improved, and only one patient's mouth opening was observed to slightly decrease after treatment.

3.2 | Significant facial improvement was revealed with 3DMM after treatment

Significantly facial improvement at T2 was revealed (Figure 5). See the Appendices S1 and S2 for animation of 3D facial changes of the average face model before and after the treatment in front and lateral view. An obvious intrusion was observed at the rectangular region of the upper and lower lip areas, which marked the subnasal and soft tissue pogonion as upper and lower boundaries, respectively, and both chelion points as lateral boundaries. A similar elliptical area with clinically significant changes (2 mm) was also observed, which marked the supralabial as the upper boundary, and the other boundaries were the same as mentioned above. A larger intrusion was observed at the lower lip area (3.29 ± 0.80 mm) compared with the upper lip area (2.20 ± 0.69 mm), and the largest changes were observed at the lower vermilion (5.00 mm). Figure 5 b shows the changes at the median sagittal plane, which showed a larger nasolabial angle and a deeper mentolabial sulcus for the average face in T2, with a significant retraction of approximately 3.02 mm at the philtrum and 3.29 mm at the mentolabial sulcus. The retraction of both lips resulted in a posterior movement of 3.02 ± 1.16 mm and 4.80 ± 1.15 mm compared with the E line for the upper and lower lips, respectively, and an approximate 1 mm protrusion was noticed at the chin area; together, this contributed to a more harmonious nose-lip-chin relationship. Moreover, a small amount of intrusion (less than 1.5 mm) was observed at the cheek region.

All of the facial measurements were significantly changed from T1 to T2 (Table 6, $P < .05$). The nasolabial angle increased by $6.98 \pm 4.80°$ with the intrusion of the incisors. Moreover, the intension of the lower lip released as the intrusion of the incisors, which caused the lower lip height and lower vermilion height to decrease. The subnasal point also moved posteriorly in T2, thus reducing

