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Changes of temporomandibular joint space volume during 1 year after transoral vertical ramus osteotomy in patients with mandibular asymmetry

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This retrospective study aimed to evaluate the difference in the temporomandibular joint (TMJ) space volume between the deviated (Dev) and non-deviated (NDev) side following transoral vertical ramus osteotomy (TOVRO) in patients with mandibular prognathism combined with asymmetry using reconstructed 3-dimensional images. Sixty joints from 30 patients who underwent TOVRO between January 2018 and December 2021 were included. Computed tomography (CT) or cone-beam CT was performed before surgery (T0), and 6 (T1) and 12 months postoperatively (T2). The volume of the overall joint space (Vjs) and its compartments (i.e., the anterior, posterior, medial, and lateral joint spaces) were calculated at each time point. A linear mixed model and repeated-measures covariance pattern with unstructured covariance were used. Vjs increased at T1 compared to T0 and decreased at T2 compared to T1 ($p < 0.0001$). Furthermore, the volume changes over time were statistically significant in all compartments ($p < 0.05$); however, there was no significant difference in the Vjs and its compartments between the Dev and NDev side over time ($p > 0.05$). Adjustments for sex and mandibular movements did not affect the results. This study can provide the basis in TMJ spatial change and predicting the prognosis after TOVRO in facial asymmetry.

Keywords Mandibular asymmetry, Temporomandibular joint, Volume, Vertical Ramus osteotomy

Transoral vertical ramus osteotomy (TOVRO) is one of the treatment option for temporomandibular joint disease (TMD)[1,2], which is associated with an improvement in the condyle–TMJ disc relationship and resolution of TMD symptoms[3,4]. Immediately after TOVRO, the proximal segment, including the condyle, can move in the anterior–inferior–medial direction with the action of the lateral pterygoid muscle. This movement of the proximal segment also occurs during TOVRO surgery due to dissection of the masseter and medial pterygoid. Then, the proximal segment can gradually recover its original position with physical therapy and recovery of surrounding muscles[3]. Accordingly, the space between the condyle and the temporal bone changes.

The temporomandibular joint space (TMJ space) is the space between the mandibular condyle and temporal bone. This articular space is necessary for the proper function of the joint[5]; however, a reduced or narrowed joint space is associated with pain and/or osteoarthritis[6,7]. Furthermore, Lee et al.[8] reported that anterior joint space narrowing of TMJ was correlated TMD. Therefore, considering the above reasons, information on the changing pattern of joint space is important to clinicians.

There have been several studies being conducted to measure the volume of the temporomandibular joint space using three-dimension (3D)[9–11]. However, few studies have been conducted regarding the differences in the 3D volumetric changes in the TMJ space between the deviated and non-deviated sides after TOVRO in patients with facial asymmetry. Lopez et al.[10] reported that the TMJ space on both sides was different in patients with facial asymmetry, but they did not report on the change pattern after surgery. Although Kim et al.[11]

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measured and analyzed 3D volumetric changes of joint space in patients with mandibular prognathism, they did not provide any information regarding joint space in patient with facial asymmetry.

After TOVRO, an improvement in the condyle is achieved through recovery of the surrounding muscles and physical therapy. Furthermore, it has been reported that the size and activity of the masseter muscle are different in patients with facial asymmetry[12,13]. In this respect, we hypothesized that there may be differences in 3D joint space changes in the overall and each compartment between the deviated side and the non-deviated side after TOVRO in patients with facial asymmetry.

This study aimed to analyze the 3D volumetric changes in the entire TMJ space and each compartment between the deviated side (Dev) and the non-deviated side (NDev) after TOVRO in patients with mandibular asymmetry accompanied by mandibular prognathism.

Methods

This retrospective study was approved by the Institutional Review Board of the Gangnam Severance Hospital (approval No. 3-2024-0125). Due to the retrospective nature of the study, the requirement for written informed consent was waived. This study was conducted in accordance with the principles of the Declaration of Helsinki for Research on Humans.

The medical records of patients who underwent orthognathic surgery with a diagnosis of mandibular asymmetry accompanied by mandibular prognathism between January 2018 and December 2021 at the Department of Oral and Maxillofacial Surgery, Gangnam Severance Hospital, Seoul, Republic of Korea, were reviewed and included in this study. Patients with the following conditions were excluded: (1) incomplete cone-beam CT (CBCT) data after surgery, (2) pathological changes in the TMJ such as condylar hyperplasia or osteochondroma, (3) congenital anomalies, such as cleft lip and palate or hemifacial microsomia, and (4) < 3 mm of chin deviation.

Preoperative (T0) CT was performed for analysis and diagnosis. After the operation, CBCT was performed at 6 months (T1) and 12 months (T2) for postoperative follow-up.

Postoperative management was performed according to our previous protocol[14]. Intermaxillary fixation was performed with six elastics on the surgical arch wires for 2 weeks after the operation. Physical therapy (including mouth opening and lateral movement) was started with two elastics until maximum mouth opening was achieved. The surgical splint was removed approximately 1 month after surgery, and postoperative orthodontic treatment was initiated.

Diagnosis of mandibular prognathism and mandibular asymmetry

Lateral cephalometric radiography was used to diagnose mandibular prognathism. The Frankfort horizontal line (the line connecting the porion and orbitale; the FH line) was set as the horizontal reference line. The vertical reference line was set as the line perpendicular to the horizontal FH line that passed through the nasion point. Mandibular prognathism was diagnosed when the pogonion was > 1 mm anterior to the vertical reference line[15].

Mandibular asymmetry was diagnosed using posteroanterior (PA) cephalometric radiography. A horizontal reference line was set by connecting the bilateral lateral orbitals. A vertical reference line was set perpendicular to the horizontal reference line and passed through the anterior nasal spine. The distance between the menton and the vertical reference line was measured, and if it exceeded 3 mm, mandibular asymmetry was diagnosed. The joint space was divided into the Dev side, which was in the same direction as chin deviation, and the NDev side, which was in the opposite direction[16,17].

Acquisition, reconstruction, and analysis of CT images

CT images were obtained using a Siemens Definition AS+ (Siemens, Erlangen, Germany) with constant settings (1 mm slice thickness, 7 s scan time, 120 kV, and 90 mAs, pixel spacing (0.63 mm.0.64 mm), voxel size = 0.403 mm^3).CBCT images were obtained using PaX-i3D (Vatech Co., Gyeonggi-do, Republic of Korea) with constant settings (0.3 mm slice thickness, 24 s scan time, 106 kV, and 65 mAs, pixel spacing (0.3 mm, 0.3 mm), voxel size = 0.027 mm^3)[11]. The field of view in CBCT was 21 cm x 19 cm. The images were reconstructed (threshold value:400 ~ 8000) and analyzed using Mimics 3D analysis software (version 22.0; Materialize, Leuven, Belgium).

