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ORIGINAL ARTICLE

Quantitative assessment of condyle positional changes before and after orthognathic surgery based on fused 3D images from cone beam computed tomography

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Abstract

Objectives To establish one method that can be used to quantitatively evaluate the condyle positional changes with 3D images in postoperative mandibular prognathism patients.

Materials and methods This is a retrospective observational study. Twenty-one patients who underwent bilateral sagittal split ramus osteotomy (BSSRO) were scanned with cone beam computed tomography (CBCT) for temporomandibular joints (TMJs) at 1 week preoperatively (T_0), 1 to 2 weeks (T_1), 3 months (T_2), 6 months (T_3), and 12 months (T_4) postoperatively. The data were then grouped into T_0T_1, T_1T_2, T_2T_3, T_3T_4 and T_0T_1, T_0T_2, T_0T_3, and T_0T_4. Semi-automatic registration was conducted, and the condyle positional changes were measured in segmented 3D models. Inter- and intra-observer variability and the repeatability of registration were analyzed with paired *t* test; the repeated measurement analysis of variance was used for analyzing the repeatability of the marked points; the consistency of segmentation was analyzed with nonparametric test of multiple paired samples (Friedman test) and the independent-sample *t* test was applied to comparing changes between different periods of time. Differences were considered to be statistically significant when $P < 0.05$.

Results In T_0T_1 and T_1T_2, the condylar position was changed greatly. In T_2T_3, the mean condylar translations were less than 0.2 mm in all directions, the mean rotational changes of condyle were less than 0.2 mm; in the period of T_3T_4, the mean condylar translations in all directions were less than 0.02 mm. For series 2, the condyle translational changes in axial, coronal, and sagittal views were within 0.10 mm, and the rotation direction of condyle in all three views was the same within 1 year after operation.

Conclusions Fused three-dimensional images can be used to qualitatively and quantitatively evaluate condyle positional changes. The condylar position might be stable at 3 months postoperatively. The condyles of most of patients did not fully return to their preoperative position within 1 year after the operation.

Clinical relevance One method for fusing images has been established to detect the condylar positional changes. This method may be applied to estimate the bony changes of condyle, even bony changes in other part of dentomaxillofacial region. Meanwhile, the data of condyle positional changes from asymptomatic patients after the surgery within 1 year can be used as a reference for further exploration of the relationship between orthognathic surgery and the occurrence of osteoarthritis postoperatively in the future.

Key Points

- *By fused 3D images, the change of condylar position after bilateral sagittal split ramus osteotomy can be observed intuitively.*
- *For the patients with mandibular prognathism, the condylar position would be stable at 3 months postoperatively.*
- *The condyles of most mandibular prognathism patients did not fully return to their preoperative position within 1 year after operation.*

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keywords Temporomandibular joint · Mandibular condyle · Multimodal imaging · Orthognathic surgery · Radiostereometric analysis

Abbreviations

CBCT	cone beam computed tomography
BSSRO	bilateral sagittal split ramus osteotomy
TMJ	temporomandibular joint
3D	three-dimensional
DICOM	digital imaging and communications in medicine
FOV	field of view

Introduction

Skeletal mandibular prognathism is one of the most common conditions of malocclusion. The condyle postoperative stability and the position should be taken into account since it may affect the result of the operation in a long run or even induce the internal derangement of temporomandibular joint (TMJ). [1–7] For surgeons, it is crucial to evaluate the location of condyles effectively and intuitively, no matter when it is in the stage of plan or follow-up. Orthognathic surgery may cause the changes of condyle from its initial position and lead to a malfunction of TMJ. [8]

In the recent studies, the changes of condylar position were mostly determined by measuring the TMJ spaces, the distance of two condyle centers, or the condyle horizontal angles at each time point. The measured values were compared indirectly by differences from each time point of two-dimensional sliced CT or cone beam computed tomography (CBCT) images [1–3, 9]. This may induce errors and cannot provide an intuitive observation. To intuitively observe the changes of a condyle, reconstructed three-dimensional (3D) images prior to and after operation should be provided for a simultaneous investigation. In the search of literature, however, the authors did not find one study exclusively investigate such an operative changes of condyles from the consecutive reconstructed 3D images.

Thus, the aims of the present study were (1) to establish one method that can be used to evaluate the condyle positional changes with reconstructed 3D images, (2) to quantitatively evaluate the condyle positional changes in the skeletal mandibular prognathism patients prior to and after operation, and (3) to assess whether the fused 3D images could provide an intuitive evaluation of condyle position changes.

Materials and methods

Subjects and study design

This study was approved by our institutional review board (PKUSSIRB-201944056), and the exemption of informed consent had been granted because this is a retrospective study. The study included 21 patients who were diagnosed with mandibular prognathism and underwent bilateral sagittal split ramus osteotomy (BSSRO) with or without Le FortI osteotomy at Department of Oral and Maxillofacial Surgery of Peking University School and Hospital of Stomatology. The patient would be excluded if he/she (1) had clinical symptoms of TMJ such as click, noise, or pain or had image findings such as cortical defects, cystic degeneration of condyle at any time point of collection; (2) had been diagnosed with systemic diseases, cleft lip and/or cleft palate, or ankyloses; (3) was asymmetry in size of bilateral TMJ.

