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Does the Glenoid Fossa Change following Orthognathic Surgery?

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Abstract

**Purpose:** Glenoid fossa morphology may change following orthognathic surgery and may subsequently affect skeletal stability and functionality, however hardly documented. Hence, the purpose of this study was to evaluate the morphological change of the glenoid fossa two years after bimaxillary surgery.

**Methods:** A case series was performed including subjects diagnosed with maxillary and/or mandibular growth disturbances, who underwent bimaxillary surgery between March 2012 and November 2017 at the Department of Oral and Maxillofacial Surgery, University Hospital of Southern Denmark, Esbjerg, Denmark. Study variables were gender, age and postoperative condylar resorption. Subjects were sampled evenly within subgroups with and without postoperative condylar resorption. The outcome variable, three-dimensional morphological change of the glenoid fossa was calculated as surface distance in mm between superimposed pre- and postsurgical (two years) CBCT-scans, and were spatially divided into four regions. Evaluation of glenoid fossa changes of more than one voxel (> 0.3 mm) and comparison of subjects with and without postoperative condylar resorption were performed by one-sample and unpaired t-tests, respectively.

**Results:** Twenty subjects (sixteen female; four male; mean age 27.6 years) with class II malocclusion and maxillomandibular retrognathia were included. The glenoid fossa changes (0.36 mm) were significant (p = 0.021), and significantly larger in subjects with condylar resorption than in those without in the anterior-lateral (0.40 mm vs. 0.27 mm, p = 0.021) and anterior-medial fossa region (0.48 mm vs. 0.26 mm, p = 0.015).

**Conclusion:** Significant morphological fossa changes were found two years after orthognathic surgery, and subjects with postoperative condylar resorption showed a significantly higher degree of morphological change in the anterior glenoid fossa than subjects without.
Introduction

Three adaptive processes in the temporomandibular joint (TMJ) are believed to contribute to the position of the mandible: 1) adaptive condylar remodeling, 2) glenoid fossa remodeling, and 3) condylar positional changes within the fossa. The adaptive condylar remodeling is thought to be induced during mastication or mechanical loading, e.g., by orthodontic treatment and orthognathic surgery where the condyles may be displaced in the glenoid cavity.

Remodeling of the glenoid fossa, a way to withstand mechanical forces and movements of the condyle in the TMJ, has been observed following TMJ disc dislocation without reduction, TMJ surgical procedures, condylar fractures, removable functional appliances, fixed functional appliances and orthognathic surgery.

Two-dimensional analysis (2D) of glenoid fossa resorption and remodeling caused by treatment has its limitations. The risk of multiple errors with 2D imaging exists, such as distortion-, magnification-, patient positioning errors and overlapping anatomical structures, making landmark identification difficult and cephalometry insufficient to explain the complex three-dimensional (3D) process. Furthermore, an inherent shortcoming of landmark-based cephalometric analysis is the accumulation of landmark identification errors, shown to range from 0.02 to 2.47 mm. The accumulated error influences the measurements and possibly exceeds the amount of morphological change of the glenoid fossa. This calls for more accurate 3D assessment techniques. However, seemingly, 3D assessment of glenoid fossa changes has been sparsely performed, with contradicting outcome, and none of the methods have been validated.

A systematic literature search showed that no studies exist on remodeling of the glenoid fossa following orthognathic surgery. In contrast, postoperative condylar remodeling following orthognathic surgery has been studied and published numerous times. Glenoid fossa remodeling is one of the adaptive processes in the TMJ and it is believed to contribute to the position of the
mandible. In order to study and understand the postoperative stability and functionality following orthognathic surgery, the focus should not solely be on the condyle, but on the entire TMJ including the glenoid fossa. Hence, the purpose of the present study was to answer the following clinical question: “Among subjects with and without postoperative condylar resorption following orthognathic surgery, does the glenoid fossa change?” The null hypotheses were: H01: no morphological change of the glenoid fossa occurs two years after orthognathic surgery, i.e. less than one voxel (≤ 0.3 mm). H02: there is no difference in the morphological change of the glenoid fossa between subjects with and without postoperative condylar resorption. The aim of the present study was to evaluate morphological changes of the glenoid fossa after bimaxillary surgery in subjects with and without postoperative condylar resorption.
Materials and methods

Permission was granted by the Institutional Ethics Committee – University Hospital of Southern Denmark, Esbjerg (21/33871). As the study comprised retrospective material, none of the subjects were exposed to any extra radiation and no extra examination has been performed to acquire additional information.