Reference points and planes

The nasion (N), orbitale (Or), porion (Po), basion (Ba), crista galli (Cg), lateral lip of eminence (Em), and most superior point of the glenoid fossa (Gf) were used as reference points. Based on previous studies, the mid-axial plane (MAP), mid-sagittal plane (MSP), coronal plane (COP), eminence plane (EmP), glenoid fossa sagittal plane (GfSP), and glenoid fossa coronal plane (GfCP) were established as follows (Fig. 1)[11]:

1. MAP: a plane connecting the Or right (OrR), Or left (OrL), and Po right (PoR).
2. MSP: a plane perpendicular to the MAP passing through the Cg and Ba.
3. COP: a plane passing through the Ba perpendicular to the MSP and MAP.
4. EmP: a plane parallel to the MAP passing through the Em (EmPR and EmPL).
5. GfSP: a plane parallel to the MSP and passing through the Gf (GfSPR and GfSPL).
6. GfCP: a plane parallel to the COP and passing through the Gf (GfCPR and GfCPL).

Superimposition of reconstructed 3D images

The preoperative CT images and postoperative CBCT images at 6 and 12 months were superimposed on the cranial region. The three-point superimposition method with three reference points (Na, PoR, and Ba) was used for the first overlap because these points did not change in position or shape before and after surgery. Any small

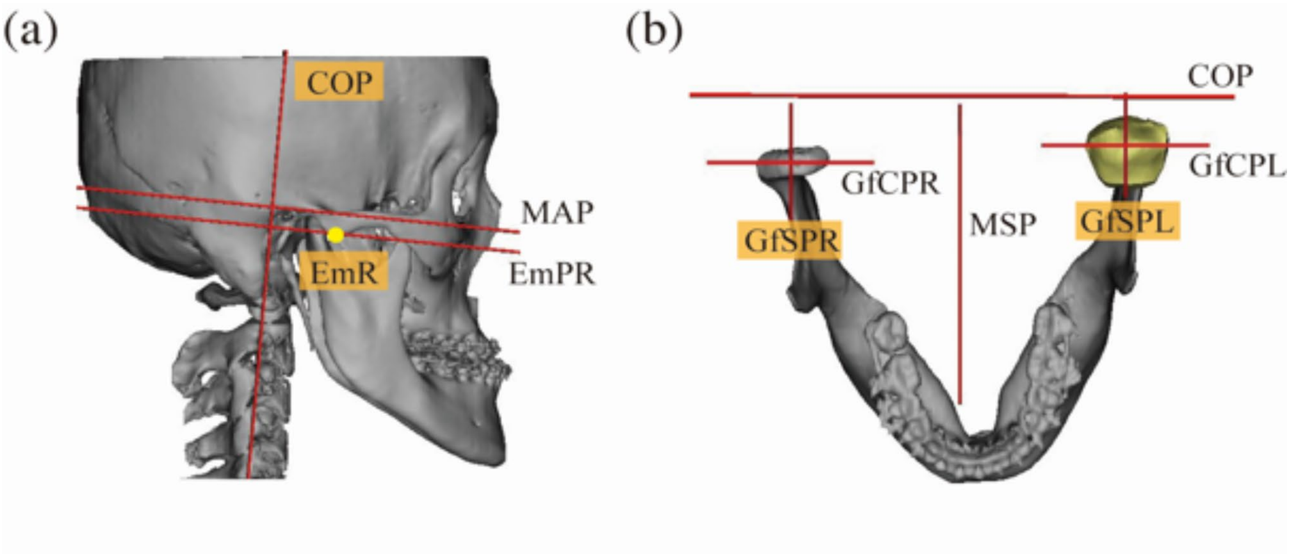

Fig. 1. Reference planes for 3D analysis. (**a**) Right side of the skull; (**b**) Left side of the skull; (**c**) occlusal view of the mandible. MAP, Mid-axial plane; MSP, Mid-sagittal plane; COP, Coronal plane; EmPR, Eminence plane right; EmPL, Eminence plane left; GfSPR, Glenoid fossa sagittal plane right; GfCPR, Glenoid fossa coronal plane right; GfSPL, Glenoid fossa sagittal plane left; GfCPL, Glenoid fossa coronal plane left.

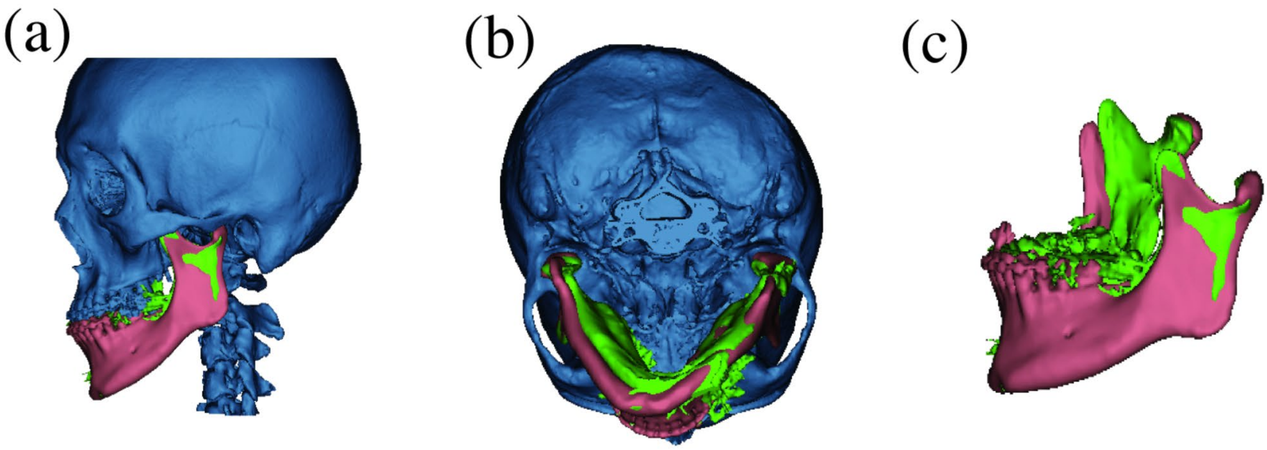

Fig. 2. Examples of superimposition images (3D) (**a**,**b**) Superimposition image of skull between pre-operative and post-operative 6 M images; (**c**) Superimposition image of mandible between pre-operative and post-operative 6 M images (Blue, skull before operation; pink, mandible before operation; green, mandible after 6 months of operation).

errors were corrected by manually for more accurate overlapping of the cranial region[11]. An example illustration of the overlap is shown in Fig. 2.

Measurement of the gf and joint space volume at T0

First, the volume of the glenoid fossa (Vgf) was measured as described in a previous study[11,18]. The analysis was performed by one observer (S.J.B.). One-third of the total subjects were randomly selected, and Vgf was measured twice, with at least 2 weeks between the measurements, to calculate the agreement. By removing the 3D reconstructed condyle, the volume of the joint space (Vjs) was measured. Vgf and Vjs were calculated as follows:

(1) First, the mandible was separated from the 3D reconstructed skull (Fig. 3a).