Data collection

The studied subject included 5 males and 16 females. The range of the patients' age is from 18 to 38, which gives an average age of 23 ± 5 years old. All the patients had undergone CBCT scans as the clinical checkups at 1 week before operation (T0), 1 or 2 weeks (T1), 3 months (T2), 6 months (T3), and 12 months (T4) after operation, respectively. The patients were asked to keep the intercuspal position to prevent motion artifact. Since patient collection was retrospective, three brands of CBCT units were used: (1) 3D Accuitomo 170 (J. Morita MFG. Corp.), the exposure parameters were 90 kVp, 5 mA, field of view (FOV) was 6 cm × 6 cm; (2) NewTom VG (Quantitative Radiology), the exposure parameters were 110 kVp, 2–3 mA, FOV was 15 cm × 15 cm; (3) i-CAT FLX (Imaging Sciences International, Inc), the exposure parameters were 120 kVp, 5 mA, FOV was 16cm × 13 cm. The acquired images were reconstructed with voxel size from 0.25 to 0.30 mm and exported as Digital Imaging and Communications in Medicine (DICOM) data sets.

The datasets were then used for the analysis of condyle positional changes of series 1 and series 2. For example, in series 1, the 3D images reconstructed from pre-surgery T_0 were compared with the images reconstructed from the data just after surgery T_1, and the 3D images reconstructed from T_1 were compared with the 3D images reconstructed from the data obtained at 3 months later T_2, and so on. Similarly, in the series 2, the 3D images reconstructed from each time point were directly compared with the 3D images reconstructed from the data obtained at the pre-operation time point T_0 (Fig. 1).

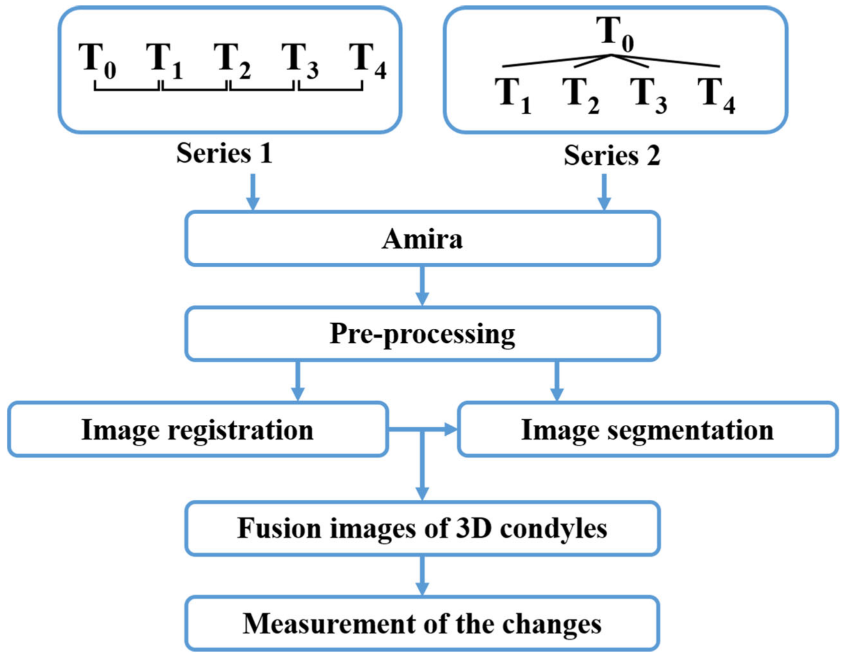

Fig. 1 The flow chart of method

Methods

Technological process

The software Amira visual (version 5.4.3, ThermoFisher Scientific Inc.) was used for the 3D image reconstruction and superimposition. Before manipulation, a pre-processing was done: all the datasets were cropped into 6 cm × 6 cm FOV and were resampled to voxel size 0.25 mm. After the pre-processing, all the condyles were segmented automatically, and then, the results of automatic segmentation were corrected by the investigator layer-by-layer and reconstructed in 3D model.

After the process of segmentation, the datasets would be imported to the module of Multi Planar Viewer. The data obtained at an earlier time point was used as the Primary Data (the fixed datasets in the process of registration), and the data obtained at a later time point was used as the Overlay Data (the floating data sets) (Fig. 2).The process of semi-automatic registration was conducted in all groups based on the skull base. The degree of skull base superimposition was used as an indicator of registration accuracy (Fig. 2b). If there was a ghost in the area of skull base after registration, the result would not be used. After the manual registration, the automatic process was performed. The normalization mutual information and rigid transformation were introduced as the basic parameters. Conjugated gradient optimizer was also used with 1 as the finest level, − 200 to 2500 as the histogram range reference, and 150 to 1400 as the histogram range model. The 3D registration process is shown in Fig. 2.

All the measurement processes were conducted after marking the points on the two 3D condylar models. The locations of the primary 3D models were calibrated firstly, and then, the related lines were set on both of the condyles. Finally, the differences between the two time-point 3D models were measured and recorded. The following is the detailed process of calibration and measurement.

