Published in final edited form as:
J Oral Maxillofac Surg. 2013 September ; 71(9): 1588–1597. doi:10.1016/j.joms.2013.04.006.

Long-term three-dimensional stability of mandibular advancement surgery

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Abstract

PURPOSE—To evaluate the three-dimensional changes in the position of the condyles, rami, and chin from 1 to 3 years after mandibular advancement surgery.

METHOD—This prospective observational study used pre and postoperative CBCT scans of 27 subjects with skeletal Class II jaw relationship and normal or deep overbite. An automatic technique of cranial base superimposition was used to assess positional and/or bone remodeling changes that were visually displayed and quantified using 3D color maps. An analysis of covariance with presence of genioplasty, age at the time of surgery, and sex as explanatory variables was used to estimate and test the adjusted mean changes for each region of interest.

RESULTS—The chin rotated downward and backwards between the 1 and 3 years post-surgery. Changes ≥ 2mm were observed in 17% of the cases. The mandibular condyles presented

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displacements and/or bone remodeling ≥ 2mm on the anterior surface (21% of the cases on the left and 13% on the right side), superior surfaces (8% on both sides) and lateral poles (17% on the left and 4% on the right side). The posterior borders of the rami exhibited symmetric lateral or rotational displacements in 4% of the cases.

CONCLUSION—In the hierarchy of surgical stability, mandibular advancement surgery is considered one of the most stable surgical procedures However, between 1 and 3 years post-surgery approximately 20% of the patients had 2-4 mm changes in the horizontal and vertical chin position, and/or changes in condylar position and adaptive bone remodeling.

INTRODUCTION

The construction of virtual 3D craniofacial surface models of patients has recently allowed scientific investigation of bone remodeling that leads to morphological changes. Registration of craniofacial surface models now enables the quantification and localization of the changes related to orthodontic/surgical protocols in the treatment of dentofacial disharmonies not readily apparent in 2D films.[1]

Over the last half century ortho-surgical treatment has been routinely used to address maxillamandibular discrepancies at skeletal maturity. Since the late 1950's[2-6], stability of orthognathic surgery procedures has been well documented using 2D cephalometry and mandibular advancement surgery has been reported to be one of the most stable surgical procedures.[6] Recent short-term studies, using CBCT for the 3D analysis of cranial and facial hard[7-10] and soft[11] tissues, have shown the regional remodeling that occurs in the first year after surgery.

While previous studies have quantified surgical displacements and short-term adaptation following mandibular advancement, the assessment of long-term results also are important.[12-13] The purpose of this study was to analyze long-term 3D alterations in the rami, condyles and chin between one and three years after surgery in patients treated with mandibular advancement.

MATERIALS AND METHODS

The sample in this observational prospective study comprised 27 patients (18 female and 9 male) with an average age of 26.7 ± 13.2 years who received orthodontic treatment in preparation for mandibular advancement surgery. All mandibular advancements were performed using bilateral sagittal split osteotomy (BSSO) and rigid fixation with plates and screws.[14-15] All patients were operated at the University of North Carolina (UNC) Memorial Hospital (North Carolina, USA) by a surgeon and assisting resident from the Department of Oral and Maxillofacial Surgery. The inclusion criteria consisted of pre-surgical Class II skeletal malocclusions with mandibular deficiency, 5-mm minimum overjet pre-surgery, and normal or increased overbite. The exclusion criteria were excessive anterior facial height, anterior open bite, and skeletal deformities from trauma, cleft lip and palate, syndromic or degenerative conditions, such as rheumatoid arthritis. The research protocol was approved by the Biomedical Institutional Review Board, and all of the participants signed an informed consent form.

The CBCT scans were performed before the surgery (T1), one year after the surgery (T2) and three years after the surgery (T3) with the NewTom 3G scanner (Aperio Services, Sarasota, FL). The imaging protocol involved a 36-second head exposure for a FOV corresponding to a 12 inch field of view. The patients maintained centric occlusion during the scan by biting on a wax bite. A trained radiology technician supervised the procedure.

The segmentation of the images of the anatomical structures of interest and the 3D model construction were performed using the ITK-SNAP open-source software (www.itksnap.org).[16] The 3D models were constructed from CBCT images with a voxel dimension of 0.5 × 0.5 × 0.5 mm. These virtual models included the cranial base, maxilla and mandible (right and left condyles, right and left rami, body and symphysis) (Figure 1). A fully automated registration method for the superimposition of the models was performed with the IMAGINE open-source software (http://www.ia.unc.edu/dev/download/imagine/index.htm) that compares two images using the intensity of the gray scale for each voxel on the cranial base because this structure is not altered by surgery.[8,17] The pre-surgical cranial base was used as a reference for superimposition of the one-year and three-year post-surgical images (Figure 2).