(2) The anterior and posterior boundaries were formed on the skull separated from the mandible by creating a curved plane connecting between the lowest rim of the articular eminence and the zygomatic arch, respectively. (Fig. 3b).

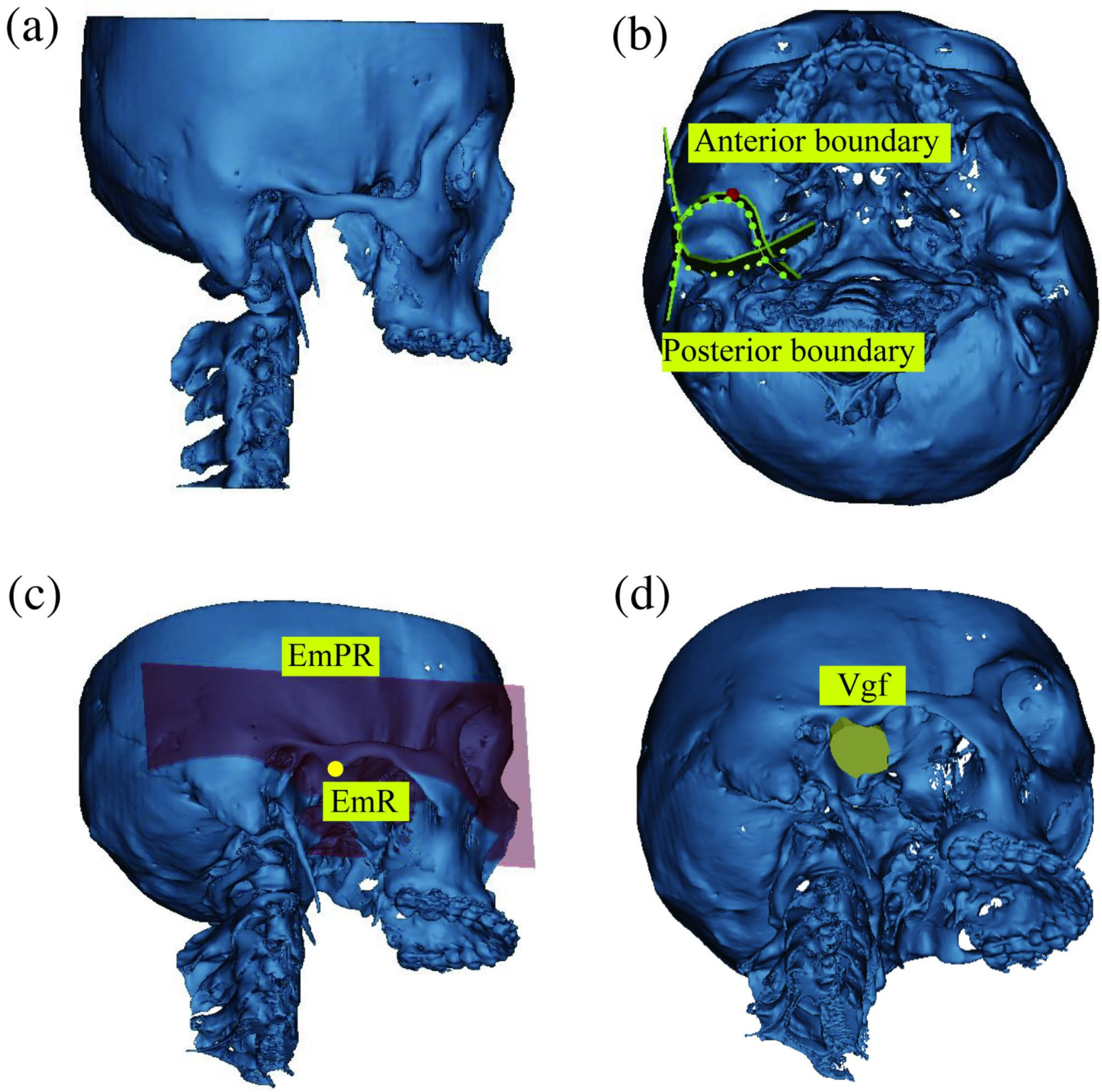

Fig. 3. Measurement of volume of the glenoid fossa (Vgf). (**a**) Separation and removal of the mandible in 3D reconstructed skull; (**b**) Formation of anterior and posterior boundary; (**c,d**) The volume of the glenoid fossa (Vgf).

(3) The superior, posterior, and medial borders were defined as the temporal, petrotympanic, and sphenoid bone borders, respectively.
(4) The space defined through (2) and (3) was bounded inferiorly by the EmP (articular eminence plane), and the volume of this space was measured and defined as Vgf (Fig. 3c,d). EmP is automatically set parallel to MAP when the eminence point is set in Mimics software.
(5) Vcon was automatically calculated by the software as the superior volume of the mandibular condyle cut by EmP. The Vjs was defined as the space remaining after removing the Vcon from the Vgf formed above (Fig. 4a,b).

(6) The Vjs separated by the GfCP as the anterior and posterior parts was measured and defined as the volume of the anterior (Vaj) and posterior joint spaces (Vpj), respectively (Fig. 4c).
(7) Similarly, the Vjs separated by the GfSP as the medial and lateral parts was measured and defined as the volume of the medial (Vmj) and lateral joint spaces (Vlj), respectively (Fig. 4d).

