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# Accuracy and stability of the condyle position after orthognathic surgery: A retrospective study

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ABSTRACT

The purpose of this study was to evaluate the accuracy and stability of condylar positioning in patients treated with bimaxillary procedures compared with patients treated with maxillary procedures alone.

All patients had undergone treatment at Odense University Hospital and were treated with inferior maxillary procedures. The primary outcome was changes in condyle position and the primary predictor variable was time: pre-operative ($T_0$) measurements to 1-week post-operative ($T_1$) and 1-year post-operative ($T_2$) measurements. Condyle movement was measured using dual voxel-based alignment.

Sixteen patients were included. Seven patients underwent solitary maxillary procedure and 9 patients bimaxillary procedure. Bimaxillary procedures overall showed a condyle positional change in pitch from $T_0$ to $T_1$ and $T_1$ to $T_2$ compared to maxillary procedures alone. Condylar translation was stable despite large differences in positioning. Compared to solitary maxillary procedures, bimaxillary procedures showed a statistically significant anterocranial rotation at 1-week follow-up movement (3.95° vs. −0.95°; SD 3,74 vs 1,05; P value = 0.000) and an additional statistically significant anterocranial movement at 1 year after surgery (4.89° vs 0.60°; SD 3,82 vs 0,92; P value = 0.000).

In conclusion a need for greater anterocranial stability of the sagittal split osteotomy than that provided by 3 bicortically fixated screws alone might be indicated.

## 1. Introduction

Correct condylar seating is paramount in orthognathic surgical procedures (Helm and Stepke, 1997). Malposition in condylar seating can potentially affect both the mandibular position and the occlusion if the condyle reposition is to the original position (Ware and Taylor, 1968; Rotskoff et al., 1991; Choi et al., 2014). It is known that the condyle may change position after sagittal split ramus osteotomy (Joss and Vassalli, 2009). However, it has not been measured exactly how much the condyles change position within the fossa nor how much of this condylar positional change affects relapse to the original condylar position.

Changes in condylar positioning during surgery influence clinical decisions such as which jaw is operated on first in bimaxillary procedures (Perez and Ellis, 2011). Virtual surgical planning (VSP) has improved the accuracy and information on condyle positioning, but to the authors, it still seems difficult to anticipate changes in condylar position postoperatively. Incorrect condylar positioning in the VSP have been shown to cause reoperations in large scale studies (Hsu et al., 2013). To control condylar seating during surgery multiple methods have been utilized; however, none of these methods have yet been implemented routinely (Bethge et al., 2015; Nova et al., 2017; Lee et al., 2019). Finally, the introduction of patient-specific implants (PSI) makes the information regarding condylar positioning even more relevant, as changes in condylar positioning can cause the individual plates to not fit to the new condylar position. Several studies therefore advocate using a hybrid model with PSI for maxillary positioning and manually adapted plates for mandibular positioning (Rückschloß et al., 2019; Jones et al., 2022). Thus, the need for accurate measurements on condylar repositioning in the fossa is more relevant than ever.

Previous studies on changes in the condyles primarily focused on volumetric changes, surface-to-surface distance, and manual reidentification of landmarks in the condylar head in 2 separate instances (Draenert et al., 2010; Chen et al., 2013; Choi et al., 2014); However,

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using these methods the measurement inaccuracies often overseed the errors in condylar displacement (Titiz et al., 2012; Baan et al., 2016; Gaber et al., 2017). In this study, the changes in condyle positioning will be evaluated by a voxel-based registration algorithm proven to reduce measurement accuracy to stabilize reliable measurements of condylar displacement (Stokbro and Thygesen, 2018a; Shaheen et al., 2019; Baan et al., 2021). Furthermore, no previous study has included a control group, and therefore it is not possible to determine how much the condyles moved after solitary maxillary procedures compared with bimaxillary procedures. For this reason, both solitary maxillary and bimaxillary procedures were included in this study.

The purpose of this study was to evaluate the accuracy and stability of condylar positioning in patients treated with bimaxillary procedures compared with patients treated with solitary maxillary procedures.

## 2. Materials and methods

### *2.1. Study design and sample*

To answer the research question, the authors implemented a retrospective cohort study design. The study included 16 patients treated at the Department of Oral and Maxillofacial Surgery at Odense University Hospital (Odense, Denmark) from 2013 to 2015. The cohort has previously been studied in relation to surgical accuracy in inferior maxillary repositioning, and therefore the inclusion criteria were orthognathic surgery with inferior positioning without segmentation of the maxilla. Exclusion criteria were deviation from virtual surgical plan during surgery or postoperative reoperation before 1-year follow-up. Surgeries were planned using 3D virtual surgical planning (3D Systems, Rock Hill, SC, USA). This study was exempt from ethical review by the institutional review board due to the retrospective nature with no direct involvement or influence on the patients. All participants were treated in compliance with the Declaration of Helsinki.