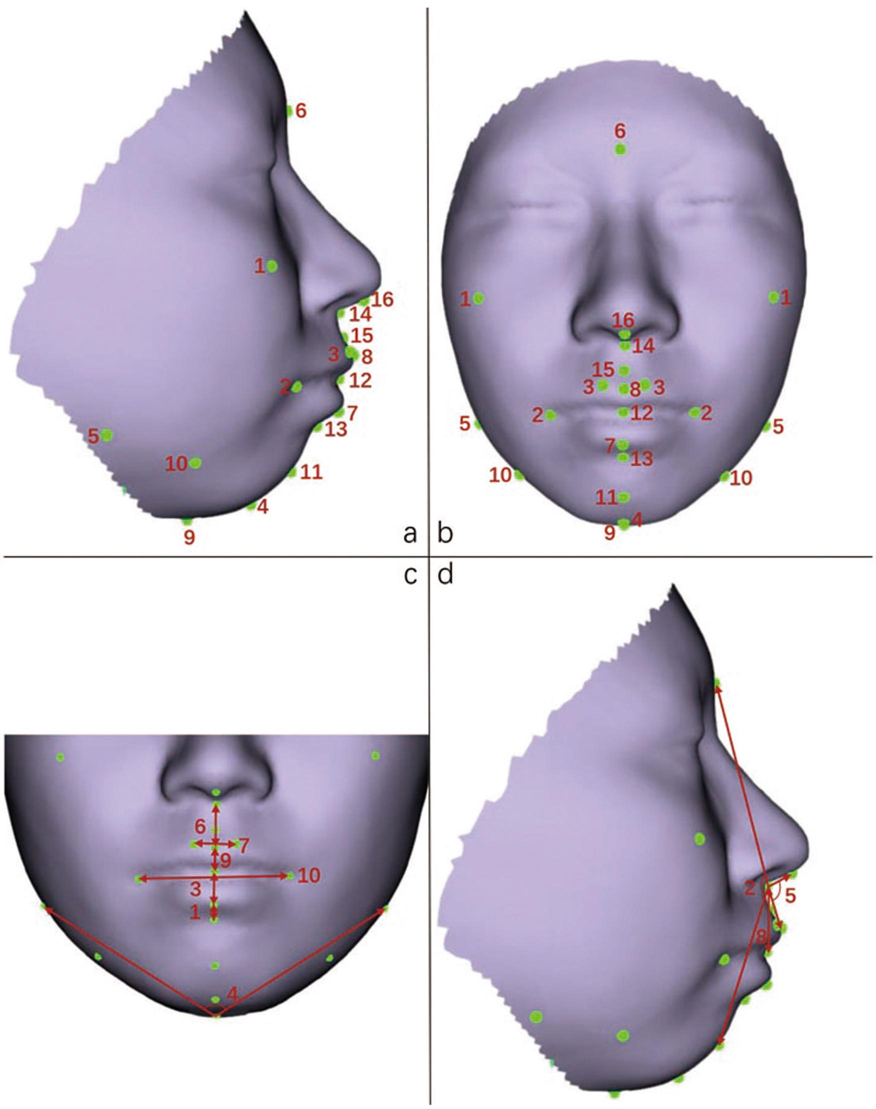

FIGURE 3 Soft tissue landmarks and measurements (A, B: 1, Left/Right Cheekbone; 2, Left/Right Chelion; 3, Left/Right Crista Philtri; 4, Soft Tissue Gnathion; 5, Left/Right Gonion; 6, Glabella; 7, Labrale Inferius; 8, Labrale Superius; 9, Soft Tissue Menton; 10, Left/Right Mid-mandibular Border; 11, Soft Tissue Pogonion; 12, Stomion Superius; 13, Sublabial; 14, Subnasale; 15, Supralabial; 16, Columella; C, D: 1, Lower Lip Height; 2, Facial Convexity; 3, Lower Vermilion Height; 4, Mandibular Contour; 5, Nasolabial Angle; 6, Philtral Length; 7, Philtral width; 8, Upper lip heigh; 9, Upper Vermilion Height; 10, Labial Fissure Width)

TABLE 3 Cephalometric measurements results

Measurements	Pre	Post	△	t	P
SNA	80.00 ± 3.61	78.63 ± 3.88	−1.91 ± 1.68	−3.77	.004*
SNB	71.96 ± 4.43	71.11 ± 4.21	−0.85 ± 0.39	−2.14	.058
ANB	8.58 ± 2.08	7.34 ± 1.89	−1.24 ± 0.32	−3.85	.003*
FH-NPo	80.07 ± 3.04	80.19 ± 3.48	0.11 ± 1.04	0.34	.743
NA-APo	19.54 ± 6.06	16.81 ± 5.38	−2.73 ± 1.81	−4.76	.001*
FH-MP	38.46 ± 6.32	36.32 ± 7.03	−2.14 ± 0.99	6.873	.000*
SGn-FH	69.91 ± 3.86	69.20 ± 4.25	−0.71 ± 1.09	−2.06	.069
MP-SN	46.75 ± 7.40	44.49 ± 7.33	−2.27 ± 0.82	8.75	.000*
Po-NB(mm)	−1.33 ± 1.54	−0.51 ± 1.46	−0.82 ± 0.70	−3.71	.005*
U1-NA(mm)	4.43 ± 2.19	−2.21 ± 1.94	−6.63 ± 0.79	26.51	.000*
U1-NA	18.88 ± 8.45	11.69 ± 9.34	−6.13 ± 4.77	4.06	.003*
L1-NB(mm)	10.97 ± 2.13	7.20 ± 1.70	−3.78 ± 1.49	7.99	.000*
L1-NB	39.20 ± 4.01	30.35 ± 3.06	−8.85 ± 3.31	8.45	.000*
U1-L1	113.35 ± 7.76	130.46 ± 10.75	−17.12 ± 6.27	−8.63	.000*
U1-SN	99.91 ± 9.49	90.71 ± 11.90	−9.21 ± 4.15	7.02	.000*
IMPA	99.99 ± 4.90	92.67 ± 5.26	−7.32 ± 2.71	8.53	.000*