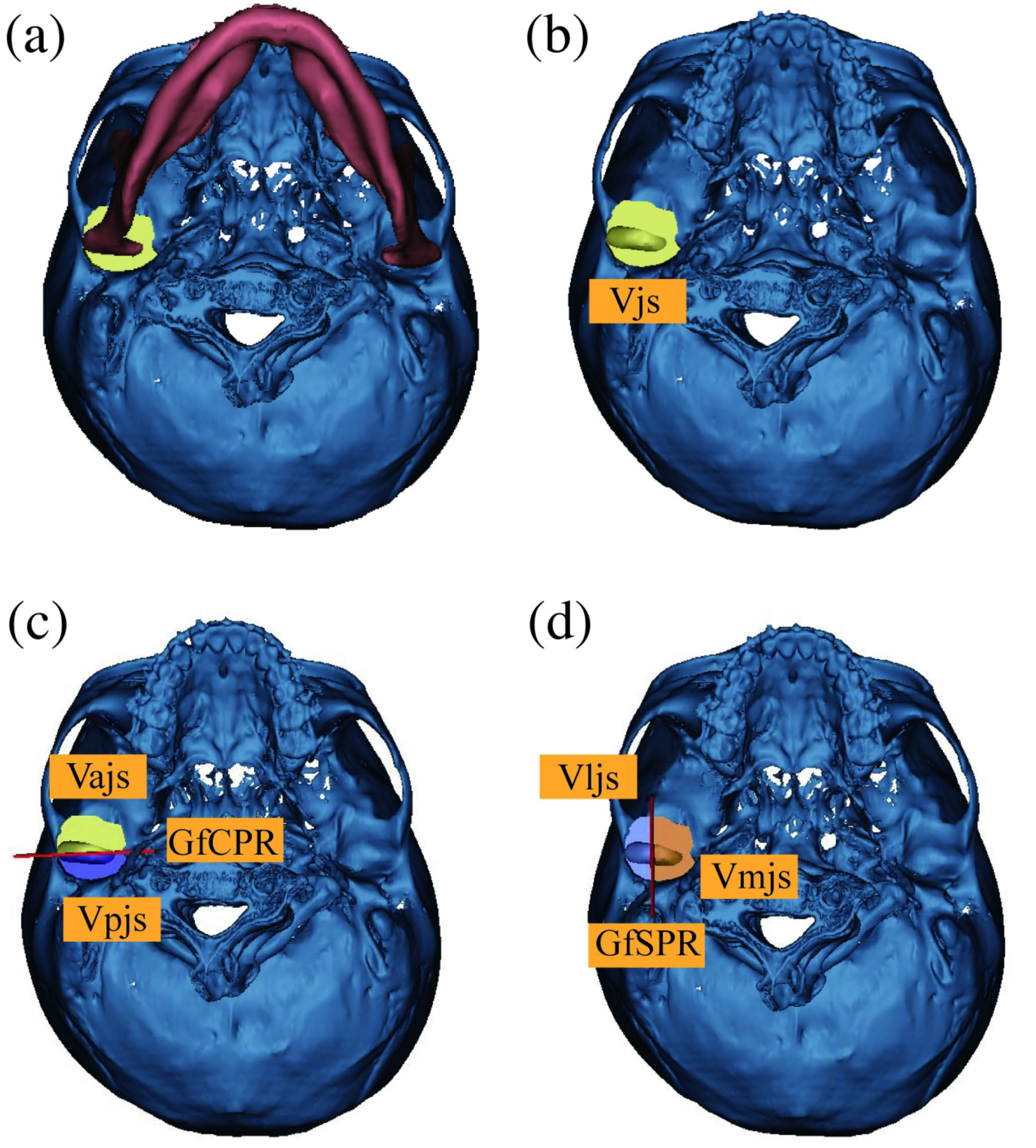

Fig. 4. Measurement of volume of the joint space (Vjs). (**a**,**b**) The volume of the joint space (Vjs); (**c**) The anterior and posterior joint space (Vajs and Vpjs), Vjs was divided by GfCP; (**d**) The mesial and lateral joint space (Vmjs and Vljs), Vjs was divided by GfSP.

Measurement of vjs at T1 and T2

Vjs was measured at T1 and T2 after removing the condyles from the Gf. Because Vgf did not change according to the operation, the value measured at T0 was used. After superimposing the postoperative reconstructed 3D image onto the preoperative 3D image and confirming the changes in the condylar position in the analysis program, the condyle was removed from the Gf. Subsequently, Vaj, Vpj, Vmj, and Vlj were measured using the methods described above.

Measurement of mandibular movement

To analyze the 3D positional changes in the mandible, including the amount of setback, we assessed the changes in the lingula before and 6 months after surgery. Lingula was defined as bony projection just above mandibular foramen[19]. Lingula was marked before surgery and 6 months after surgery, and the distance between the two points was measured. Measurements were performed automatically by the Mimics 3D analysis software.

Statistical analysis

Data pre-processing was performed using Excel 2016 (Microsoft, Redmond, WA, USA). SAS version 9.4 (SAS Institute, Cary, NC, USA) was used for analysis and statistical processing. Paired t-test was used to compare Vgf between NDev and Dev before surgery. A linear mixed model and repeated-measures covariance pattern with unstructured covariance were used to evaluate significant changes in the TMJ space volume over time. In the post-hoc analysis, Bonferroni correction was applied, and a *p*-value of <0.05 was considered statistically significant.

Results

A total of 30 patients (age 22.77 ± 3.91 years; 19 males and 11 females) were included in the study. Twenty-six patients underwent (86.67%) bimaxillary orthognathic surgery (TOVRO with a Le Fort I osteotomy), and four (13.33%) underwent TOVRO alone. The TMJ space volume (30 Dev and 30 NDev sides) was analyzed. Vgf was measured twice in 11 randomly selected subjects. The intraclass correlation coefficient (ICC) was 0.9986 for Dev and 0.9970 for NDev. The mean Vgf on the Dev and NDev side was 1622.27 mm^3 (1408.56–1835.97 mm^3) and 1674.54 mm^3 (1468.19–1880.88 mm^3), which did not show a significant difference (difference = 52.27 (– 138.24–242.78), $t_{(29)}$ = 0.56, p = 0.5790). The mean volume of the condyle (Vcon) on the Dev and NDev side was 566.24 mm^3 (486.73–645.76 mm^3) and 584.34 mm^3 (495.87–672.80 mm^3), which did not show a significant difference (difference = 18.10 (– 53.29 to 89.48), $t_{(29)}$ = 0.52, p = 0.6081)

Changes in the overall vjs between the Dev and NDev sides over time (non-adjusted)

The Vjs changed over time for both the Dev and NDev sides. The Vjs of the Dev was significantly increased at T1 (1167.56 mm^3 (1027.20–1307.93 mm^3) compared to T0 (1068.03 mm^3 (936.07–1199.99 mm^3) (difference = 99.53 (68.51–130.55), $t_{(58)}$ = 6.42, $p < 0.0001$), and significantly decreased at T2 (1110.71 mm^3 (969.06–1252.37 mm^3) compared to T1 (difference = – 56.85 (– 80.92–32.79), $t_{(58)}$ = -4.73, $p < 0.0001$). A significant increase was observed at T2 compared to T0 (difference = 42.68 (9.40–75.96), $t_{(58)}$ = 2.57, p = 0.0129). The Vjs of the NDev side was significantly increased at T1 (1153.67 mm^3 (1029.62–1277.72 mm^3) compared to T0 (1073.56 mm^3 (956.94–1190.18 mm^3)) (difference = 80.11 (52.69–107.52), $t_{(58)}$ = 5.85, $p < 0.0001$) and significantly decreased at T2 (1085.07 mm^3 (959.89–1210.26 mm^3) compared to T1 (difference = – 68.60 (– 89.86–47.33), $t_{(58)}$ = – 6.46, $p < 0.0001$), similar to the Dev. The Vjs of the NDev at T2 (1085.07 mm^3 (959.89–1210.26 mm^3) was larger than that at T0 (1073.56 mm^3 (956.94–1190.18 mm^3); however, there was no statistical significance (difference = 11.51 (– 17.90–40.93), $t_{(58)}$ = 0.78, p = 0.4365) (Table 1). Overall, there was no significant difference in the changes between the Dev and NDev sides over time ($F_{(2, 58)}$ = 1.57, p = 0.2166) (Fig. 5a).