Evaluation of the condyle position changes

Before evaluation, some anatomic points were designated to make the measurement explicitly. On the 3D condyle of the primary data set, the medial pole was designated as point A, the lateral pole was designated as point B, the lowest point of sigmoid notch was designated as point C, the lowest point of articular tubercle was designated as point F, the lowest point of squamotympanic fissure was designated as point G, and the superior pole of condyle was designated as point S. The corresponding points on the 3D condyle of the overlay data set were determined with the same letters but with “ ’ ”, such as A’, B’, C’, F’, G’, and S’ (Figs. 3a, 4a, and 5a)

1. Anteroposterior translational changes and axial angular changes (Figure 3) Evaluation of the anteroposterior translational changes was conducted in the axial view. The line crossing points A and B of the 3D condyle of the primary data paralleled to the horizontal line, while the maximum cross-sectional plane was perpendicular to the horizontal line and the observer’s visual line. The tangent line through the most anterior point was recorded as D1, while the tangent line through the most posterior point was recorded as D2. Accordingly, the tangent lines through the most anterior point

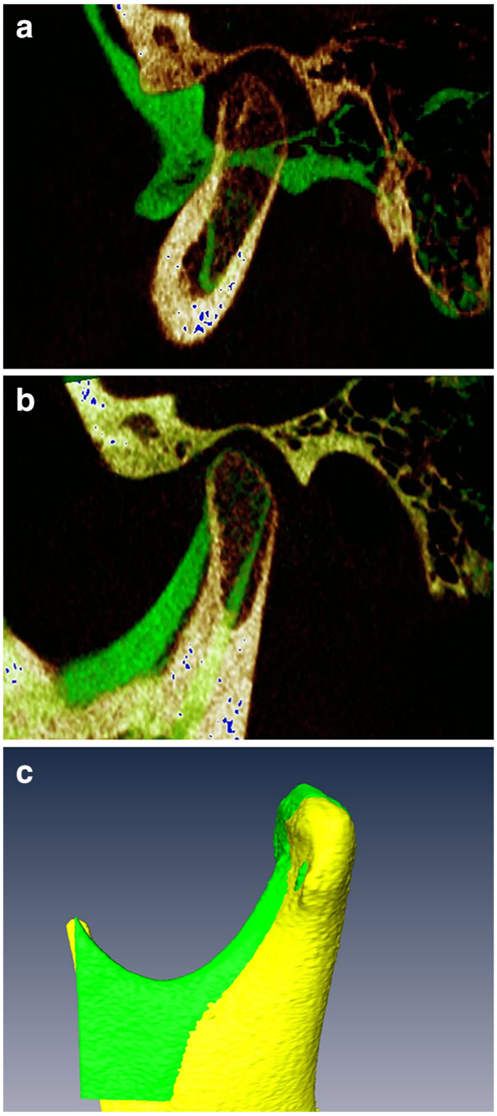

Fig. 2 Process and result of the registration. The image layer in green represented the primary data, which was the earlier time point image set of a group; the yellow layer expressed the overlay data, which was the later time point image set. The same colors were used in the 3D model after segmenting the condyles. **a** The sagittal view of the unregistered image sets. **b** The sagittal view after registration. **c** The sagittal view in 3D model after registration

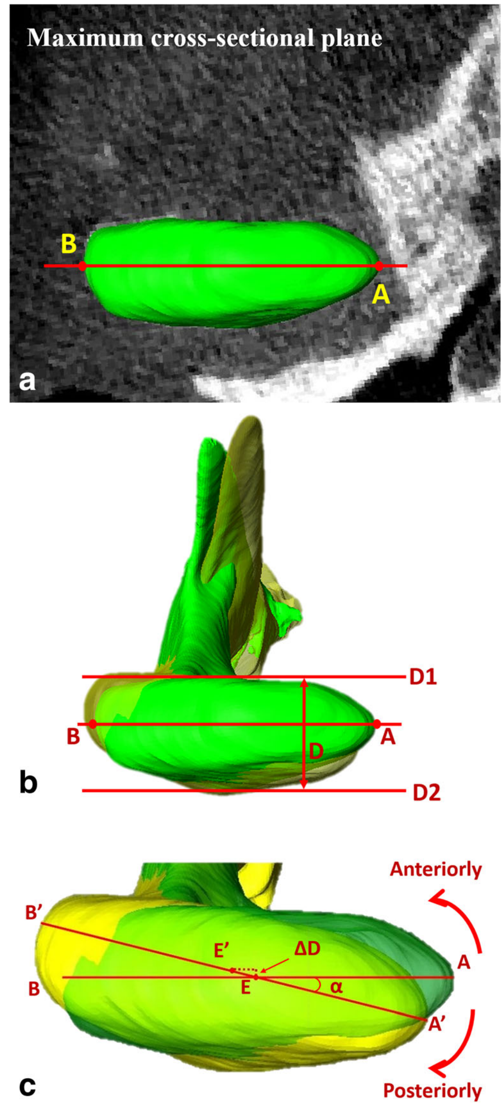

Fig. 3 Calibration and measurement of the condyle in axial view. **a** The correction of the condylar posture during measuring, and the location of mark point A and B. **b**, **c** The lines and angle need to be marked in the measurement. In this case, ΔD is positive, which means that the condyle moves anteriorly; ∠α is negative, which means that the condyle rotates posteriorly

of the condyle of the corresponding overlay data was D1' (Fig. 3a, b).