Study design

The investigators conducted a case series applying a validated semi-automatic approach for 3D assessment of morphological change of the glenoid fossa to evaluate the glenoid fossa changes following orthognathic surgery. The study sample was evenly sampled, such that half of the patients were diagnosed with postoperative condylar resorption and the other half was without.

The present study was based on pre- and postsurgical (two years) CBCT-scans from a study sample diagnosed with maxillary and/or mandibular growth disturbances, who underwent a combined bilateral sagittal split osteotomy (BSSO) and Le Fort I procedure between March 2012 and November 2017 at the Department of Oral and Maxillofacial Surgery, University Hospital of Southern Denmark, Esbjerg, Denmark.

Inclusion criteria: age range of 18–65 years; diagnosis indicating a combined BSSO and Le Fort I osteotomy; availability of patients’ pre- and postoperative (two years) CBCT scans. Exclusion criteria: previous history of oral and maxillofacial surgery, presence of craniofacial anomaly or syndrome.

Study variables

The study variables were, gender, age and postoperative condylar resorption (binary) two-year after of bimaxillary surgery. The primary outcome variables were the morphological change of the
glenoid fossa in mm and the spatial division of the change: anterior-lateral, anterior-medial, posterior-lateral and posterior-medial.

**Data collection**

The CBCT-images were acquired using an i-CAT scanner, version 17–19 (Imaging Sciences International, Hatfield, PA): 120 kVp; 5 mA; 7 seconds exposure time; Field-of-View (FOV) = 23x17.8 cm (768x768x576 voxels); isotropic voxels of 0.30 mm. The patients were scanned upright in natural head position. The condyles were seated in centric relation (CR) and the preoperative occlusion in CR was fixed by a wax-bite, however, without a wax-bite at the postoperative CBCT scanning acquisition. The CBCT data were exported in DICOM format and imported into Mimics® 24.0 (Materialise NV, Leuven, Belgium).

The surgery was performed in general anesthesia as a mandible-first procedure. After BSSO, the distal mandibular segment was positioned using an intermediate splint and fixated bilaterally to each proximal segment with two 2.0 four hole osteosynthesis plates (KLS Martin, Tuttlingen, Germany). A position pin (Medicon® eG, Tuttlingen, Germany) placed at the Glabella was used as an external reference point to establish the planned vertical position of the upper incisors. Following the Le Fort I osteotomy, in segmental cases, the maxilla was segmented into three pieces, and the tooth-bearing segments were positioned into the final occlusion without the use of a splint, and subsequently fixated using two 2.0 Y-plates anteriorly and two L-plates posteriorly (KLS Martin, Tuttlingen, Germany). All osteotomy sites were grafted and subjects were instructed to wear elastics during the first period following surgery.

The cranial bone was semi-automatically segmented using Mimics® 24.0 (Materialise NV, Leuven, Belgium) using the CT Bone Wizard (Fig. 1), which is a more advanced bone segmentation tool compared to a standard global threshold. Initially, the region of interest was specified by desired- and undesired seed points, which are grid points selected to agglomerate the surrounding volume.
Seed thresholds and region growing sensitivity were specified in Hounsfield Unit (HU) (Fig. 1.a). The regions were then grown from these seed points to adjacent points depending on a region membership criterion, and avoiding regions grown from undesired seed points. The desired seed point was placed on the upper cortical skull bone. Undesired skeletal parts, in this case the mandible, were discarded using undesired seed points. Next, the threshold of the mask was chosen (Fig. 1.b). The minimum threshold was set to 226 HU, a predefined lower threshold for CT bone. The resulting segmented glenoid fossa with holes and missing bone is shown in Fig. 1.c. Local thresholding and 3D interpolation were applied to reconstruct missing bone (Fig. 1.d).

Reconstruction of holes in thin bone in two clicks (Fig. 1.e), a custom plugin for Mimics® 24.0 (Materialise NV, Leuven, Belgium), was applied to repair holes and ensure that the glenoid fossa bone was correctly segmented as a closed surface. Any remaining noise was removed manually using the Edit Mask tool. The final 3D reconstructed part of the glenoid fossa is shown in Fig. 1.f.