Changes in Vaj, Vpj, Vmj, and Vlj in the Dev and NDev sides over time (non-adjusted)

There were no differences in Vaj and Vmj between T0 and T1 for the Dev and NDev sides. A significant decrease in the NDev side was observed at T2 compared to T0. There was no significant difference in the Vaj or Vmj between the Dev and NDev sides over time ($F_{(2, 58)}$ = 0.69, p = 0.5059 and $F_{(2, 58)}$ = 0.25, p = 0.7797). Regarding the Vpj, the increase was greater in the Dev side (468.27 mm^3 (405.46–531.08 mm^3) at T0 and 531.47 mm^3 (454.47–608.46 mm^3) at T2) than in the NDev side (453.71 mm^3 (382.16–525.27 mm^3) at T0 and 499.37 mm^3 (411.65–587.09 mm^3) at T2). However, no significant difference was observed between the Dev and NDev groups over time ($F_{(2, 58)}$ = 0.84, p = 0.4362). The Vlj showed a tendency similar to that of Vpj; the Dev side (489.69 mm^3 (421.97–557.40 mm^3) at T0 and 558.69 mm^3 (481.63–635.75 mm^3) at T2) showed a greater increase than the NDev side (433.35 mm^3 (365.63–501.07 mm^3) at T0 and 473.33 mm^3 (396.27–550.38 mm^3) at T2). Finally, there was no difference in the change over time between the Dev and the NDev sides ($F_{(2, 58)}$ = 2.88, p = 0.0641). These results are summarized in Table 1; Fig. 5b–e.

Changes in the overall and compartment joints space volume between the Dev and NDev sides over time (adjusted for sex and amount of mandibular movement)

The results were similar when the data were adjusted for sex and mandibular movements. The Vjs in the Dev side was significantly increased at T1 (1140.86 mm^3 (1007.51–1274.21 mm^3) compared to T0 (1041.33 mm^3 (915.97–1166.68 mm^3) (difference = 99.53 (69.10–129.96), $t_{(58)}$ = 6.55, $p < 0.0001$) and significantly decreased at T2 (1084.01 mm^3 (949.13–1218.89 mm^3) compared to T1 (difference = – 56.85 (– 80.40 to 33.30), $t_{(58)}$ = – 4.83, $p < 0.0001$). A significant increase was observed at T2 compared to T0 (difference = 42.68 (9.90–75.46), $t_{(58)}$ = 2.61, p = 0.0116). Vjs in the NDev side was significantly increased at T1 (1127.70 mm^3 (1006.08–1249.33 mm^3) compared to T0 (1047.60 mm^3 (933.24–1161.95 mm^3)) (difference = 80.11 (52.40–107.82), $t_{(58)}$ = 5.79, $p < 0.0001$), and significantly decreased at T2 (1059.11 mm^3 (936.09–1182.13 mm^3) compared to T1 (difference = – 68.60 (– 90.04 to 47.15), $t_{(58)}$ = – 6.4, $p < 0.0001$), similar to the Dev. Although the Vjs in the NDev group at T2 was larger than that at T0, the difference was not statistically significant (difference = 11.51 (– 18.33 to 41.36), $t_{(58)}$ = 0.77, p = 0.4431) (Table 2). However, there was no significant difference in the changes between the Dev and NDev groups over time ($F_{(2, 58)}$ = 1.52, p = 0.2266) (Fig. 6a).

Variable	Dev Estimated mean (95% CI)	NDev Estimated mean (95% CI)	Overall p-value	Deviation status post-hoc p-value		Time post-hoc p-value			Deviation status × Time post hoc p-value	
					Dev vs. NDev		Dev	NDev		
Vjs (mm^3)										
T0	1068.03 (936.07–1199.99)	1073.56 (956.94–1190.18)	Deviation status: 0.8770 Time: <0.0001† Deviation status*Time: 0.2166	T0	0.9373	T0 vs. T1	<0.0001†	<0.0001†	T0 vs. T1 & Dev vs. NDev	0.2422
T1	1167.56 (1027.20–1307.93)	1153.67 (1029.62–1277.72)		T1	0.8525	T0 vs. T2	0.0129†	0.4365	T0 vs. T2 & Dev vs. NDev	0.0825
T2	1110.71 (969.06–1252.37)	1085.07 (959.89–1210.26)		T2	0.7339	T1 vs. T2	<0.0001†	<0.0001†	T1 vs. T2 & Dev vs. NDev	0.3610
Vajs (mm^3)										
T0	539.95 (476.87–603.02)	566.98 (502.76–631.20)	Deviation status: 0.5646 Time: 0.0126† Deviation status*Time: 0.5059	T0	0.5303	T0 vs. T1	0.4874	0.9188	T0 vs. T1 & Dev vs. NDev	0.6633
T1	531.52 (470.17–592.86)	565.72 (503.26–628.18)		T1	0.4148	T0 vs. T2	0.1005	0.0083†	T0 vs. T2 & Dev vs. NDev	0.4164
T2	515.01 (451.91–578.12)	525.43 (461.17–589.68)		T2	0.8088	T1 vs. T2	0.2732	0.0103†	T1 vs. T2 & Dev vs. NDev	0.2453
Vpjs (mm^3)										
T0	468.27 (405.46–531.08)	453.71 (382.16–525.27)	Deviation status: 0.5645 Time: <0.0001† Deviation status*Time: 0.4362	T0	0.7284	T0 vs. T1	<0.0001†	<0.0001†	T0 vs. T1 & Dev vs. NDev	0.2234
T1	559.49 (482.06–636.92)	523.60 (435.38–611.82)		T1	0.4880	T0 vs. T2	<0.0001†	<0.0048†	T0 vs. T2 & Dev vs. NDev	0.3382
T2	531.47 (454.47–608.46)	499.37 (411.65–587.09)		T2	0.5327	T1 vs. T2	0.0414†	0.1188	T1 vs. T2 & Dev vs. NDev	0.8325
Vmjs (mm^3)										
T0	519.22 (440.80–597.64)	579.92 (507.88–651.96)	Deviation status: 0.2237 Time: <0.0001† Deviation status*Time: 0.7797	T0	0.1917	T0 vs. T1	0.9179	0.4436	T0 vs. T1 & Dev vs. NDev	0.6080
T1	518.11 (440.49–595.73)	572.36 (501.05–643.66)		T1	0.2379	T0 vs. T2	0.0209†	0.0009†	T0 vs. T2 & Dev vs. NDev	0.4839
T2	495.31 (417.58–573.03)	547.69 (476.29–619.10)		T2	0.2548	T1 vs. T2	0.0015†	0.0002†	T1 vs. T2 & Dev vs. NDev	0.8179
Vljs (mm^3)										
T0	489.69 (421.97–557.40)	433.35 (365.63–501.07)	Deviation status: 0.1646 Time: <0.0001† Deviation status*Time: 0.0641	T0	0.2121	T0 vs. T1	<0.0001†	<0.0001†	T0 vs. T1 & Dev vs. NDev	0.5178
T1	579.93 (502.71–657.16)	514.91 (437.68–592.13)		T1	0.2067	T0 vs. T2	<0.0001†	0.0003†	T0 vs. T2 & Dev vs. NDev	0.0379†
T2	558.69 (481.63–635.75)	473.33 (396.27–550.38)		T2	0.0983	T1 vs. T2	0.0110†	<0.0001†	T1 vs. T2 & Dev vs. NDev	0.0616

Table 1. Changes of overall and compartments of joint space volume according to time and deviation status (unadjusted). *Vjs, Volume of joint space; Vajs, Volume of anterior joint space; Vpjs, Volume of posterior joint space; Vmjs, Volume of medial joint space; Vljs, Volume of lateral joint space; NDev, Non-deviated side; Dev, Deviated side; T0, pre-operative; T1, post-operative 6months; T2, post-operative 12months. †Indicates $p < 0.05$.