### *2.2. Variables*

The primary outcomes variables were the 3D linear and rotational positional changes of the condyle. The accuracy of the condylar position was assessed by measuring the preoperative condyle position compared to the 1-week postoperative position. The stability of the condylar position was assessed by measuring the 1-week postoperative position compared to the 1-year postoperative position.

Confounding variables were age, gender, preoperative occlusal relation (angle class I, II, III), and bimaxillary procedure.

### *2.3. Cone-beam computed tomography*

A NewTom 3G CBCT scanner (NewTom, Verona, Italy) was used with standard settings (field of view, 20 _ 20 cm; 110 kV; radiation exposure, 59 mSv according to 2005 International Commission of Radiological Protection tissue weighing factors) (Ludlow et al., 2006). Scans were performed before surgery ($T_0$) and 1 week ($T_1$) and 1 year after surgery ($T_2$).

### *2.4. Orthognathic surgery*

The patients were treated by 5 departmental surgeons. The surgeons were calibrated in terms of routine VSP planning and surgical technique. In bimaxillary procedures, the mandible was operated on first. The distal segment was positioned using an intermediate splint, and the condyles were positioned using bivector seating. The maxilla was repositioned using a surgical splint. Vertical height was measured from the orthodontic bracket on the first incisor to medial canthal ligament. The maxilla was fixated by 4 L-shaped plates and mandible with 3 bicortical position screws in each side without the use of bone clamps.

### *2.5. Voxel-based alignment and semiautomatic measurement technique*

The linear and rotational positional change of the condyle was measured using a well-established voxel-based semiautomatic technique (Stokbro and Thygesen, 2018a; Shaheen et al., 2019; Baan et al., 2021). It is a semiautomatic technique based on voxel-based superimposition. The freeware software Slicer 4.8.1 (www.slicer.org) was used to perform the segmentation of preoperative, 1 week- and 1-year postoperative CBCT scans. Bilateral condyle segmentation was performed including the ramus and segmentation of the cranial base in a natural head position. Three identical and fixed fiducial points were placed on the superimposed condyle segments. A fiducial point was placed at the most lateral point on the head of the condyle, at the mandibular angle, and at the most cranial part the coronoid process (Fig. S1- *in supplement files*). A 4th interfiducial reference point was placed between the lateral condyle and coronoid points. With the fiducial points fixed in the condyle segments, a superimposition of the cranial base was done. This allowed visualization of the movement change in the condyle segments in relation to the fixed fiducial points in each condyle segment.

Linear movements were measured as the distance between the lateral condyle points in the anterior, superior, and lateral planes. Rotational movements were measured as the yaw angle between the planes of the interconnected condyle and coronoid fiducial points. Pitch and roll angles were measured between the planes of the interconnected mandibular angle and 4th interfiducial point. Data were extracted from Slicer 4.8.1 to Excel. In Excel, data were inverted unilaterally in lateral translation and rotational jaw and roll movements for bilateral comparability. Thereby, positive movements in the lateral axis indicated that the condylar head moved laterally regardless of side. A positive movement along the anterior and superior axis indicated that the condylar head moved in an anterior and superior direction. Positive movements in the jaw indicated that the condyle rotated medially in relation to the anterior part of the ramus. Positive pitch indicated that the angular part of the condyle rotated in an anterior and superior direction. A positive roll indicated that the angular part of the condyle segment moved laterally relative to the condylar head regardless of side.

Asymmetry cases with more than 1 mm lateral translation were used for maxilla asymmetry.

### *2.6. Repeatability*

The repeatability of the measurement method has previously been established. A measure of repeatability was also incorporated in the technique by repeating measurements of 10 datasets by the primary investigator (FOB). The primary investigator was blinded to the previous fiducial markers and measurements during the repeated measurements.

### *2.7. Statistical analysis*

Analysis of the data was performed in STATA 15.0 (StataCorp, College Station, TX, USA).

Data were analyzed for normality of distribution using the Shapiro-Wilk test and visual q-q- plots. The data were normally distributed and further analyzed using mean, standard deviation, and 1-sample *t* tests to evaluate whether the results differed from 0.

Repeatability was evaluated by intraclass correlation coefficients (absolute agreement: single measurement in 2-way mixed model with random patient effects and fixed measurements effects). Repeatability was also evaluated by mean and standard deviation of both relative and absolute values.

The statistical significance level was set at a *P* value equal to or less than 0.05.

## 3. Results

The cohort consisted of 16 patients (5 females, 11 males, mean age

27 years). All patients underwent maxillary inferior repositioning and 9 patients had additional mandibular surgery (Table 1).