The distance between the midpoint E of line AB and the midpoint E' of line A'B' was determined asΔD (Fig. 3c). In case that the E' located anterior to the E, the value would be positive giving an indication that the condyle moved anteriorly; conversely, the value would be negative. The angle between line AB and line A'B' was determined as∠α.If ∠α located anterior to the line AB, the angle was positive. This indicated an anterior rotation; if the ∠α located posterior to the line AB, the angle was negative. This indicated a posterior rotation of condyle (Fig. 3c).

2. Mediolateral translational changes and coronal angular changes (Fig. 4) To evaluate the mediolateral translational changes, the line across point S and C of the condyle reconstructed from the primary data was set to perpendicular to the horizontal line, while the maximum coronal-sectional plane was perpendicular to the horizontal line and the observer's visual line. The tangent line through the point A was recorded as W1, while the tangent line through the point B was recorded as W2 (Fig. 4c). Accordingly, the corresponding lines on the condyle reconstructed from the overlay data were W1'.

The distance between W1 and W1' was determined as ΔW (Fig. 4d). If the W1' located medial to the W1, the value

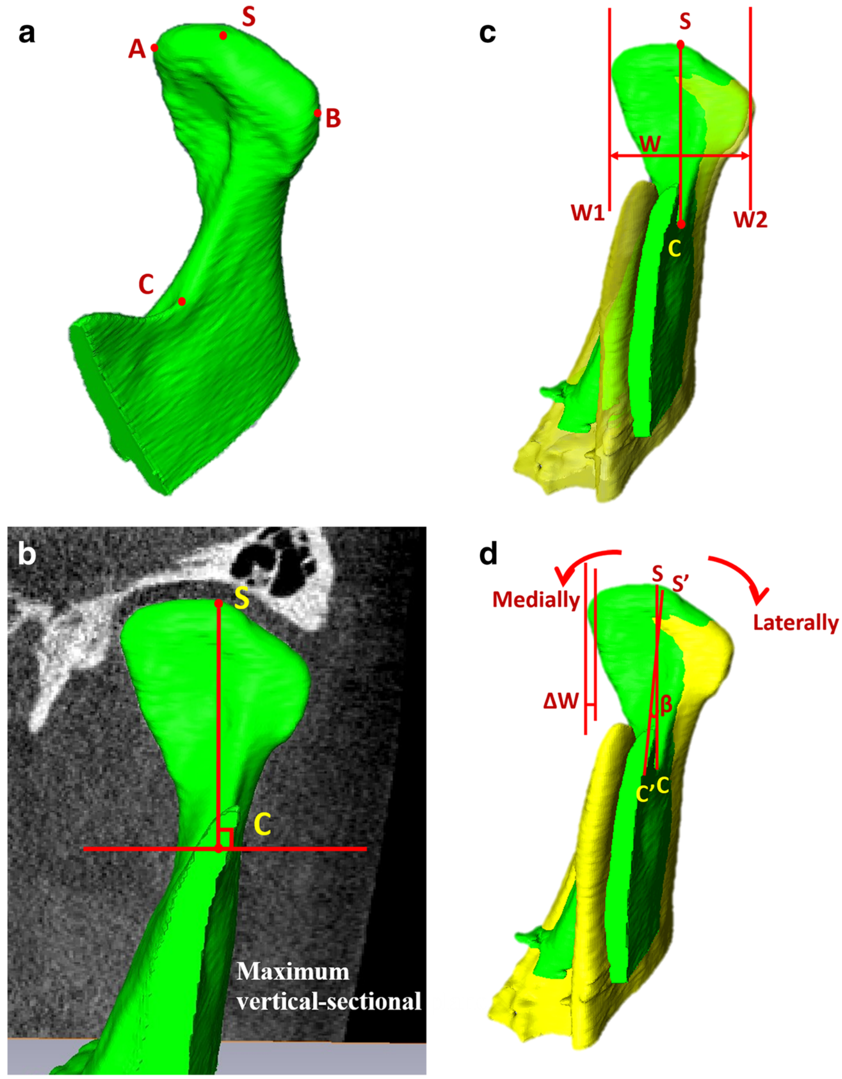

Fig. 4 Calibration and measurement of the condyle in coronal view. **a** The location of mark point S and C. **b** The correction of the condylar posture during measuring. **c**, **d** The lines and angle need to be marked in the measurement. In this case, ΔW is negative, which means that the condyle moves laterally; ∠β is negative, which means that the condyle rotates laterally

would be positive; conversely, the value would be negative. The inferior angle between line SC and line S'C' was determined as∠β. If ∠β located lateral to the line SC, the angle was positive (rotate medially); inversely, the angle was negative (rotate laterally) (Fig. 4d).