Abbreviations: △IMPA, the changes of angle formed by the mandibular plane and mandibular central incisor; △L1-NB(mm), the changes of vertical distance between the mandibular central incisor and NB line; △L1-NB, the changes of angle formed by the NB line and mandibular central incisor; △Po-NB(mm), the changes of vertical distance between Pogonion and NB line; △U1-L1, the changes of interincisal angle; △U1-NA(mm), the changes of vertical distance between the maxillary central incisor and NA line; △U1-NA, the changes of angle formed by the NA line and maxillary central incisor; △U1-SN, the changes of angle formed by the SN plane and maxillary central incisor; ANB, A point-Nasion-B point angle; FH-NPo, the angle formed by the FH line and NPo line; MP/FH, the angle formed by the Frankfort horizontal plane and mandibular plane; Mp-SN, the angle formed by the SN plane and mandibular plane; NA-APo, the angle formed by the NA line and Apo line; SGn-FH, the angle formed by the SGN line and FH line; SNA, Sella-Nasion-A point angle; SNB, Sella-Nasion-B point angle.

*$P < .05$.

TABLE 4 Idiopathic condylar resorption radiographic evaluation scoring results

	condylar condition from T1 to T2				
	Subchondral cyst	Erosion	Sclerosis	Osteophyte	Flatten
Better					
No. of joint	2	9	5	6	3
%	5.26%	23.68%	13.16%	15.79%	7.89%
Steady					
No. of joint	35	26	32	31	33
%	92.11%	68.42%	84.21%	81.58%	86.84%
Worse					
No. of joint	1	3	1	1	2
%	2.63%	7.89%	2.63%	2.63%	5.26%

the excessive facial convexity. The mandibular contour was enlarged in T2 with the counterclockwise rotation of the mandible. In addition, the distances of the upper and lower lip to the E line were 1.33 ± 1.83 mm and 1.21 ± 1.59 mm, which were reduced by 3.02 ± 1.16 mm and 4.80 ± 1.15 mm, respectively. For the transverse measurements, philtral width and labial fissure width were significantly decreased ($P < .05$), which may be due to the retrusion and narrowing of anterior dentition at T2.

Moreover, all of the landmarks showed significant position changes between T1 and T2 (Table 7, $P < .05$). Sagittal significant changes were observed for the chelion, labrale superius, labrale inferius, supralabial, and subnasale ($P < .05$), which was in accordance with the retrusion of the incisors. Additionally, with soft tissue remodelling and counterclockwise rotation of the mandible, the soft tissue pogonion moved upward by 2.34 ± 2.03 mm. The complete table is shown in the Table S1.