The mean linear movement of the condyle showed a high degree of accuracy (movement less than 0.2 mm from $T_0$ to $T_1$ and also a high degree of stability, with movement less than 0.3 mm from $T_1$ to $T_2$ (Table 2). However, the individual variation was high, with large standard deviations and maximal movement. The largest individual movements occurred during surgery, change from $T_0$ to $T_1$, with relatively large variations along all axes (large posterior movement of the condyle is shown in Fig. S2 *in supplementary files*). The postoperative stability of the individual condyle positions was more stable, with slightly smaller standard deviations and maximal linear movements from $T_1$ to $T_2$. The pitch axis showed a statistically significant rotational movement of 1.81° from $T_0$ to $T_1$. From $T_1$ to $T_2$, a further mean pitch rotation of 3.01° was observed (Table 2). This indicates an additional anterocranial movement of angle of the mandible, and not a relapse toward the preoperative condylar position as could have been expected.

The mean condylar movement showed high accuracy, less than 0.2 mm, but several individual outliers in accuracy were observed (Fig. S2 *in supplementary files*). Overall, outliers showed remarkably stable positions, with only minor changes at 1-year follow-up. Outliers along the lateral axis also showed stable positions despite a medial or lateral reposition of 3 mm. The lateral or medial displaced outliers showed no correlation with signs of condylar sagging (indicated by inferior condylar repositioning at 1-week follow-up) or sign of resorption (indicated by superior condylar repositioning at 1-year follow-up). Only 2 condyles showed reposition in the superior direction from 1 week to 1 year after surgery, which could have been caused by condyle resorption.

The multivariable analysis showed a statistically significant correlation with the positional change and bimaxillary procedures compared to the Le Fort 1 procedure alone (Table 3). No correlation existed between the displacement in the anterior-posterior direction and changes in the superior-inferior direction or medial-lateral direction. Similarly, none of the other confounding factors influenced the accuracy of condylar positioning.

Evaluation of the difference between bimaxillary procedures and Le Fort 1 procedures showed a statistically significant difference in pitch. An anterocranial rotational movement occurred during surgery, but an additional positive pitch also occurred during the first year after surgery (Table 4). A positive pitch indicated an anterior rotation of the condylar segment during surgery, which was expected. However, 1 year after surgery, a large additional anteriocranial rotation was also observed in the bimaxillary procedures compared with a minor anterior rotation in the Le Fort 1 procedures, indicating instability in the mandibular osteosynthesis. (Fig. S3 *in supplementary files*).

Repeatability of the measurements showed less than 1 mm and less than 2 degrees of diference between repeated measurements (Table 5). The intraclass correlation coefficients ranged from fair to excellent, with the highest interclass correlation coefficient (ICC) related to the lateral movement and the lowest ICC in the superior direction.

**Table 1**
Cohort analysis.

| | N |
|---|---|
| Cohort analysis | |
| Included participants (n) | 16 |
| Female gender (n) | 5 |
| Mean age (yr.) | 27 |
| Range (yr.) | 17 to 64 |
| Occlusion (angle classification) | |
| Neutral (Class I) | 5 |
| Distal (Class II) | 4 |
| Mesial (Class III) | 7 |
| Surgery (n) | |
| Maxillary surgery | 16 |
| Additional mandibular surgery | 9 |
| Mandibular advancement | 8 |
| Mandibular setback | 1 |

## 4. Discussion

The purpose of the study was to evaluate the positional condyle change using a voxel-based semiautomatic analysis, which has been verified for 3D positional changes in orthognathic surgery (Stokbro and Thygesen, 2018a). The hypothesis was that some positional condyle change occurred to explain the previously observed skeletal instability in this cohort (Stokbro and Thygesen, 2018b).

The knowledge of actual 3-dimensional translation and rotational condyle movement is not described, since there have been no precise measurement methods. Relapse tendency after BSSO has been shown to differ depending on using 2D or 3D measurements (Sun et al., 2018).

In this study, large individual changes in condylar position were measured, even though mean changes in the condyle position were minimal, from preoperative scanning to 1-week postoperative scanning. The condylar positions remained stable from the 1-week to the 1-year postoperative scans. The multivariable analysis showed that patients operated with bimaxillary procedures had significantly more condylar movement compared to patients operated with solitary Le Fort 1 procedures. The largest differences were found in pitch, indicating an anterocranial rotation in bimaxillary procedures during surgery or during the first week after surgery.

Costas et al. had similar findings showing that maxillary osteotomies do not seem to influence condylar position, and furthermore that condylar displacements correlate with degree of mandibular advancement (Costas et al., 2018).

The expected condyle translation and stability in postoperative position makes the use of patient specific plates in the mandible difficult, because it will cause imprecision of the plate and/or proximal segment compared to the virtually planned position.