After the registration steps, all reoriented virtual models, originally saved in an open source image file format (.gipl format), were converted to a 3D interchange file format (.iv format). This allowed quantitative evaluation of the greatest surface displacement by the CMF application software (developed at the M.E. Müller Institute for Surgical Technology and Biomechanics, University of Bern, Switzerland, under the funding of the Co-Me network, http://co-me.ch).[18]

The CMF software calculates thousands of color-coded point-to-point comparisons (surface distances in mm) between pre and 1-year post-surgery surface models (T1-T2), and between 1-year and 3-year post-surgery models (T2-T3, long-term surgical stability)(Figure 3), so that the difference between two surfaces at any location can be quantified.[8] For quantitative assessment of the changes between the 3D surface models, the isoline tool was used. It allows the user to define a surface-distance value that is expressed as a contour line (isoline) that corresponds to regions having a surface distance equal to or greater than the defined value. The isoline tool was used to quantitatively measure the greatest displacements between points in the 3D surface models (in millimeters) at 14 specific anatomical areas: the (right and left) posterior condylar surfaces, the (right and left) medial condylar poles, the (right and left) anterior condylar surfaces, the (right and left) lateral condylar poles, the (right and left) superior condylar surfaces, the (right and left) posterior ramus borders, the anterior surface of the chin and the inferior border of the chin (Table I). The condylar lateral and medial poles were defined as tangents to the condylar neck, and the superior surface was defined as the articular surface separating the anterior and posterior condylar surfaces. The chin surfaces were limited bilaterally by tangents to the long axis of the canines.

Between the overlaid structures, the color-coded maps and isolines indicated inward displacement as blue and a negative value and outward displacement as red and a positive value. (Figure 3). An absence of change (0mm) was indicated by green. Displacements in the same direction are shown in different colors depending on the anatomic region.[1] For example, displacements in an anterior direction are displayed as red positive values in the anterior surface of the chin and in the anterior surface of the condyles, but are displayed as blue negative values in the posterior surface of the ramus and condyles. Displacements in a posterior direction are displayed as blue negative values in the anterior surface of the chin and in the anterior surface of the condyles, but are displayed as red positive values in the posterior surface of the ramus and condyles. For the inferior border of the mandible, positive values represented an inferior displacement and negative values superior displacement. Due to the adaptive capacity of the condyles, red positive values represent displacement and/or bone apposition and blue negative values indicate displacement and/or bone resorption. Semitransparent overlays were also used for visualization of the location and direction of the skeletal displacements/bone remodeling, with one of the models in an opaque view superimposed onto another partially transparent view (Figures 6-9).

Statistical analysis

The reproducibility of the method was tested in 10 randomly selected superimpositions. The greatest displacement in each area was measured twice at 15-day intervals; the agreement between the repeated measures was assessed using intraclass correlation (ICC).

An analysis of covariance was performed for each anatomical area considering the presence of genioplasty, age at the time of surgery and gender as explanatory variables to estimate and test whether the average adjusted change from one to three years after surgery was 0. The level of significance was set at 0.05. The percentage of patients who exhibited positive or negative displacement greater than 2 mm at each region was calculated.

RESULTS

The agreement between the repeated measurements using the isoline tool was excellent, with ICCs above 0.99 in all of the anatomical areas of interest measurements.

Two-thirds of the subjects were female (67%). Forty percent of the subjects also had a genioplasty. The follow-up in years for Time 2 was 1.1 ± 0.2 and for Time 3 was 3.4 ± 0.4. The average changes from presurgery to 1 year postsurgery were smallest on the posterior border of the ramus and on the medial poles of the condyle. As expected, the average displacement was the largest for the chin (Table I). On average, smaller than .5mm changes between 1 and 3 year post-surgery occurred in almost all anatomic regions, and average changes in overbite was −0.1 ± 0.8mm and overjet was −0.5 ± 0.9mm. The largest average changes occurred on the anterior and inferior surface of the chin (Table I) even after adjusting for the presence of a genioplasty, age at the time of surgery, and gender (Table II). The small adjusted mean alterations observed in 13 out of the 14 areas of interest were not statistically different from zero. The inferior border of the mandible was the only area that had a statistically significant average change. The 1.11mm average change indicated an inferior displacement of the chin.

Virtually all patients had more than 2mm of anterior movement of the chin at 1 year postsurgery. Approximately 40% had more than 4mm anterior displacement of the anterior surface of the chin (Figure 4).