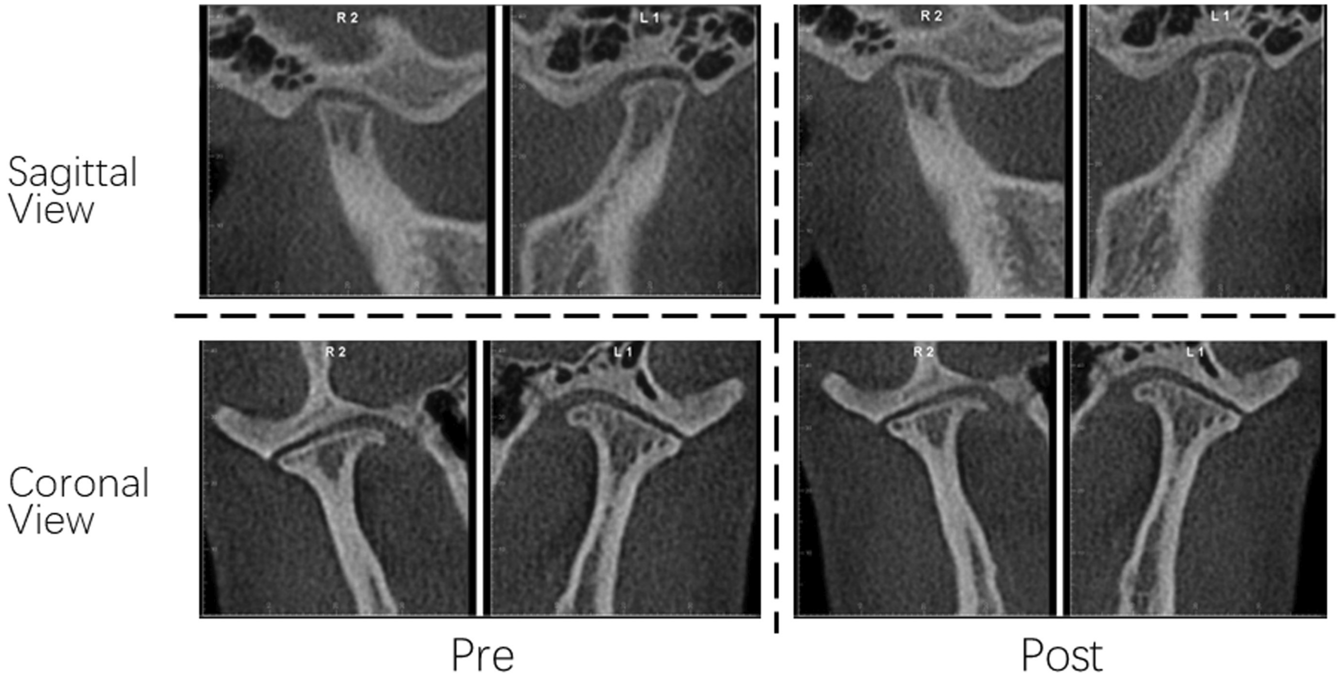

FIGURE 4 The CBCT pre- and posttreatments of one patient involved in this study

TABLE 5 Clinical findings of orofacial pain, temporomandibular joint (TMJ) sounds, and TMJ function

	Scale		
	Better	Steady	Worsen
Orofacial pain			
Arthralgia	4	15	
Myalgia	4	15	
TMJ sounds			
Crepitation	7	11	
Click	4	15	
Any TMJ sound	6	13	
TMJ function			
TMJ locking	2	17	
Decreased mouth opening	6	12	1

3.3 | The retrusion of incisors and intrusion of upper molars were demonstrated by cephalometric measurement and dental cast measurements

As shown by the cephalometric measurement, the measurements indicated changes in the upper and lower incisors; specifically, U1-NA (mm), U1-NA, L1-NB (mm), L1-NB, U1-L1, U1-SN, and IMPA changed significantly with the retrusion and uprighting of the incisors (Table 3, $P < .05$). Due to the fact that TADs were used as maximum anchorage in the treatment of all of the patients, the upper first incisors gained 6.63 ± 0.79 mm of retrusion. Moreover, the IMPA decreased 7.32 ± 2.71° to 92.67 ± 5.26° after treatment, which was within the range of normal values (92.6 ± 7.0°). However, U1-NA reached 18.88 ± 8.4° after treatment, which is smaller than the normal value (22.8 ± 5.7°). Furthermore, larger Po-NB (mm) values were observed ($P < .05$) in T2, which indicates a protrusion of the pogonion. The decrease of MP-SN shown an average of 2.27 ± 0.82° counterclockwise rotation of the mandibular plane. According to the dental cast measurement results, the upper first molars reached approximately 2.65 ± 0.75 mm intrusion ($t = 11.17$, $P < .01$), and the upper first incisors gained 6.32 ± 1.06 mm retrusion ($t = 17.85$, $P < .01$), which was in accordance with the U1-NA (mm) results from the cephalometric analysis. Only 4 patients had open bite, and the average overbite and overjet values before treatment were 1.00 ± 2.54 mm and 5.24 ± 2.42 mm, respectively. No anterior intrusion was subscribed for patients with open bite.