The clinical relevance concerning the instability in the pitch plane might indicate a need for more stable osteosynthesis than 3 bicortically fixated screws used in this orthognathic setup. More rigid fixation has been shown to reduce flexibility and minimize reduction of condyle displacement (Han and Hwang, 2015). Instability in the pitch plane might lead to occlusal changes such as open bite. Furthermore, linear translations with less accuracy might not be a clinical problem because condyle movements were stable and not affected by the linear accuracy. This should be seen in a broader perspective that includes occlusion changes, temporomandibular disorders (TMD), bone remodeling, and late relapse.

These findings are in accordance with previous studies. Ruo-han Ma et al. (2020) also found that although the condyles changed position during bilateral sagittal split osteotomy (BSSO), the changes were stable and did not return to the original position at 12-month follow-up, (N = 21 patients). Méndez-Manjón et al. (2016) likewise found that the condyles did change position during BSSO, but the condyles did not return to the original position at 12-month follow-up, measured by surface-to-surface 3D distance mapping (N = 22 patients with skeletal class II). However, some studies have found that the change in condyle position was reseated to the original position at the 12-month follow-up. Chen et al. (2013) found that condyles moved inferoposteriorly 3–5 days after surgery followed by anterosuperior movement at 3-month follow-up, which remained stable at 12-month follow-up (N = 27 patients who underwent bimaxillary procedure). As such, an overall trend was observed indicating that the condylar position changed following orthognathic surgery, but the available evidence is divided regarding whether the condyle is stable in the new position.

The analysis of rotational movement showed that inaccuracy and instability was present in the pitch plane, with a mean rotation of 1.81° from the preoperative scan to the 1-week postoperative scan and a further 3.01° at the 1-year postoperative scan. This was interesting because a relapse did not occur to the preoperative position, but instead a significant additional anterocranial rotation was observed. This

**Table 2**
Linear and rotational movements of the condyles at 1 week and 1 year after surgery.

| | 1 week postoperative (N = 32) | | | | 1 year postoperative (N = 32) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | *P* value | Mean | SD | Range | *P* value |
| Linear movement (mm) | | | | | | | | |
| Anterior | −0.11 | 1.37 | −3.2 to 4.5 | .654 | −0.06 | 1.22 | −2.8 to 2.6 | .785 |
| Superior | −0.07 | 1.68 | −2.4 to 5.1 | .809 | 0.03 | 1.45 | −1.7 to 4.9 | .908 |
| Lateral | −0.00 | 1.02 | −2.7 to 2.9 | .988 | −0.26 | 0.98 | −1.7 to 4.9 | .138 |
| Rotational movement (°) | | | | | | | | |
| Yaw (°) | 0.18 | 2.24 | −5.7 to 6.1 | .645 | −0.15 | 2.43 | −6.4 to 5.9 | .728 |
| Pitch (°) | 1.81 | 3.77 | −3.2 to 15.7 | **.011** | 3.01 | 3.61 | −1.9 to 14.3 | **.000** |
| Roll (°) | 0.90 | 2.50 | −4.25 to 8.9 | **.051** | 0.64 | 2.35 | −4.6 to 8.2 | .131 |

**Table 3**
Mixed model analysis of linear condylar positional changes during surgery (N = 16).

| | | | 95% Confidence Interval | |
|---|---|---|---|---|
| | β | *P* Value | Lower Limit | Upper Limit |
| Position (Internal correlation with anterior displacement) | | | | |
| Superior | 0.04 | .895 | −0.57 | 0.65 |
| Lateral | 0.11 | .733 | −0.51 | 0.72 |
| Age | 0.00 | .850 | −0.04 | 0.03 |
| Female Gender | 0.01 | .981 | −0.63 | 0.64 |
| Surgery | | | | |
| Bimaxillary surgery | 1.17 | **.025** | 0.15 | 2.20 |
| Asymmetry maxilla 1 mm | 0.25 | .445 | −0.38 | 0.88 |
| Malocclusion | | | | |
| Distal (angle class II) | −0.49 | .398 | −1.63 | 0.65 |
| Mesial (angle class III) | 0.94 | **.019** | 0.16 | 1.73 |
| Constant | −1.07 | .099 | −2.34 | 0.20 |
| SD (Cons) | $3e^{-13}$ | | $2e^{-17}$ | $4e^{-9}$ |
| SD (Residual) | 1.25 | | 1.09 | 1.44 |

Abbreviations: SD, standard deviation.