The postoperative CBCT scan was registered to the preoperative CBCT scan by VBR using the anterior cranial base, zygomatic arches, and forehead as the volume of interest (VOI) unaffected by the surgery (Fig. 2).  

The analysis of the post-operative morphological change of the glenoid fossa was implemented in 3-matic® 16.0 (Materialise NV, Leuven, Belgium) and the workflow was automated using Python scripting, Python 3.8 (Python Software Foundation, Fredericksburg, Virginia). No cephalometric landmarks were required for this holistic analysis of the glenoid fossa. The only manual input required was the tracing of a curve engulfing the preoperative glenoid fossa. A duplicate of this curve, automatically attracted and attached to the surface of the postoperative skull, was thereby defining the postoperative glenoid fossa. For the spatial analysis of the glenoid fossa, the glenoid fossa was divided into four sub-regions. For this purpose, the Frankfurt horizontal plane and midsagittal plane were created and the orthogonal coronal plane was computed. The glenoid fossa was
divided anteroposteriorly and transversally, through its center of gravity, parallel to the coronal and mid-sagittal plane, respectively. Surface discrepancies were represented by color-coded distance maps, and quantified by the root mean square (RMS)-, mean-, minimum- and maximum surface distance of the total glenoid fossa and the defined four fossa sub-regions (Fig. 3).

Data analysis

Statistical analysis of the data was performed in STATA\textsuperscript{®} 16.1 (StataCorp, College Station, TX). To determine the sample size for the present study, a power calculation was performed based on the mean and variation of the assessment outcome of the validation study using a one sample t-test (H0: \(x \leq 0.3\) mm, power = 0.8, alpha = 0.05). The one sample t-test was applied on the study sample to statistically evaluate if the glenoid fossa change was significantly (p < 0.05) larger than one voxel (0.3 mm). An unpaired t-test was applied to statistically evaluate if the morphological change of the glenoid fossa regions was significantly (p < 0.05) different between subjects with and without postoperative condylar resorption. The RMS-, mean-, minimum- and maximum surface distance of the total glenoid fossa and the four sub-regions were summarized using the mean and standard deviation (SD).
Results

The statistical sample size calculation resulted in a required sample size of \( n = 35 \) fossae to obtain a statistical power of 0.8. Hence, twenty post-pubertal patients, who were treated by two senior surgeons, and who met the inclusion- and exclusion criteria, were included. Sixteen female; four male; mean age 27.6 ± 8.0 years; class II malocclusion with mandibular retrognathia (sixteen subjects); maxillomandibular retrognathia (four subjects); anterior open bite (fourteen subjects); lateral open bite (one subject); deep bite (one subject); mandibular asymmetry (four subjects); vertical maxillary hyperplasia (one subject); treated with maxillomandibular advancement (eighteen subjects); mandibular advancement (two subjects); maxillary expansion (nineteen subjects) and supplementary genioplasty (five subjects).

The sample size and gender were evenly distributed for the condylar resorption study variable, while the age was significantly different (Table 1). However, the outcome variable (glenoid fossa change) was not correlated with the age nor significantly different based on gender (Table 2). Table 2 presents the between groups comparison of subjects with and without postoperative condylar resorption showed a significantly higher degree of glenoid fossa changes in subjects with condylar resorption (\( p = 0.007 \)).

Fig. 4 shows the visual results of the 3D glenoid fossa assessment for the study sample, and Table 3 presents a univariate analysis of the glenoid fossa changes. The RMS distance of glenoid fossa changes in all subjects was significantly larger (\( p = 0.021 \)) than one voxel (0.3 mm). When dividing the study sample into subjects with (ten) and without (ten) postoperative condylar resorption, the subjects with condylar resorption showed significant glenoid fossa changes (\( p = 0.007 \)), while the subjects without condylar resorption did not (\( p = 0.635 \)).
Table 4 presents the bivariate association between condylar resorption and the spatially divided fossa region. A significantly different change was exclusively observed in the anterior-lateral ($p = 0.021$) and anterior-medial fossa regions ($p = 0.015$).
Discussion

The purpose of the present study was to evaluate morphological changes of the glenoid fossa after bimaxillary surgery. The null hypotheses were: $H_0_1$: no morphological change of the glenoid fossa occurs two years after orthognathic surgery, i.e. less than one voxel ($\leq 0.3$ mm). $H_0_2$: there is no difference in the morphological change of the glenoid fossa between subjects with and without postoperative condylar resorption.