Changes in Vaj, Vpj, Vmj, and Vlj in the dev and NDev sides over time (adjusted for sex and amount of mandibular movement)

The results were similar when the data were adjusted for sex and mandibular movements. There were no differences in the Vaj and Vmj between T0 and T1 for the Dev and NDev sides. A significant decrease was observed at T2 compared to T0 in the NDev group. There was no significant difference between Dev and NDev sides for the Vaj ($F_{(2,\,58)}$= 0.69, $p = 0.5078$) or Vmj ($F_{(2,\,58)}$= 0.24, $p = 0.7847$). Regarding the Vpj, the increase was greater in the Dev side (454.45 mm^3 (395.68–513.22 mm^3) at T0 and 517.65 mm^3 (444.16–591.14 mm^3) at T2) than in the NDev side (439.76 mm^3 (370.20–509.32 mm^3) at T0 and 485.42 mm^3 (398.30–572.53 mm^3) at T2). However, no significant difference was observed between the Dev and NDev groups over time ($F_{(2,\,58)}$= 0.78, $p = 0.4618$). Vlj showed a tendency similar to that of Vpj; the Dev side (475.59 mm^3 (409.36–541.82 mm^3) at T0 and 544.60 mm^3 (467.91–621.29 mm^3) at T2) showed a greater increase than the NDev side (419.30 mm^3 (359.87–478.72 mm^3) at T0 and 459.27 mm^3 (390.49–528.05 mm^3) at T2). Finally, there was no difference in the change over time between the Dev and NDev sides ($F_{(2,\,58)}$= 2.83, $p = 0.0675$). These results are summarized in Table 2; Fig. 6b–e.

Discussion

Facial asymmetry can be caused by several factors, including genetic factors, which can lead to inherent skeletal imbalances. Developmental factors, such as excessive growth in a specific area of the mandible or uneven growth rates between the maxilla and mandible, can also contribute to asymmetry. Additionally, facial trauma during development, muscle imbalances affecting jaw alignment, and temporomandibular joint (TMJ) dysfunction can further exacerbate facial asymmetry.

After TOVRO, proximal segment sagging can occur depending on the direction of action of the lateral pterygoid, which returns to its original position to some extent during the recovery process[11]. Previous studies have reported that changes in TMJ structures differ between the Dev and NDev sides over time after orthognathic surgery[20]; however, no significant difference in the changes on both sides has also been reported[14]. These previous studies performed 2D analysis of the length and angle. In contrast, this study aimed to determine whether

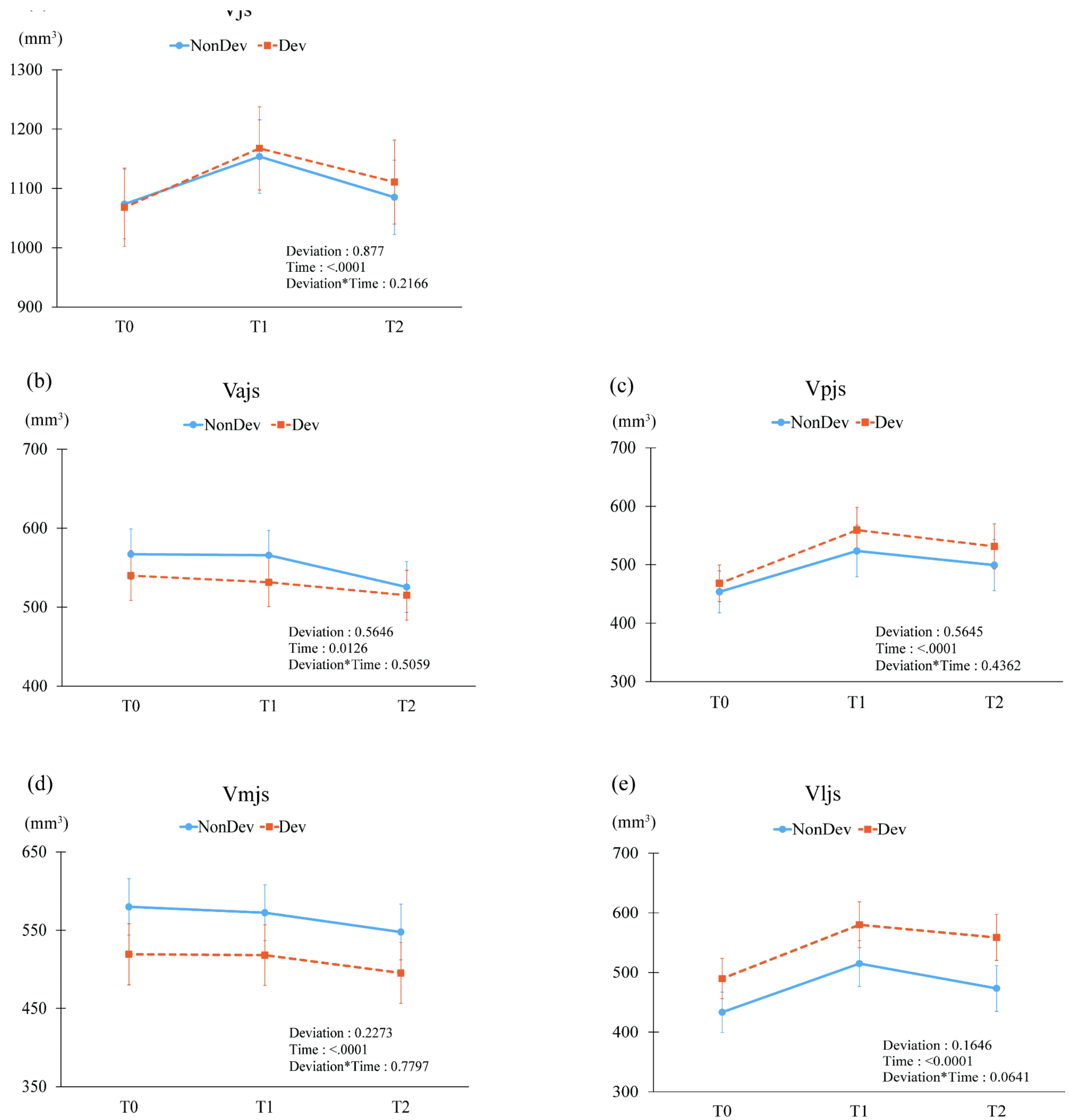

Fig. 5. Changes of joint spaces between deviated side (Dev) and non-deviated side (NDev) (Non-adjusted). (**a**) Vjs, the volume of the joint space; (**b**) Vajs, the anterior joint space; (**c**) Vpjs, the posterior joint space; (**d**) Vmjs, the mesial joint space; (**e**) Vljs, the lateral joint space.