**Table 4**
Comparing condylar positioning in bimaxillary surgery with Le Fort 1.

| | Bimaxillary surgery (N = 18) | | Le Fort 1 (N = 14) | | *P* value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Bimax vs LF1 |
| 1 week after surgery | | | | | |
| Anterior (mm) | 0.17 | 1.70 | −0.47 | 0.68 | .197 |
| Superior (mm) | −0.29 | 1.55 | 0.22 | 1.61 | .373 |
| Lateral (mm) | 0.15 | 1.25 | −0.19 | 0.62 | .363 |
| Yaw (°) | 0.53 | 2.92 | −0.26 | 0.68 | .333 |
| Pitch (°) | 3.95 | 3.74 | −0.95 | 1.05 | **.000** |
| Roll (°) | 1.44 | 3.14 | 0.20 | 1.06 | .167 |
| 1 year after surgery | | | | | |
| Anterior (mm) | −0.15 | 1.42 | 0.05 | 0.95 | .658 |
| Superior (mm) | 0.23 | 1.44 | −0.22 | 1.48 | .392 |
| Lateral (mm) | −0.38 | 1.20 | −0.11 | 0.60 | .437 |
| Yaw (°) | −0.26 | 3.23 | −0.01 | 0.68 | .778 |
| Pitch (°) | 4.89 | 3.82 | 0.60 | 0.92 | **.000** |
| Roll (°) | 0.96 | 3.03 | 0.23 | 0.89 | .388 |

Abbreviations: SD, standard deviation.

significant additional rotation may be explained by instability at the fixation of the osteotomy, the rotation of the ramus being affected by the pull of the masticatory forces. It is not believed that the instability of the Le Fort 1 osteotomy influenced the ramus, because inferior maxillary repositioning was undertaken in both the bimaxillary procedures and the Le Fort 1 procedures. Likewise, the role of condylar head resorption did not seem to play a role in this cohort study because no overall linear superior movement of the lateral condylar point occurred. These results indicate that at 1 week after surgery, the osteotomy at the BSSO is still not stable and masticatory forces may affect the stability of the long-term result. The measure of instability in this study could be caused by the use of postoperative splint at 1-week postoperative scanning by

**Table 5**
Repeatability of 10 measurements in 10 patients.

| | Mean | SD | Mean abs | SD abs | ICC |
|---|---|---|---|---|---|
| Linear movement (mm) | | | | | |
| Anterior | −0.15 | 0.76 | 0.73 | 0.59 | .984 |
| Superior | 0.08 | 0.21 | 0.64 | 0.42 | .569 |
| Lateral | 0.12 | 0.97 | 0.77 | 0.57 | .882 |
| Rotational movement (°) | | | | | |
| Yaw | 0.31 | 1.63 | 1.14 | 1.18 | .748 |
| Pitch | −0.15 | 2.78 | 1.91 | 1.97 | .883 |
| Roll | 1.00 | 1.64 | 1.33 | 1.38 | .836 |

Abbreviations: abs, absolute values. SD, standard deviation. ICC[a], intraclass correlation coefficient.

[a] ICC, intra-class correlation coefficient, absolute agreement, mixed effects model.

having a tendency to induce posterior pitch rotation.

The data in the cohort also were analyzed for evidence of condylar sag, as described by Reyneke et al. (Reyneke and Ferretti, 2002). Condylar sag can be defined as either immediate or late change in occlusion caused by compression between the condyle and fossa due to condylar malpositioning. Immediate condylar sag results in malocclusion due to surgical inferior positioning (central sag), while late condylar sag is caused by resorption, followed by superior translation, due to peripheral contact with the glenoid fossa (peripheral sag).

In the 1-week postoperative scan, the condyles were positioned slightly inferior and remained stable in this position in the 1-year postoperative scan (Fig. S3 *in supplementary files*). A single condyle was positioned 2 mm lower after surgery and relapsed to the original position at 1-year follow-up. However, despite this single finding, no other signs of condylar sag were found.

There are several limitations to the interpretation of this study. This study did not include an evaluation of the TMD, and thus, the changes in condylar position cannot be correlated with development of TMD. A setup equivalent to that of Chen et al. (2013) with a blinded TMD examination would be preferable and a good measure of clinical outcome. Likewise, the occlusion and relapse in the mandibular position was not a part of this study. As such, the changes in condylar positioning should be seen as a part of a larger picture in future studies. This is especially important because changes in condylar positioning can alter the surgical accuracy of the mandibular and maxillary positioning depending on which jaw is operated on first. Other limitations of this study include the size of the cohort, the use of five operators, cohort inhomogeneity, no occlusion measurements, postoperative surgical splint at 1 week scanning and remodeling in mandibular condyle and ramus is not investigated.