A statistically significant morphological change of the glenoid fossa was observed. Hence, the null hypothesis $H_0_1$ was rejected. Only subjects with condylar resorption showed significant glenoid fossa changes, and a significantly larger amount than those without. When spatially dividing the fossa region, a significantly different change was exclusively observed in the anterior-lateral and anterior-medial fossa regions. Therefore, the null hypothesis $H_0_2$ was also rejected.

The findings are in line with the functional anatomy of the TMJ. Unlike the paper thin bony roof of the glenoid fossa, the articular eminence in the anterior glenoid fossa is made up of a fairly thick layer of dense bone and the fibrous tissue covering the articular eminence is thick and firm. These morphologic characteristics reinforce the hypothesis that the articular eminence, but not the roof of the glenoid fossa, is loaded by routine joint reaction forces developed among the articular surfaces of the mandibular condyle, the articular disc, and the squamous temporal bone.

In Fig. 4, the morphological changes can be visual inspected. The study sample represents some diversity, from close to no change of the glenoid fossa to a higher degree of change in the distinctive spatial regions for patients with postoperative condylar resorption. The mean maximum surface distance was 1.15 mm (0.61), and a maximum change in the anterior-medial glenoid fossa region of up to 3.7 mm was observed in a patient with severe condylar resorption. Hence, the sample included subjects with a high degree of postoperative bone resorption of the glenoid fossa. This emphasizes the importance of this study and the need for further studies to evaluate the clinical
relevance of glenoid fossa remodeling in conjunction with condylar remodeling to study the combined effect on skeletal stability and treatment relapse following orthognathic surgery. The mean minimum surface distances of all regions were close to zero (< 0.01 mm) with low SD (< 0.06 mm). This indicates that there was no erroneous offset in the superimposition and assessment.

No literature was identified which assessed glenoid fossa remodeling with 3D (CB)CT following orthognathic surgery, and most previous studies on resorption and remodeling of the glenoid fossa relied on 2D assessment of lateral cephalograms. Three-dimensional assessment of glenoid fossa changes has only been sparsely performed in growing subjects, with contradicting outcome, and none of the methods have been validated. LeCornu et al. showed by 3D CBCT an anterior translation of the condyle with resorption of the anterior wall and bone deposition at the posterior wall of the glenoid fossa following Herbst appliance treatment. Whereas Atresh et al. showed a posterior displacement of the condyle and glenoid fossa. Studies suggest 3D superimposition methods to assess the glenoid cavity. Again, the reliability of these methods was not validated. Hence, there was a need for a validated and reliable approach to be developed and applied. To meet this requirement, the present study proposed and validated a reliable approach, which can be applied in future studies for evaluating the growth or asymmetry of the mandible, involving spatial assessment of morphological change of the glenoid fossa, e.g. following orthognathic surgery in adult patients. Spatial analysis by division of the glenoid fossa into sub-regions has, to the knowledge of the authors, not been presented before. However, it is important in order to assess the spatial distribution of the morphological change related to the postoperative outcome of orthognathic surgery.

Voxel-based registration on the cranial base of CBCT has been validated before, and applied for analysis of skeletal repositioning and airway morphology. However, assessment of the morphological change of the glenoid fossa in 3D using CBCT, including the combined
segmentation-, 3D reconstruction-, tracing- and quantification of the glenoid fossa by the individual observer, is challenging. The roof of the glenoid fossa is a part of the temporal bone, which is very thin and which separates the cranial fossa and the temporomandibular joint. This can cause discontinuities in 3D CBCT scans due to low contrast, the spatial resolution, noise and artefacts, making it difficult to accurately segment and evaluate the glenoid fossa. Often the glenoid fossa cannot be completely segmented using global image segmentation techniques, and manual segmentation is often time consuming and subject to operator errors. The proposed approach applies semi-automatic bone segmentation (Fig.1.a-c) coupled with local reconstruction of holes in thin bone in two clicks (Fig.1.e) and 3D interpolation (Fig.1.d) for complete 3D reconstruction of the glenoid fossa (Fig.1.f). Nonetheless, the resulting 3D reconstruction is an estimation of the actual glenoid fossa. Furthermore, the manual tracing of the glenoid fossa region is subject to some observer variation. For assessment of relatively small morphological changes, such variations affect the reliability of the assessment. Hence, when making the assessment more detailed by spatially dividing the glenoid fossae into four sub-regions, the intra- and inter-observer reliability was reduced from excellent to good for some regions. Although the approach is semi-automatic, the segmentation and tracing of the fossa region require some manual labor. However, due to the aforementioned challenges, it is difficult to fully automate the assessment.