4 | DISCUSSION

In this retrospective study, 3D facial changes in class II hyperdivergent patients with stable ICR after orthodontic camouflage treatment with vertical control using TAD were evaluated with 3DMM. The status of TMJ was analysed via CBCT and clinical records before and after the treatment, and the cephalometric analysis and dental cast measurements were also performed. The results suggested that ICR remained stable according to both the imaging and clinical examinations after orthodontic treatment. With the assistance of TAD as both sagittal and vertical anchorage, improvement of the facial profile was observed, and lip retraction was obvious (Figure 6). The retraction of the incisors and the counterclockwise rotated mandible

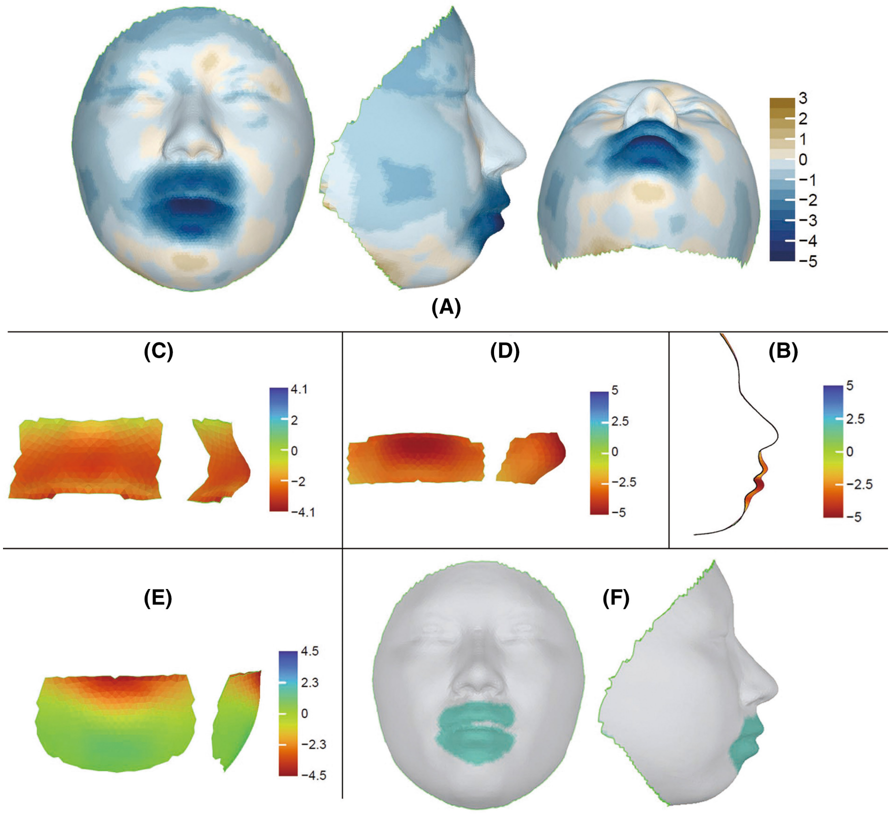

FIGURE 5 Changes in the face before and after orthodontic treatment (negative values indicate retrusion after treatment, and positive values indicate protrusion, in mm). A, Changes in the whole face area; B, changes in the median sagittal outline; C, changes in the upper lip area; D, changes in the lower lip area; E, changes in the chin area; F, facial regions with changes over 2 mm are marked in cyan

TABLE 6 Change of facial measurements

Measurements	Mean ± SD	t	P
△LL H	−0.63 ± 0.65	3.05	.014*
△FC	0.99 ± 0.98	−3.20	.011*
△L Verm H	−0.96 ± 1.03	2.93	.017*
△Mand Cont	3.83 ± 3.43	−3.52	.006*
△Nasolabial A	6.98 ± 4.80	−4.59	.001*
△Philtral L	−0.29 ± 0.78	1.17	.273
△Philtral W	−0.57 ± 0.38	4.72	.001*
△ULH	0.10 ± 1.20	−0.27	.792
△U Verm H	0.02 ± 1.10	−0.07	.947
△LFW	−1.82 ± 1.05	5.47	.000*
△Me A	5.92 ± 15.95	1.17	.271
△UL-E line	3.02 ± 1.16	8.25	.000*
△LL-E line	4.80 ± 1.15	13.22	.000*

Abbreviations: △, change of value after treatment; FC, Facial Convexity; L Verm H, Lower Vermilion Height; LFW, Labial Fissure Width; LL H, Lower Lip Height; LL-E line, distance of lower lip to E line; Mand Cont, Mandibular Contour; Me A, mentolabial sulcus angle; Nasolabial A, Nasolabial Angle; Philtral L, Philtral Length; Philtral W, Philtral Width; U Verm H, Upper Vermilion Height; UL-E line, distance of upper lip to E line; ULH, Upper Lip Height.
*$P < .05$.

plane that was caused by the intrusion of the upper molars may account for the profile improvement. These inspiring results imply that camouflage orthodontic treatment with TAD for vertical control is acceptable for class II hyperdivergent patients with ICR, thus leading to the improvement of the facial profile.