The strength of the study is the reliability of the voxel-based semi-automatic measurement method. A comparison of accuracy of voxel-based registration and surface-based registration for 3D assessment of surgical changes following orthognathic surgery was previously assessed by Almuktar et al. (Almukhtar et al., 2014) They found no significant statistical difference between the methods, and any differences were thus unlikely to have clinical significance. The voxel-based semiautomatic method has limitations, as it does not measure adaptive, morphological changes in the condyle. Studies on patients who underwent orthognathic surgery show condylar remodeling (Kobayashi et al., 2012; Park et al., 2012; Ueki et al., 2021). Despite not measuring the morphological changes in the condyle, any effect of the resorption or apposition of bone on the condylar positioning can still be detected by the semiautomatic method regardless of morphological changes. Further studies could investigate which segment of the mandibular ramus is best suited for voxel-based superimposition or surface-based registration because remodeling of the mandibular ramus, coronoid process, angulus, and condylar head may occur.

## 5. Conclusion

In conclusion, large individual condyle translations occurred, but the condylar position remained stable 1 year after surgery regardless of repositioning, indicating minimal condylar sag. The expected condyle translation and stability in postoperative position makes the use of patient specific plates in the mandible difficult. Anterocranial rotational instability indicates a need for greater stability of the osteotomy than that provided by 3 bicortically fixated screws. Condylar measurements should be seen as only a part of a larger overall analysis, and future studies should correlate condylar positional changes with TMD symptoms, changes in occlusion, condyle remodeling, and relapse of mandibular position.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2023.12.008.

## Appendix

The following is a detailed description of measurement and data extraction:

The freeware software Slicer 4.8.1 (www.slicer.org) was used to perform the segmentation of preoperative and 1-week- and 1-year postoperative CBCT scans in DICOM format. The segmentation is a performed procedure with the following steps:

Go to" All modules" and "enter" Surface Models > "Grayscale model maker". Set threshold to 950. Apply. Go to "Editor". Choose master volume. In editor press "ThresholdEffect". Set Grayscale to 950. In editor press "Painteffect". Set PaintEffect to 0 and paint over only. In the axial frame segment with PaintEffect bilaterally paint through the basis cranii cranially for infraorbital margin of the orbit. Perform same segmentation in the axial frame at caput mandibulae level and just above the mandibular incisure. In the coronal frame, the segmentation is made between tooth number 5 and number 6 in the mandible. This will give 4 segments. Basis cranii, right and left ramus segment, and a segment from regio mentalis to regio mentalis. Go to editor and press "IdentifyIslandEffect" - > apply. Go to "Surface models" ->" Model maker". Set input volume to the chosen label volume in "Editor". The four segments will appear in 4 different colors and given labels. Save each segment as a label. With the labels in place, it is now possible to align basis cranii in the 2 scans to measure movement of the condylar segment.

Scanning should be put in natural head position and basis cranii aligned through "Transforms". Go to "Registration – CMF – Label extraction" and extract condylar labels. Create and place 3 individual fiducial points at the most lateral point mandibular head, at the top of the coronoid process, and at mandibular angle. In "markups" make a second set of replicated the fiducial points. Make a voxel-based non-growing registration through "Registration – CMF registration". Make a label map, linear transform, and volume of the preoperative condylar segment realigned to the 1-week postoperative condylar segment. The linear transform can now be applied to the replicated fiducial points. In this way the movement of the condyle is visible. All semiautomatic segment movements were controlled by the investigator and manually replaced to correct position if needed. A "Quantification, Q3DC" is performed to measure movement distance in all planes and pitch, yaw, and roll of the condylar segment. The process is repeated for 1-year postoperative segments. Data can now be extracted for analysis.

## References


Almukhtar, A., Ju, X., Khambay, B., McDonald, J., Ayoub, A., 2014. Comparison of the accuracy of voxel based registration and surface based registration for 3D assessment of surgical change following orthognathic surgery. PLoS One 9 (4), e93402. https://doi.org/10.1371/journal.pone.0093402.

Baan, F., Liebregts, J., Xi, T., Schreurs, R., de Koning, M., Bergé, S., Maal, T., 2016. A new 3D tool for assessing the accuracy of bimaxillary surgery: the OrthoGnathicAnalyser. PLoS One 11 (2), e0149625. https://doi.org/10.1371/journal.pone.0149625.

Baan, F., Sabelis, J.F., Schreurs, R., Steeg, G Van De, Xi, T., Riet, T.C.T.V., Becking, A.G., TJJ, Maal, 2021. Validation of the OrthoGnathicAnalyser 2 . 0 — 3D accuracy assessment tool for bimaxillary surgery and genioplasty. PLoS One 16 (1), e0246196. https://doi.org/10.1371/journal.pone.0246196.

Bethge, L.S., Ballon, A., Mack, M., Landes, C., 2015. Intraoperative condyle positioning by sonographic monitoring in orthognathic surgery verified by MRI. J. Cranio-Maxillofacial Surg. 43 (1), 71–80. https://doi.org/10.1016/j.jcms.2014.10.012.