The aim of the present study was to evaluate if morphological change of the glenoid fossa occurs following orthognathic surgery in adult patients, including its spatial characteristics. For this purpose, twenty subjects were included based on a power calculation. Further studies are encouraged applying the validated approach on larger cohorts for statistical evaluation of postoperative morphological change of the glenoid fossa and its clinical relevance, such as spatial tendencies and association with surgical procedure, amount- and direction of skeletal movement, and skeletal fixation and -stability.
Conclusion

Glenoid fossa remodeling is believed to be one of three adaptive processes in the TMJ, which contributes to the position of the mandible.\textsuperscript{1,15,32} Therefore, it is highly relevant to take glenoid fossa remodeling into consideration, e.g. when evaluating maxillomandibular growth disturbances or the outcome and relapse of orthognathic surgical treatment. Hence, a study was conducted to evaluate if the glenoid fossa morphologically changes after bimaxillary surgery, and whether a difference exists between subjects with and without postoperative condylar resorption. The study sample showed significant glenoid fossa changes, and subjects with postoperative condylar resorption showed significantly higher degree of glenoid fossa changes than subjects without. When spatially dividing the fossa region, a significantly different change was exclusively observed in the anterior-lateral and anterior-medial fossa regions.

Acknowledgments

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References


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Tables

Table 1. Summary of study variables.

<table>
<thead>
<tr>
<th>Variable name (and type)</th>
<th>With condylar resorption</th>
<th>Without condylar resorption</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size (n)</td>
<td>10 (50%)</td>
<td>10 (50%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Gender (binary) - female</td>
<td>8 (80%)</td>
<td>8 (80%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Age (continuous)</td>
<td>22.8 ± 4.0 years</td>
<td>32.3 ± 8.3 years</td>
<td>0.004*</td>
</tr>
</tbody>
</table>

*Statistically significant.

Table 2. Summary of bivariate association between study variables and outcome variables. Root-mean-square (RMS)-, mean-, minimum (min)- and maximum (max) surface distances, and standard deviations for the measurements of glenoid fossa changes in mm.

<table>
<thead>
<tr>
<th>Variable name (and type)</th>
<th>RMS</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condylar resorption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>0.43 (0.22)</td>
<td>0.31 (0.13)</td>
<td>0.00 (0.00)</td>
<td>1.33 (0.74)</td>
<td></td>
</tr>
<tr>
<td>Without</td>
<td>0.29 (0.11)</td>
<td>0.23 (0.09)</td>
<td>0.00 (0.00)</td>
<td>0.97 (0.35)</td>
<td>0.007*</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.37 ± 0.17</td>
<td>0.24 ± 0.08</td>
<td>0.00 ± 0.00</td>
<td>1.06 ± 0.37</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.36 ± 0.19</td>
<td>0.28 ± 0.12</td>
<td>0.00 ± 0.00</td>
<td>1.17 ± 0.66</td>
<td>0.925</td>
</tr>
<tr>
<td>Age (correlation)</td>
<td>-0.247</td>
<td>-0.248</td>
<td>-0.174</td>
<td>-0.233</td>
<td>0.125</td>
</tr>
</tbody>
</table>

*Significantly higher degree of glenoid fossa changes (RMS distance) in subjects with condylar resorption.

Table 3. Summary of univariate analysis of outcome variables. Root-mean-square (RMS)-, mean-, minimum (min)- and maximum (max) surface distances, and standard deviations for the measurements of glenoid fossa changes in mm.