ICR should be differentiated from temporomandibular joint osteoarthritis (TMJOA), which is similar to ICR in clinical manifestations and imaging features at the time of diagnosis. However, for ICR, no obvious incentives, such as scissors bite, crossbite, point contact, secondary occlusion disorders, or bad chewing habits, could be observed. According to Hatcher,[24] ICR proceeds through a destructive phase of loss of the cortex that begins along the anterosuperior surface of the condyle. A cavitation defect extends into the subchondral bone, thus resulting in the loss of condylar volume. This active phase is followed by the reparative phase of condylar flattening and recortication.

Vertical change and joint stability have been long-researched topics for decades. According to a review published in recent years, there is no indication that permanent alteration in the occlusion vertical dimension will produce long-lasting TMD symptoms,[25] which is supported by the results of this study. Decades ago, some researchers expressed their concerns about the "dangers" of altering the occlusal vertical dimension,[26,27] which may lead to signs and symptoms of TMD. Compared with the increase in the occlusal vertical dimension, the decrease in the vertical dimension was thought to be more acceptable because the stomatognathic system naturally adapts to vertical decreases due to dental abrasion.[26,27]

In this study, stable TMJ status was demonstrated after orthodontic treatment with vertical control. Based on the samples of this study, for most of the condyles, no remarkable progression of ICR was observed after the treatment. According to the radiographic

TABLE 7 3D deviation between different soft tissue landmarks before and after treatment

Landmarks	Mean ± SD	*t*	*P*
X			
NA			
Y			
Pg'	2.34 ± 2.03	3.65	.005*
Z			
R Chl	−3.22 ± 2.13	−4.77	.001*
L Chl	−2.85 ± 2.41	−3.74	.005*
R Go	−1.52 ± 1.30	−3.71	.005*
Li	−5.11 ± 2.17	−7.44	.000*
Ls	−3.54 ± 1.41	−7.97	.000*
L Mid-Mb	−1.08 ± 0.81	−4.23	.002*
Sl	−4.50 ± 1.98	−7.19	.000*
Sn	−1.34 ± 0.91	−4.63	.001*
D			
R Chb	1.65 ± 0.48	10.83	.000*
L Chb	1.44 ± 0.53	8.60	.000*
R Chl	4.02 ± 1.85	6.86	.000*
L Chl	3.53 ± 2.19	5.09	.001*
Gn'	3.06 ± 1.24	7.80	.000*
R Go	2.69 ± 0.87	9.77	.000*
L Go	2.08 ± 1.33	4.94	.001*
Li	5.74 ± 1.95	9.32	.000*
Ls	3.91 ± 1.53	8.11	.000*
Me'	3.20 ± 1.60	6.33	.000*
R Mid-Mb	3.44 ± 1.78	6.12	.000*
L Mid-Mb	2.77 ± 1.06	8.24	.000*
Pg'	3.28 ± 1.60	6.50	.000*
Sl	5.22 ± 1.84	8.97	.000*
Sn	1.73 ± 0.92	5.92	.000*

Abbreviations: Cl, Columella; D, three dimensional distance; leftward, upward, and protrusion was set positive value; Gl, Glabella; Gn', Soft Tissue Gnathion; L/R Chb, Left/Right Cheekbone; L/R Chl, Left/Right Chelion; L/R CPh, Left/Right Crista Philtri; L/R Go, Left/Right Gonion; L/R Mid-Mb, Left/Right Mid-mandibular Border; Li, Labrale Inferius; ls, Labrale Superius; Me', Soft Tissue Menton; Pg', Soft Tissue Pogonion; Sl, Sublabial; Sn, Subnasale; Spl, Supralabial; Sto, Stomion Superius; X, horizontal direction; Y, vertical direction; Z, sagittal direction.