volumetric changes in the TMJ space differed between the Dev and NDev sides over time after TOVRO in patients with mandibular asymmetry. We found no significant differences in the volumetric changes in the TMJ space between the Dev and NDev sides over time. To ensure reliability in volume measurement, one observer measured Vgf twice on one-third of the patients, and the agreement was 0.9986 on the deviated side and 0.9970 on the non-deviated side, indicating that this measurement was reliable. Vcon is automatically measured based on the reference plane. Since Vjs is the result of subtracting Vcon from Vgf, we consider that Vgf could be the cause of the error. Therefore, only Vgf was measured twice.

Previous studies measured the activity of the masticatory muscles before and after orthognathic surgery[21,22]. The electromyographic activity of the masticatory muscles on both sides differed before surgery; however, the masseter and anterior temporalis muscle activity tended to be balanced on both sides after surgery. This suggests that muscle activity on both sides was harmoniously regulated during the patient's recovery process after surgery,

Variable	Dev Estimated mean(95% CI)	NDev Estimated mean(95% CI)	Overall *p*-value	Deviation status post-hoc *p*-value		Time post-hoc *p*-value			Deviation status × Time post hoc *p*-value	
					Dev vs. NDev		Dev	NDev		
Vjs (mm³)										
T0	1041.33 (915.97–1166.68)	1047.60 (933.24–1161.95)	Deviation status: 0.8813 Time: <0.0001# Deviation status × Time: 0.2266	T0	0.9265	T0 vs. T1	< 0.0001†	< 0.0001†	T0 vs. T1 & Dev vs. NDev	0.2476
T1	1140.86 (1007.51–1274.21)	1127.70 (1006.08–1249.33)		T1	0.8558	T0 vs. T2	0.0116†	0.4431	T0 vs. T2 & Dev vs. NDev	0.0871
T2	1084.01 (949.13–1218.89)	1059.11 (936.09–1182.13)		T2	0.7340	T1 vs. T2	< 0.0001†	< 0.0001†	T1 vs. T2 & Dev vs. NDev	0.3653
Vajs (mm³)										
T0	526.86 (467.05–586.67)	553.99 (489.61–618.37)	Deviation status: 0.5522 Time: 0.0104† Deviation status × Time: 0.5078	T0	0.5219	T0 vs. T1	0.4761	0.9213	T0 vs. T1 & Dev vs. NDev	0.67
T1	518.43 (460.71–576.15)	552.74 (490.61–614.86)		T1	0.4017	T0 vs. T2	0.0896	0.0099†	T0 vs. T2 & Dev vs. NDev	0.4227
T2	501.93 (443.00–560.85)	512.44 (449.02–575.87)		T2	0.8008	T1 vs. T2	0.2522	0.0113†	T1 vs. T2 & Dev vs. NDev	0.2466
Vpjs (mm³)										
T0	454.45 (395.68–513.22)	439.76 (370.20–509.32)	Deviation status: 0.5565 Time: <0.0001† Deviation status × Time: 0.4618	T0	0.7185	T0 vs. T1	< 0.0001†	< 0.0001†	T0 vs. T1 & Dev vs. NDev	0.2399
T1	545.67 (472.49–618.85)	509.64 (422.90–596.39)		T1	0.4804	T0 vs. T2	< 0.0001†	< 0.0054†	T0 vs. T2 & Dev vs. NDev	0.3489
T2	517.65 (444.16–591.14)	485.42 (398.30–572.53)		T2	0.5294	T1 vs. T2	0.0347†	0.1210	T1 vs. T2 & Dev vs. NDev	0.8348
Vmjs (mm³)										
T0	507.33 (430.25–584.41)	568.07 (495.64–640.50)	Deviation status: 0.2222 Time: < 0.0001† Deviation status × Time: 0.7847	T0	0.1887	T0 vs. T1	0.9169	0.4479	T0 vs. T1 & Dev vs. NDev	0.6116
T1	506.23 (430.18–582.28)	560.50 (489.03–631.97)		T1	0.2331	T0 vs. T2	0.0197†	0.0011†	T0 vs. T2 & Dev vs. NDev	0.4895
T2	483.42 (407.66–559.18)	535.84 (464.64–607.04)		T2	0.2474	T1 vs. T2	0.0013†	0.0003†	T1 vs. T2 & Dev vs. NDev	0.8196
Vljs (mm³)										
T0	475.59 (409.36–541.82)	419.30 (359.87–478.72)	Deviation status: 0.1459 Time: 0.0001† Deviation status × Time: 0.0675	T0	0.1869	T0 vs. T1	< 0.0001†	< 0.0001†	T0 vs. T1 & Dev vs. NDev	0.5370
T1	565.84 (489.46–642.22)	500.85 (432.35–569.35)		T1	0.1874	T0 vs. T2	< 0.0001†	0.0001†	T0 vs. T2 & Dev vs. NDev	0.0418†
T2	544.60 (467.91–621.29)	459.27 (390.49–528.05)		T2	0.0864	T1 vs. T2	0.0153†	< 0.0001†	T1 vs. T2 & Dev vs. NDev	0.0675

Table 2. Changes of overall and compartments of joint space volume according to time and deviation status (adjusted sex and amount of mandibular movement). *Vjs, Volume of joint space; Vajs, Volume of anterior joint space; Vpjs, Volume of posterior joint space; Vmjs, Volume of medial joint space; Vljs, Volume of lateral joint space; NDev, Non-deviated side; Dev, Deviated side; T0, pre-operative; T1, post-operative 6months; T2, post-operative 12 months. †Indicates $p < 0.05$.

which may have led to similar changes in the volume of the TMJ space on both sides. A relatively recent study on young Korean asymmetric patients reported that the difference in masticatory muscle volume on both sides was significantly reduced after surgery and that there was no statistical difference between the two sides[23]. These results are consistent with the results of the present study, which showed no difference between the Dev and NDev sides. Although it was a linear measurement, Chou et al. reported no differences in the anterior, middle, and posterior joint spaces between the deviated and non-deviated sides, similar to this study[24].

The Vjs in the Dev and NDev sides increased at 6 months postoperatively (T1) and gradually decreased until 12 months postoperatively (T2), similar to previous studies[11,14]. Vajs and Vmjs decreased slightly at T2 compared to presurgery (T0), but the difference was not statistically significant. Vpjs and Vljs increased at T2 compared to T0, which was the same result as our previous study[11].