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>RMS</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All subjects</td>
<td>0.36 ± 0.18</td>
<td>0.27 ± 0.12</td>
<td>0.00 ± 0.00</td>
<td>1.15 ± 0.61</td>
<td>0.021*</td>
</tr>
<tr>
<td>With condylar resorption</td>
<td>0.43 ± 0.22</td>
<td>0.31 ± 0.13</td>
<td>0.00 ± 0.00</td>
<td>1.33 ± 0.74</td>
<td>0.007*</td>
</tr>
<tr>
<td>Without condylar resorption</td>
<td>0.29 ± 0.11</td>
<td>0.23 ± 0.09</td>
<td>0.00 ± 0.00</td>
<td>0.97 ± 0.38</td>
<td>0.635</td>
</tr>
</tbody>
</table>

*RMS distance significantly larger than one voxel (0.3 mm).
Table 4. Summary of bivariate association between condylar resorption and spatially divided outcome variables. Root-mean-square (RMS)-, mean-, minimum (min)- and maximum (max) surface distances, and standard deviations for the measurements of glenoid fossa changes in mm.

<table>
<thead>
<tr>
<th>Variable name (and type)</th>
<th>RMS</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomical location (categorical)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior-lateral fossa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With condylar resorption</td>
<td>0.40 (0.23)</td>
<td>0.32 (0.16)</td>
<td>0.00 (0.00)</td>
<td>1.06 (0.68)</td>
<td></td>
</tr>
<tr>
<td>Without condylar resorption</td>
<td>0.27 (0.14)</td>
<td>0.22 (0.13)</td>
<td>0.01 (0.05)</td>
<td>0.74 (0.43)</td>
<td>0.021*</td>
</tr>
<tr>
<td>Anterior-medial fossa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With condylar resorption</td>
<td>0.48 (0.41)</td>
<td>0.38 (0.32)</td>
<td>0.00 (0.01)</td>
<td>1.17 (0.80)</td>
<td></td>
</tr>
<tr>
<td>Without condylar resorption</td>
<td>0.26 (0.13)</td>
<td>0.22 (0.12)</td>
<td>0.00 (0.02)</td>
<td>0.69 (0.30)</td>
<td>0.015*</td>
</tr>
<tr>
<td>Posterior-lateral fossa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With condylar resorption</td>
<td>0.33 (0.12)</td>
<td>0.26 (0.10)</td>
<td>0.00 (0.01)</td>
<td>0.94 (0.45)</td>
<td></td>
</tr>
<tr>
<td>Without condylar resorption</td>
<td>0.28 (0.11)</td>
<td>0.23 (0.08)</td>
<td>0.00 (0.00)</td>
<td>0.75 (0.35)</td>
<td>0.128</td>
</tr>
<tr>
<td>Posterior-medial fossa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With condylar resorption</td>
<td>0.39 (0.20)</td>
<td>0.30 (0.14)</td>
<td>0.00 (0.00)</td>
<td>1.11 (0.58)</td>
<td></td>
</tr>
<tr>
<td>Without condylar resorption</td>
<td>0.31 (0.16)</td>
<td>0.25 (0.16)</td>
<td>0.01 (0.06)</td>
<td>0.83 (0.32)</td>
<td>0.085</td>
</tr>
</tbody>
</table>

*Significantly higher degree of glenoid fossa changes (RMS distance) in subjects with condylar resorption.
Figure legends

Fig. 1. Illustration of the segmentation process in sagittal coronal-, axial-, sagittal- and 3D view. (a) CT bone wizard: selection of desired and undesired seed points and settings. (b) CT bone wizard: mask threshold. (c) Segmented glenoid fossa with holes and missing bone (d) Local thresholding and 3D interpolation of missing bone. (e) Reconstruction of holes in thin bone. (f) Final 3D part of the glenoid fossa.

Fig. 2. Voxel-based registration on the anterior cranial base, prealigment and volume of interest boundary box.

Fig. 3. Analysis of morphological differences between the pre- and postoperative glenoid fossa using color-coded distance map showing surface discrepancies in mm.

Fig. 4. Visual results of the 3D glenoid fossa assessment showing morphological changes of the study sample using color-coded distance maps in mm. On the left: subjects without postoperative condylar resorptions. On the right: subjects with postoperative condylar resorption.