Chen, S., Lei, J., Wang, X., Fu, K., Farzad, P., Yi, B., 2013. Short- and long-term changes of condylar position after bilateral sagittal split ramus osteotomy for mandibular advancement in combination with Le Fort I osteotomy evaluated by cone-beam computed tomography. J. Oral Maxillofac. Surg. 71 (11) https://doi.org/10.1016/j.joms.2013.06.213, 1956–66.

Choi, B.-J., Choi, Y.-H., Lee, B.-S., Kwon, Y.-D., Choo, Y.-J., Ohe, J.-Y., 2014. A CBCT study on positional change in mandibular condyle according to metallic anchorage methods in skeletal class III patients after orthogenetic surgery. J. Cranio-Maxillo-Fac. Surg. 42 (8), 1617–1622. https://doi.org/10.1016/j.jcms.2014.05.001.

Costas, A., Sanromán, J.F., Castro, P., Ferro, M.F., Lopez, A., Stavaru, B., 2018. Study of condylar positional changes after sagittal split osteotomy for mandibular advancement: a prospective cohort study. J. Cranio-Maxillofacial Surg. 46 (7), 1079–1090. https://doi.org/10.1016/j.jcms.2018.04.017.

Draenert, F.G., Erbe, C., Zenglein, V., Kämmerer, P.W., Wriedt, S., Al Nawas, B., 2010. 3D analysis of condylar position after sagittal split osteotomy of the mandible in mono- and bimaxillary orthognathic surgery - a methodology study in 18 patients. J. Orofac. Orthop. 71 (6), 421–429. https://doi.org/10.1007/s00056-010-1021-9.

Gaber, R.M., Shaheen, E., Falter, B., Araya, S., Politis, C., Swennen, G.R.J., Jacobs, R., 2017. A systematic review to uncover a universal protocol for accuracy assessment of 3-dimensional virtually planned orthognathic surgery. J. Oral Maxillofac. Surg. 75 (11), 2430–2440. https://doi.org/10.1016/j.joms.2017.05.025.

Han, J.J., Hwang, S.J., 2015. Three-dimensional analysis of postoperative returning movement of perioperative condylar displacement after bilateral sagittal split ramus osteotomy for mandibular setback with different fixation methods. J. Cranio-Maxillofacial Surg. 43 (9), 1918–1925. https://doi.org/10.1016/j.jcms.2015.08.004.

Helm, G., Stepke, M.T., 1997. Maintenance of the preoperative condyle position in orthognathic surgery. J. Cranio-Maxillofacial Surg. 25 (1), 34–38. https://doi.org/10.1016/S1010-5182(97)80022-4.

Hsu, S.S.-P., Gateno, J., Bell, R.B., Hirsch, D.L., Markiewicz, M.R., Teichgraeber, J.F., Zhou, X., Xia, J.J., 2013. Accuracy of a computer-aided surgical simulation protocol for orthognathic surgery: a prospective multicenter study. J. Oral Maxillofac. Surg. 71 (1), 128–142. https://doi.org/10.1016/j.joms.2012.03.027.

Jones, J.P., Amarista, F.J., Jeske, N.A., Szalay, D., Ellis, E., 2022. Comparison of the accuracy of maxillary positioning with interim splints versus patient-specific guides and plates in executing a virtual bimaxillary surgical plan. J. Oral Maxillofac. Surg. 80 (5), 827–837. https://doi.org/10.1016/j.joms.2022.01.006.

Joss, C.U., Vassalli, I.M., 2009. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. J. Oral Maxillofac. Surg. 67 (2), 301–313. https://doi.org/10.1016/j.joms.2008.06.060.

Kobayashi, T., Izumi, N., Kojima, T., Sakagami, N., Saito, I., Saito, C., 2012. Progressive condylar resorption after mandibular advancement. Br. J. Oral Maxillofac. Surg. 50 (2), 176–180. https://doi.org/10.1016/j.bjoms.2011.02.006.

Lee, S.J., Yang, H.J., Choi, M.H., Woo, S.Y., Huh, K.H., Lee, S.S., Heo, M.S., Choi, S.C., Hwang, S.J., Yi, W.J., 2019. Real-time augmented model guidance for mandibular proximal segment repositioning in orthognathic surgery, using electromagnetic tracking. J. Cranio-Maxillofacial Surg. 47 (1), 127–137. https://doi.org/10.1016/j.jcms.2018.10.016.

Ludlow, J.B., Davies-Ludlow, L.E., Brooks, S.L., Howerton, W.B., 2006. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofacial Radiol. 35 (4), 219–226. https://doi.org/10.1259/dmfr/14340323.

Ma, R.-H., Li, G., Yin, S., Sun, Y., Li, Z., Ma, X., 2020. Quantitative assessment of condyle positional changes before and after orthognathic surgery based on fused 3D images from cone beam computed tomography. Clin. Oral Invest. 24 (8), 2663–2672. https://doi.org/10.1007/s00784-019-03128-z.