*$P < .05$.

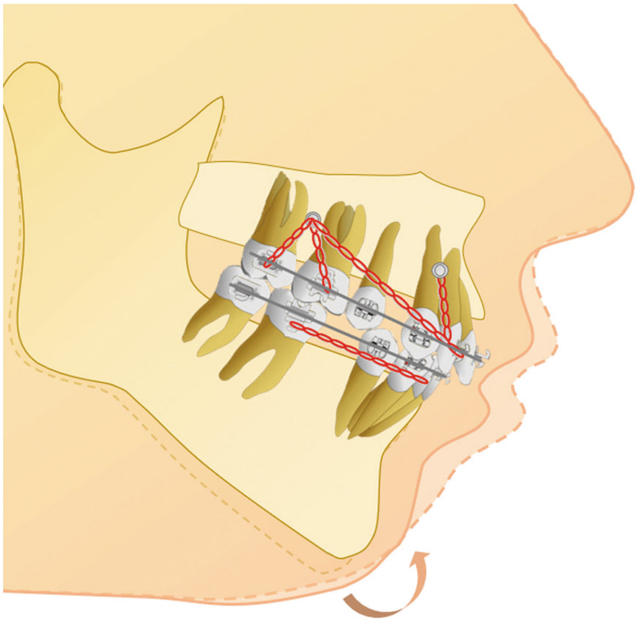

FIGURE 6 Treatment strategy: temporary anchorage devices (TADs) were implanted in the bilateral buccal and lingual sides of the alveolar bone between the roots of the upper first molar and upper second molar, with or without the TADs implanted in the anterior segment for incisor intrusion to correct gummy smile. The facial profile improved with the retraction of the incisors and the counterclockwise rotated mandible

results, all 5 types of classic osseous changes in most of the condyles remained steady or improved. Moreover, even for a few condyles with increased severity of radiographic diagnosis (such as 15% of the samples showing a slight worsening of erosion), the results of the corresponding clinical examinations did not show worsening effects. According to the studies from Yisi et al.[28] and Kristensen et al.,[29] symptoms and signs of TMJ arthralgia and myalgia are frequent in patients with ICR, and most patients with ICR showed symptoms and signs of TMD. The patients involved in our study had similar symptoms and received relative treatment till the symptoms relived or disappeared. The orthodontic treatment started after the TMJ remained stable for at least 1 year to ensure treatment effectiveness. Most of the clinical findings of orofacial pain, TMJ sounds, and TMJ function remained mild and steady; additionally, for several patients, better clinical symptoms were observed. Moreover, only one patient's mouth opening was slightly decreased after treatment.

Orthodontists should be extra careful with ICR patients. Before, during, and after treatment, orthodontists are required to supervise the status of the TMJ to make early diagnoses to prevent larger risks. The status of the TMJ is closely related to the result and stability of orthodontic treatments, and successful orthodontic treatments are based on a positive response of the TMJ.[30] With the usage of TAD as maximum anchorage, inter-arch elastic, which exerts an extra burden on the TMJs, can be minimized. Moreover, orthognathic surgery has been reported to be an iatrogenic cause for progressive ICR due to the increased load of TMJs after surgery,[2] which makes orthodontic treatment a more moderate alternative for patients with less severe skeletal and joint problems. It is worth mentioning that some ICR patients exhibit unstable occlusion.[31] Therefore, clinical examinations of unstable occlusion should be performed before orthodontic treatment for patients with ICR. Some researchers have suggested the use of a stabilization splint before orthodontic treatment to achieve stable occlusion, as well as to reduce TMD symptoms, in patients with unstable occlusion, and orthognathic surgery should be further conducted.[32] However, the necessity of using a stabilization splint is controversial.[31] For patients who were included in this study, no unstable occlusion was diagnosed before and during treatment.