3. Craniocaudal translational changes and sagittal angular changes (Fig. 5) To evaluate the craniocaudal linear changes, the line across point F and G was set to parallel with the horizontal line, while the maximum sagittal-sectional plane, which was through S and perpendicular to the line AB was set to perpendicular to the horizontal line and the observer's visual line. The tangent line through S was recorded as H1, the tangent line through point C was determined as H2, the tangent line through the back edge of condylar neck was named as H3. Accordingly, the corresponding lines obtained from the overlay data were H1', H2', and H3' (Fig. 5b, c).

The distance between H1 and H1' was determined as ΔH (Fig. 5d). If the H1' located superiorly to the H1, the value would be positive, giving an indication of the condyle moved cranially; conversely, the value would be negative. The angle between line H3 and H3' was determined as∠γ.If ∠γlocated posterior to the H3, the angle was positive (rotate cranially); conversely, the angle was negative (rotate caudally) (Fig. 5d).

Consistency and repeatability of the methods

Inter- and intra-observer consistency

All measurements were carried out by the same investigator. To test the intra-observer consistency, 40 datasets were selected to conduct a re-examination after an interval of 2 weeks. At the same time, the same datasets were examined by another calibrated investigator (Shuang Yin) to test the inter-observer consistency.

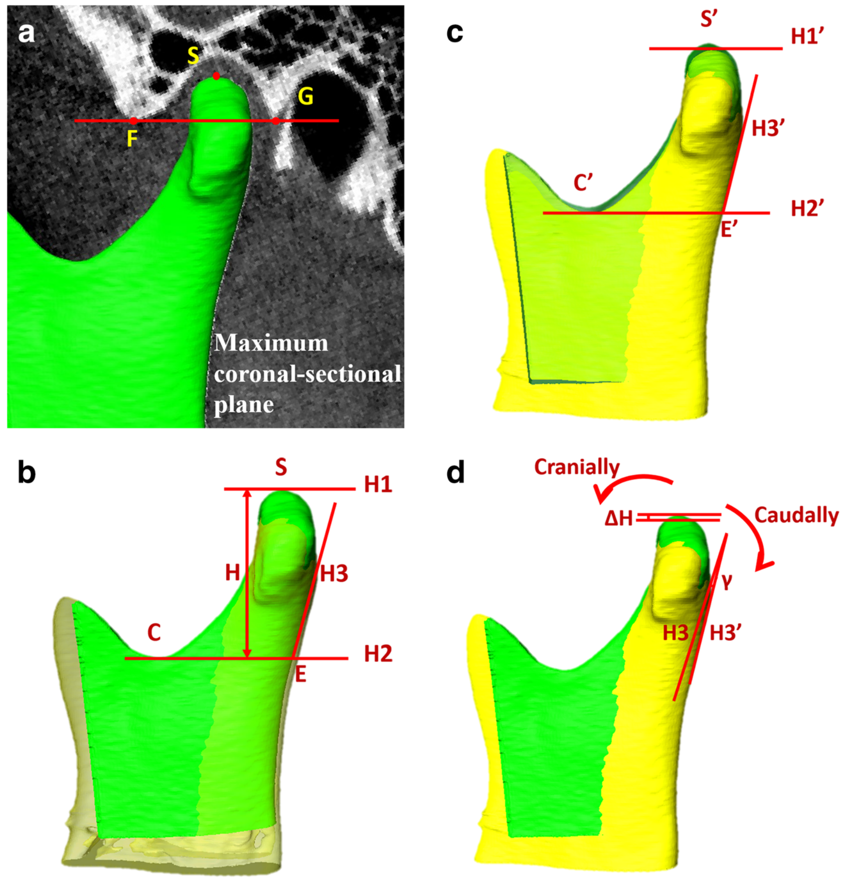

Fig. 5 Calibration and measurement of the condyle in sagittal view. **a** The location of mark point F and G, and the correction of the condylar posture during measuring. **b**–**d** The lines and angle need to be marked in the measurement. In this case, ΔH is negative, which means that the condyle moves caudally; ∠γ is negative, which means that the condyle rotates caudally

Repeatability of registration

To test the repeatability of the registration process, 48 datasets from 6 patients were conducted for registration two times (interval of 3 weeks) at a random order. The change of coordinate values and the angles of the 48 overlay datasets were recorded.

Repeatability of marked points

To verify the repeatability and the consistency of the marked points of the 3D segmentation condyle, the datasets from T_0 of all included patients were selected to conduct the measurement on 3D models. The anteroposterior diameter (the distance between D1 and D2 was recorded as D; Fig. 3b), the width (the distance between W1 and W2 was recorded as W; Fig. 4c), and the height (the distance between H1 and H2 was recorded as H; Fig. 5b) of the 3D condyle were measured and recorded by the same investigator. This examination was done 4 times with a time interval of 2 weeks.

Consistency of segmentation

Because the datasets were from different CBCT units, the consistency of segmentation from different units should be validated to ensure the reliability of measurements. To test the validation of segmentation consistency, each time point (T_0, T_1, T_2, T_3, T_4) datasets were segmented, and the anteroposterior diameter, the width, and the height of the condyle were measured.

Statistical analysis

The statistical analysis was performed by using SPSS® Statistics 19.0 (SPSS, Inc., Chicago, IL).