In this study, the analysis was performed after adjusting for sex and the amount of mandibular movement. The extent of mandibular movement was based on 3D positional changes in the lingula. This is because the distal segment does not simply move backward when mandibular setback but also moves vertically and laterally. As this study aims to measure the changes in the condyle space of the proximal segment after IVRO, we considered it is more appropriate to select points on the distal segment. When measuring the amount of mandibular setback, point B is usually used[25]; however, this study compared the Dev and NDev sides. Therefore, a point that was considered reliable on both sides was selected. Considering the above reasons, we concluded that the lingula is the most suitable point to reflect the mandibular movement changes along the x, y, and z axes, as it remains in the same segment before and after surgery. The results did not differ after adjusting for sex and amount of mandibular movement. In TOVRO, the amount of setback is expected to be less affected because interference between the proximal and distal segments is minimized through cortical grinding[26].

There was no difference in the Vcon and Vgf between the Dev and NDev sides. Kim et al.[18] reported no difference in the Vjs between larger and smaller Vcons. However, according to a study by Chou et al.,[24] the Vcon showed a significant difference between the Dev and NDev sides. Facial asymmetry can be caused by various

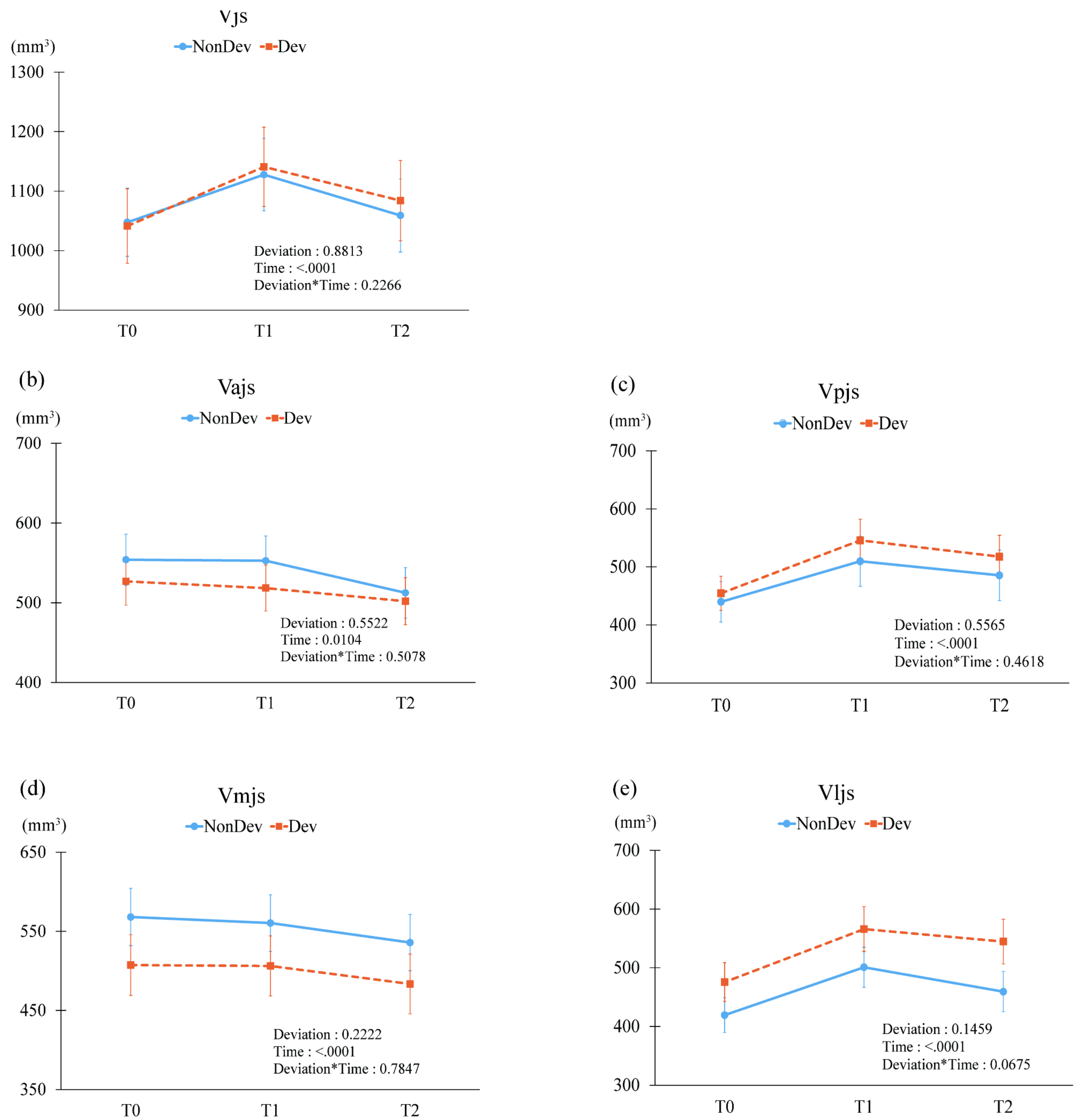

Fig. 6. Changes of joint spaces between deviated side (Dev) and non-deviated side (NDev) (Adjusted by sex and mandibular movement). (**a**) Vjs, the volume of the joint space; (**b**) Vajs, the anterior joint space; (**c**) Vpjs, the posterior joint space; (**d**) Vmjs, the mesial joint space; (**e**) Vljs, the lateral joint space.

reasons[27], including differences in the Vcon, mandibular body length, or ramus. It is thought that the different results obtained by Chou et al. compared to this study are due to the differences in patient selection.

Considering the radiation dose, CBCT was taken after surgery. However, CBCT has a fundamental difference from CT taken before surgery. Although the threshold was set to the same value (400–8000) during the analysis process, and there are previous study using this method[11], this may be a limitation in this study.

In the future, it is expected that a more in-depth analysis of condylar movement on the Dev and NDev sides will be possible by considering the cause of facial asymmetry. In addition, since this tendency was more evident when long-term follow-up observations were performed, long-term data collection > 1 year is necessary. Furthermore, studies have reported that luxated condyles return to their original position over time, suggesting that this may also affect long-term changes in the TMJ space[28]. Therefore, long-term follow-up observations are necessary for more accurate volume measurements.

In conclusion, this study provides important insights into the TMJ spatial changes after TOVRO in patients with facial asymmetry and can be used as basic data for clinical treatment and research directions.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

H.-S.Y. and S.J.B. wrote the original draft; J.-Y.K. and J.-K.H. designed the research; S.J.B. and H.L. collected and analyzed the data. H.-S.K., J.-K.H., and J.-Y.K. revised the manuscript and edited the manuscript; All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

The study was approved by the institutional review board of Yonsei University Gangnam Severance Hospital approved this retrospective study (IRB No. 3-2024-0125), and waiver of written informed consent for this retrospective study. This study was also conducted according to the principles of the Declaration of Helsinki for research on humans.

Additional information

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