For class II hyperdivergent patients, vertical control is difficult and essential to perform. In this study, the intrusion of the upper molars and retraction of incisors contributed to a better nose-lip-chin relationship. Similar results were obtained by Erverdi et al., who treated 10 anterior open bite patients with TAD, and an average of 2.6 mm intrusion of the upper first molar with the 1.7° counterclockwise rotation of the mandibular plane was observed.[33] Likewise, assisted by TAD, an average of 2.03 mm intrusion of the upper first molar and 1.57° counterclockwise rotation of the mandibular plane were achieved by Oliveira et al.[9] Similarly, Kuroda et al.[34] used TADs to intrude the molars of a skeletal Class II hyperdivergent patient with severe anterior open bite. The results indicated good occlusion was achieved with 3.0 mm molar intrusion, and the profile was improved with the upward rotation of the mandible.

With 3DMM, the change in the nose-lip-chin relationship can be intuitively and accurately demonstrated. By using 2 mm as the threshold for clinical significance,[22] an elliptical area marked by supralabial, soft tissue pogonion, and both chelion points was observed. The largest retrusion of the lips was at the lower vermilion (5.00 mm), which was supported by previous studies.[35,36] With 3DMM, accurate, reproducible, and intuitively interpretable facial measurements can be obtained. A recent study proved that most of the landmarks had differences between raters of approximately 0.5–1 mm[4]. In addition, the 3D deviation measurement function in conventional 3D processing software is based on the ICP algorithm, which can illustrate 3D deviation between two 3D models by minimizing the difference between two pointclouds.[37] In the field of orthodontics, doctors aim to know the changes between the corresponding anatomic areas before and after treatment. However, the conventional ICP method cannot offer these results; instead, it shows the changes between the closest points between the two models. The 3DMM method is a highly precise method of detecting dense facial landmarks from a given 3D face model by non-rigidly transforming a 3DMM to the target face. An error of less than 0.2 mm was demonstrated for the 3DMM method, which has a better reproducibility compared with manual landmarking.[5] Currently, this approach is being increasingly used in various aspects of facial shape analyses, including in the field of orthodontic early treatment, orthognathic surgery, and facial asymmetry.[6–8]

There were several limitations of this study. First, the sample size of this study was relatively small, which was due to the difficulty of clinical collection for the ICR patients who met the inclusion criteria. A previous study found that orthodontists encountered patients with ICR at a rate of 1 case per 5000 orthodontic patients, which results in most of the published ICR studies being case reports or case series.[15] Patients with severe asymmetric mandible were initially excluded from this study according to the inclusion criteria. The orthodontic camouflage treatment with vertical control for asymmetric patients with ICR is much more complex, and more attention should be paid to gain a balance result between TMJ stability and facial improvement. Post-treatment analyses were carried out immediately after the treatment was finished. Even though our previous study has proved the long-term stability of vertical control with TADs for hyperdivergent patients,[38] however, the long-term stability of the treatment for patients with ICR needs further follow-up records. Moreover, even though this retrospective study included patients with consistent baseline to the greatest extent, a randomized control trial study design should provide clinical evidence with better quality.

5 | CONCLUSION

Camouflage orthodontic treatment with TAD for vertical control is acceptable for class II hyperdivergent patients with ICR, which can lead to facial improvements. 3DMM is suitable for 3D facial analysis when comparing facial changes before and after orthodontic treatment.

AUTHOR CONTRIBUTIONS

Bochun Mao: investigation, methodology, writing- original draft; Yajing Tian: investigation, methodology; Jing Li: funding acquisition, methodology, writing- review& editing; Yanheng Zhou: funding acquisition, supervision, writing- review& editing; Xuedong Wang: clinical treatment, funding acquisition, supervision, writing- review& editing.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest, either directly or indirectly, in the information or products listed in the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL

This retrospective study was approved by the bioethics committee of the Peking University School and Hospital of Stomatology (No. PKUSSIRB-201630096). Written informed consent was obtained from the participant. The ethics approval and the written informed consent included the permission of using the raw data of CBCT of the patient.

CONSENT FOR PUBLICATION

All authors of this manuscript approved the publication.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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