Paired *t* test was used to determine the statistical significance of the consistency of inter- and intra-observer and the repeatability of registration. A *p* value of 0.05 or less was considered significant.

The repeated measurement analysis of variance was applied to verifying the repeatability of the marked points. The *p* value was adopted based on the result of the Mauchly's test of sphericity. A *p* value of 0.05 or less was considered significant.

The nonparametric test of multiple paired samples (Friedman test) was introduced to determine the consistency of segmentation. A *p* value of 0.05 or less was considered significant.

Independent-sample *t* test was applied to comparing changes between different periods of time. A *p* value of 0.05 or less was considered significant.

Results

Table 1 shows the mean values of the linear and the angular changes of series 1 and series 2, which presents the stability of the condyles after operation and the change of the condylar position at each time point, respectively.

The ranges and distributions of the translational and the angular changes from series 1 and 2 are shown in Fig. 6, respectively. For series 1 (Fig. 6a, b), the major changes occurred in the first two periods (T_0T_1/T_1T_2), while the changes were small in the last two periods (T_2T_3/T_3T_4). Figure 6 a and b also obviously and clearly show the distribution range and the direction of values for the condyle positional variations at each period. For series 2 (Fig. 6c, d), by comparing the condyles between preoperative and each postoperative time, the effect of the surgery on the condylar position can be observed. The condylar position is stable from 3 months postoperatively which is consistent with the results from series 1.

For the change of condylar position, there were significant differences of all translational and angular variances between T_0T_1 and T_0T_2, T_0T_1 and T_0T_3, T_0T_1 and T_0T_4, except for the anteroposterior change (Table 2).

No significant differences were found for intra-observer ($p = 0.887$ with 95%CI − 0.10, 0.12), inter-observer ($p = 0.472$ with 95%CI − 0.13, 0.29) variances, and repeatability of registration ($p = 0.275$ with 95%CI − 0.02, 0.05).

For the repeatability of marking points, the results from sphericity test did not satisfy with the sphericity ($p = 0.011$), the Greenhouse-Geisser was adopted. There was no significant difference for marking points ($p = 0.115$).

According to the results of Friedman test, no significant differences were shown for the consistency of segmentation ($p = 0.075$).

Discussion

To observe and measure the condyle positional changes after the orthognathic surgery in the mandibular prognathism patients comprehensively, the 3D measurement of the condyle positional change was implemented by combining longitudinal rigid registration and segmentation of condyles in the present study. In series 1, the mean values of the translational change showed that the condyle moved anteriorly, laterally, and caudally after the operation immediately. The mean values of the angular change indicated that the condyle rotated posteriorly in axial view, laterally in coronal view and cranially in sagittal view in the period of T_0T_1. The angular change of condyle showed that the condyle had a tendency to go back to its original position in T_1T_2. Statistical analysis indicates that the condylar position is stable from the 3 months after operation. The results from series 2 show that most of the condyles did not fully regress to the preoperative position qualitatively through the registered 3D condylar model.

With the introduction of medical image fusion to dentistry, it has been applied to assessing the skeletal changes prior to and after an orthognathic surgery [10, 11]. Some of the previous studies superimposed the images from different time point and/or showed the changes by different colors to assess the condyle positional changes [12–16]. However, the angular changes were assessed still by comparing the value of measurement on 2D images [16]. As to whether the condyle

Table 1 The mean value of the linear and the angular changes of series 1 and series 2

	Mean ± Std. deviation (95%CI) (millimeters for translational change/degrees for angular change)					
	Anteroposterior translational change	Mediolateral translational change	Craniocaudal translational change	Axial angular change	Sagittal angular change	Coronal angular change
T_0T_1	0.10 ± 0.81 (− 0.13, 0.34)	− 0.88 ± 0.94 (− 1.17, − 0.59)	− 0.94 ± 0.87 (− 1.21, − 0.67)	− 6.41 ± 4.17 (− 7.71, − 5.12)	2.45 ± 3.77 (1.28, 3.62)	− 3.71 ± 3.13 (− 4.68, − 2.73)
T_1T_2	− 0.02 ± 0.70 (− 0.24, 0.20)	0.86 ± 0.69 (0.64, 1.07)	0.97 ± 0.75 (0.73, 1.20)	1.55 ± 1.76 (1.00, 2.09)	− 1.49 ± 2.02 (− 2.12, − 0.86)	1.96 ± 1.96 (1.35, 2.57)
T_2T_3	0.01 ± 0.10 (− 0.04, 0.04)	0.03 ± 0.17 (− 0.02, 0.09)	− 0.16 ± 0.25 (− 0.23, − 0.08)	0.15 ± 0.75 (− 0.09, 0.39)	− 0.18 ± 1.03 (− 0.50, 0.14)	0.12 ± 0.88 (− 0.17, 0.38)
T_3T_4	0.00 ± 0.13 (− 0.06, 0.11)	− 0.02 ± 0.11 (− 0.05, 0.01)	− 0.01 ± 0.16 (− 0.06, 0.04)	− 0.02 ± 0.43 (− 0.15, 0.12)	− 0.03 ± 0.34 (− 0.13, 0.08)	− 0.11 ± 0.62 (− 0.30, 0.08)
T_0T_2	0.02 ± 0.51 (− 0.13, 0.17)	0.06 ± 0.65 (− 0.14, 0.27)	0.06 ± 0.41 (− 0.07, 0.19)	− 4.14 ± 3.70 (− 5.29, − 2.98)	0.95 ± 2.88 (0.05, 1.85)	− 1.49 ± 1.92 (− 2.08, 0.89)
T_0T_3	0.09 ± 0.48 (− 0.07, 0.23)	0.05 ± 0.64 (− 0.49, 0.25)	− 0.12 ± 0.38 (− 0.24, − 0.01)	− 4.10 ± 3.86 (− 5.31, − 2.90)	0.78 ± 3.13 (− 0.19, 1.76)	− 1.30 ± 2.21 (− 1.99, − 0.61)
T_0T_4	0.08 ± 0.47 (− 0.07, 0.22)	0.02 ± 0.65 (− 0.18, 0.22)	− 0.09 ± 0.40 (− 0.21, 0.04)	− 3.67 ± 3.22 (− 4.67, − 2.66)	0.41 ± 2.92 (− 0.50, 1.32)	− 1.77 ± 2.22 (− 2.46, − 1.08)