Méndez-Manjón, I., Guijarro-Martínez, R., Valls-Ontañón, A., Hernández-Alfaro, F., 2016. Early changes in condylar position after mandibular advancement: a three-dimensional analysis. Int. J Oral Maxillofac. Surg. 45 (6), 787–792. https://doi.org/10.1016/j.ijom.2016.01.002.

Nova, I., Kallus, S., Berger, M., Ristow, O., Eisenmann, U., Freudlsperger, C., Hoffmann, J., Dickhaus, H., 2017. Computer assisted positioning of the proximal segment after sagittal split osteotomy of the mandible: preclinical investigation of a novel electromagnetic navigation system. J. Cranio-Maxillofacial Surg. 45 (5), 748–754. https://doi.org/10.1016/j.jcms.2017.01.036.

Park, S.-B., Yang, Y.-M., Kim, Y.-I., Cho, B.-H., Jung, Y.-H., Hwang, D.-S., 2012. Effect of bimaxillary surgery on adaptive condylar head remodeling: metric analysis and image interpretation using cone-beam computed tomography volume superimposition. J. Oral Maxillofac. Surg. 70 (8) https://doi.org/10.1016/j.joms.2011.08.017, 1951–9.

Perez, D., Ellis, E., 2011. Sequencing bimaxillary surgery: mandible first. J. Oral Maxillofac. Surg. 69 (8), 2217–2224. https://doi.org/10.1016/j.joms.2010.10.053.

Reyneke, J., Ferretti, C., 2002. Intraoperative diagnosis of condylar sag after bilateral sagittal split ramus osteotomy. Br. J. Oral Maxillofac. Surg. 40 (4), 285–292. https://doi.org/10.1016/S0266-4356(02)00147-X.

Rotskoff, K.S., Herbosa, E.G., Villa, P., 1991. Maintenance of condyle-proximal segment position in orthognathic surgery. J. Oral Maxillofac. Surg. 49 (1), 2–8. https://doi.org/10.1016/0278-2391(91)90256-l.

Rückschloß, T., Ristow, O., Müller, M., Kühle, R., Zingler, S., Engel, M., Hoffmann, J., Freudlsperger, C., 2019. Accuracy of patient-specific implants and additive-manufactured surgical splints in orthognathic surgery — a three-dimensional retrospective study. J Cranio-Maxillofacial 47 (6), 847–853. https://doi.org/10.1016/j.jcms.2019.02.011.

Shaheen, E., Shujaat, S., Saeed, T., Jacobs, R., Politis, C., 2019. Three-dimensional planning accuracy and follow-up protocol in orthognathic surgery: a validation study. Int. J. Oral Maxillofac. Surg. 48 (1), 71–76. https://doi.org/10.1016/j.ijom.2018.07.011.

Stokbro, K., Thygesen, T., 2018a. A 3-dimensional approach for analysis in orthognathic surgery-using free software for voxel-based alignment and semiautomatic measurement. J. Oral Maxillofac. Surg. 76 (6), 1316–1326. https://doi.org/10.1016/j.joms.2017.11.010.

Stokbro, K., Thygesen, T., 2018b. Surgical accuracy in inferior maxillary reposition. J. Oral Maxillofac. Surg. 76 (12), 2618–2624. https://doi.org/10.1016/j.joms.2018.05.022.

Sun, Y., Tian, L., Luebbers, H.-T., Politis, C., 2018. Relapse tendency after BSSO surgery differs between 2D and 3D measurements: a validation study. J. Cranio-Maxillo-Fac. Surg. 46 (11), 1893–1898. https://doi.org/10.1016/j.jcms.2018.09.012.

Titiz, I., Laubinger, M., Keller, T., Hertrich, K., Hirschfelder, U., 2012. Repeatability and reproducibility of landmarks–a three-dimensional computed tomography study. Eur. J. Orthod. 34 (3), 276–286. https://doi.org/10.1093/ejo/cjq190.

Ueki, K., Yoshizawa, K., Saito, Y., Takayama, A., Baba, N., Kimura, Y., Koizumi, M., Fujimoto, K., Iguchi, R., Sato, M., Osada, A.H., Moroi, A., 2021. Evaluation of condylar surface CT values related to condylar height reduction after orthognathic surgery. J. Cranio-Maxillofacial Surg. 49 (8), 639–648. https://doi.org/10.1016/j.jcms.2021.01.005.

Ware, W.H., Taylor, R.C., 1968. Condylar repositioning following osteotomies for correction of mandibular prognathism. Am. J. Orthod. 54 (1), 50–59. https://doi.org/10.1016/0002-9416(68)90145-0.