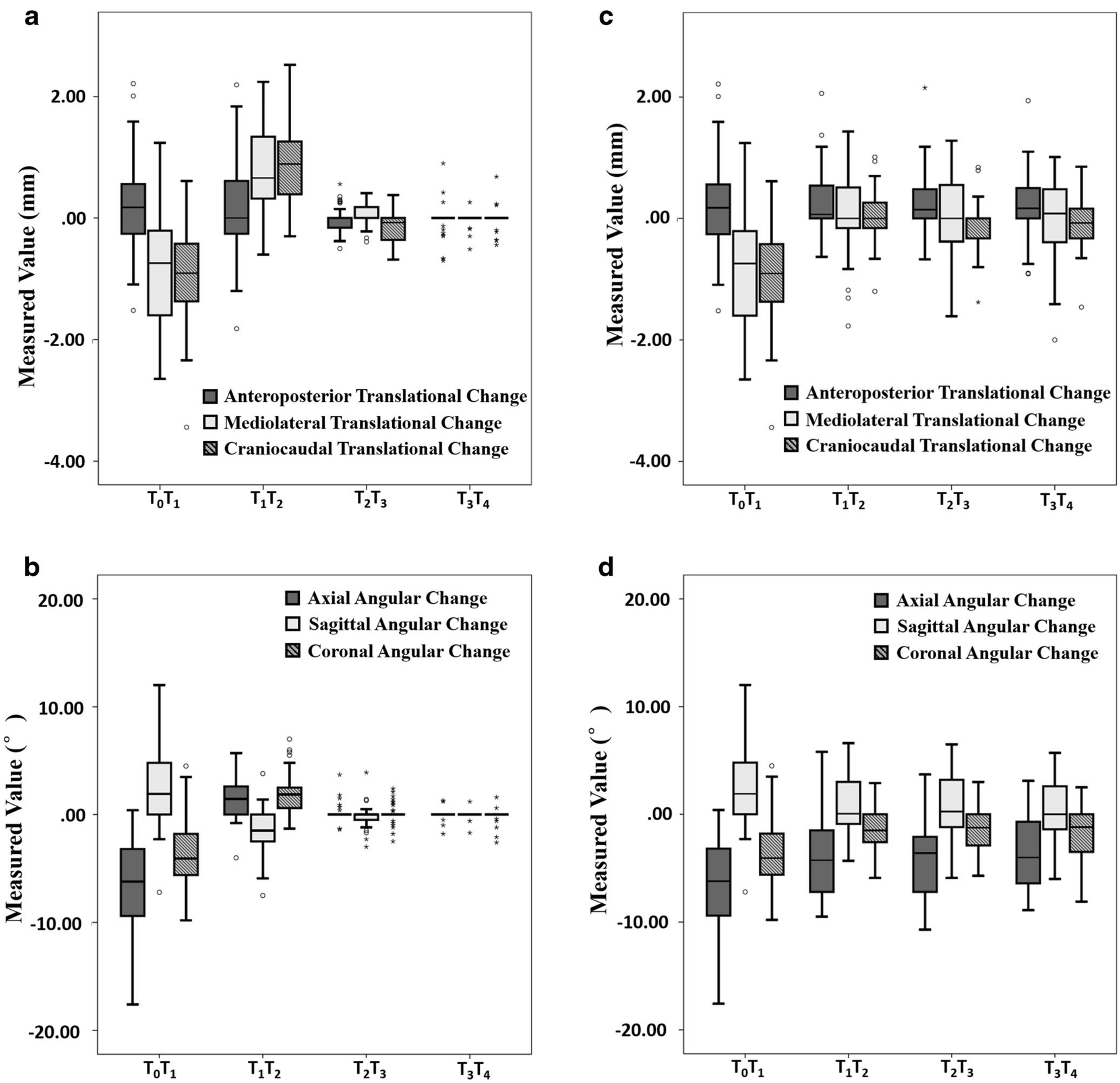

Fig. 6 The box plot of the translational and angular changes 1. **a** The translational variations of series 1. **b** The rotational variations of series 1. **c** The translational variations of series 2. **d** The rotational variations of series 2

returns to the preoperative position and when the condyle will be stable, the results from the previous studies are inconsistent. Draenert et al. [9] demonstrated that the condyle regressed to the pre-operation state during the follow-up, and Choi et al. [1] had a similar demonstration. While others indicated that the anterior joint space of TMJ expanded significantly after comparing the space of pre-operation and that of 1 year after the operation [8]. Zafar et al. concluded that there were approximately half of the condyles that still showed forward or backward positional change at 7 to 10 months postsurgical time point [17]. Han et al. found that the range of the condyle translational change was < 1 mm and the rotational change < 4°, respectively [15]. The above results indicate a necessity for an intuitive observation of condyle positional changes.

To ensure that the sample size is sufficient, the investigators had to ignore the differences among CBCT units due to the nature that this is a retrospective study. This induces the main

Table 2 *P* value between different time periods of the condyle positional variations for series 2

	P value* (95%CI)		
	T_0T_2	T_0T_3	T_0T_4
Anteroposterior translational change			
T_0T_1	> 0.05 (− 0.33, 0.48)	> 0.05 (− 0.39, 0.40)	> 0.05 (− 0.38, 0.41)
T_0T_2		> 0.05 (− 0.36, 0.22)	> 0.05 (− 0.35, 0.23)
T_0T_3			> 0.05 (− 0.27, 0.29)
Mediolateral translational change			
T_0T_1	< 0.05 (− 1.42, − 0.47)	< 0.05 (− 1.40, − 0.45)	< 0.05 (− 1.38, − 0.43)
T_0T_2		> 0.05 (− 0.36, 0.40)	> 0.05 (− 0.34, 0.43)
T_0T_3			> 0.05 (− 0.36, 0.41)
Craniocaudal translational change			
T_0T_1	< 0.05 (− 1.40, − 0.59)	< 0.05 (− 1.21, − 0.41)	< 0.05 (− 1.25, − 0.45)
T_0T_2		> 0.05 (− 0.05, 0.41)	> 0.05 (− 0.09, 0.39)
T_0T_3			> 0.05 (− 0.27, 0.20)
Axial angular change			
T_0T_1	< 0.05 (− 3.89, − 0.65)	< 0.05 (− 3.93, − 0.69)	< 0.05 (− 4.37, − 1.13)
T_0T_2		> 0.05 (− 1.65, 1.58)	> 0.05 (− 2.09, 1.15)
T_0T_3			> 0.05 (− 2.05, 1.18)
Sagittal angular change			
T_0T_1	< 0.05 (0.12, 2.88)	< 0.05 (0.29, 3.04)	< 0.05 (0.66, 3.42)
T_0T_2		> 0.05 (− 1.21, 1.54)	> 0.05 (− 0.84, 1.92)
T_0T_3			> 0.05 (− 1.00, 1.75)
Coronal angular change			
T_0T_1	< 0.05 (− 3.76, − 0.69)	< 0.05 (− 4.01, − 0.81)	< 0.05 (− 3.54, − 0.34)
T_0T_2		> 0.05 (− 1.40, 1.03)	> 0.05 (− 0.93, 1.51)
T_0T_3			> 0.05 (− 0.83, 1.78)

*$p < 0.05$ statistically significant difference

limitation of this study. To overcome this limitation, the datasets from different CBCT units were resampled to 0.25 mm × 0.25 mm voxel size. The results from the test for segmentation accuracy demonstrated that there were no significant differences among the different time point data of the same patient. This indicates that the different sources of the data have no noticeable impact on segmentation and measurement. This result was consistent with those of the previous studies in which carious lesions, periodontitis, and external root resorption were evaluated and the alveolar bone measurements were performed [18–20].

According to the recent studies, orthognathic operations are always followed by the condyle morphological changes, especially in the patients with skeletal class 2 jaw relationship [16, 21–23]. Thus, to exclude the influence of possible factors, only the patients who had no symptoms of TMJ pre- and post-operation were included in the present study. In the future, the TMJ symptomatic patients would be included to explore the relationship between condylar movement and the symptoms of TMJ after orthognathic operation.

In conclusion, the fused 3D images can be used to evaluate the condyle positional changes intuitively for the mandibular prognathism patients with orthognathic surgery. The condyle tended to be stable from 3 months after surgery. Most of the condyles did not return to the preoperative position during the 1-year follow-up. The condyles were moved anteriorly 0.21 mm and the translational changes in coronal and sagittal view were < 0.1 mm on average; for angular change, the condyles rotated posteriorly in axial view, cranially in sagittal view, and laterally in coronal view.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in the study involving human participants were in accordance with the ethical standards of

Institutional Review Board of Peking University School and Hospital of Stomatology (PKUSSIRB-201944056) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Written informed consent was not required for this study because all of the included patients in the present investigation were collected retrospectively. Exemption of informed consent will not affect the rights and health of included patients. The application for free informed consent has been approved by the Institutional Review Board.

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