The greatest long-term displacements and/or bone remodeling in the condylar areas occurred at the anterior surfaces (21% of the cases on the left side and 13% on the right side), superior surfaces (8% on both sides) and the lateral condylar poles (17% of the cases on the left side and 4% on the right side, Figure 5).

Regarding changes in the chin area between 1 and 3 years post-surgery, 17% of the cases presented inferior displacement and 17% of the cases presented posterior displacement between 2 and 4 mm. Overbite changes greater than 1mm were noted for 17% of the cases and overjet changes greater than 1.5mm were noted for 17% of the cases. The posterior border of the ramus exhibited symmetric 4% displacement on both sides, with lateral or rotational long-term adaptation of the ramus (Figure 5).

DISCUSSION

A series of studies published since the 1990s based on the data of the Dentofacial Program of the University of North Carolina[5-6,12-13,19-20] categorized the stability of orthognathic surgical procedures for different dentofacial disharmonies, utilizing 2D superimpositions or cephalometric measurements at different time points. Those studies provided parameters for orthodontists and oral-maxillofacial surgeons for decision-making in the treatment of skeletal malocclusions involving the maxilla and mandible. Proffit et al,[20] in 2007, updated the hierarchy of orthognathic surgery stability with follow-up to five years after surgery and stressed the importance of the long-term assessment of surgical orthodontic procedures. The present study quantified the 3D surgical displacements and bone remodeling following mandibular advancement between one and three years after surgery.

A fully automated voxel-wise registration of the cranial base 3D superimposition has recently been applied to assess the stability of dental, skeletal and soft tissue alterations one year after jaw surgery. [1,7-12,17] The work of Carvalho et al[10] and Motta et al[1] cannot be directly compared to the present study, because 1/3 of the sample at 1 year follow up did not return for the long term assessments, and other patients have been recruited and added to the sample. The 3D image analysis methods in the present study have also focused on additional anatomic regions of interest to better evaluate local bone remodeling changes in the condylar surfaces and the inferior border of the mandible.

In these short-term studies[1,10] the chin position varied between splint removal and 1 year post-surgery. Recorded changes indicated forward movement by 2 mm or more in five cases (19%) and relapsed (displacement ≤ −2 mm) in seven cases (26%). In addition, the posterior border of the ramus exhibited 2 mm or more posterior displacement in six rami and anterior displacement in two (n=54). In the present study, 4 patients (17% of the cases) had ≥ 2mm downward rotation of the inferior border of the mandible and posterior displacement of the anterior surface of the chin, with partial relapse of the amount of mandibular advancement from 1 to 3 years after surgery. Overbite changes for these patients were >1mm and overjet changes were >1.5mm, as partial dental compensation occurred to the observed skeletal changes. Only 1 patient (4%) presented ≥2mm bilateral posterior rotation of the ramus during this time interval.

Carvalho et al.[10] reported that, between the immediate post-surgical period and the 1 year follow up for 27 patients treated with mandibular advancement (54 condyles), 3 condyles exhibited ≥2 mm anterior-inferior displacement and 6 condyles had posterior-superior displacement. The present study has shown that small condylar changes continue to occur beyond the first year post-surgery with variable direction of changes: between 1 and 3 years post-surgery follow-up of 24 patients (48 condyles), 4 condyles presented ≥ 2mm changes indicative of anterior displacements and/or bone apposition and 4 condyles had ≤−2mm indicative of posterior displacements and/or bone resorption in the anterior surface of the condyle. Four condyles also presented ≥ 2mm superior displacement as shown in the patient in Figures 7 and 9, and 4 condyles presented ≥ 2mm lateral displacements and/or bone apposition in the lateral poles, leading to changes in condylar torque relative to the ramus.

In summary, the results of the present study indicate that, over the three-year-period, mandibular advancement surgery was, on average, stable, which corroborates previous studies' findings.[5-6, 20-22] However, ≥2 mm downward and backward rotation of the chin, as well as condylar displacement and/or remodeling adaptive changes were observed in 17% of the patients. Previous studies[23-28] have questioned whether condylar displacements or remodeling after orthognathic surgery might cause temporomandibular disorders (TMD) or relapse-related displacements. Draenert et al.[29] emphasized that, although the condylar position might change after surgery, the treatment results do not alter the clinical characteristics of the temporomandibular joints although symptoms might worsen in patients already exhibiting TMD before surgery.

The 3D analysis of CBCTs in this study gives additional information regarding bone remodeling and positional changes following mandibular advancement compared to traditional cephalometric methods. In this study, to measure distances between the bone surfaces at 2 time points, the closest surface point method was used. Current open source and commercially available software (such as Geomagic Studio, Geomagic U.S. Corp, Research Triangle Park, NC, and Vultus, 3dMD, Atlanta, GA) calculate the closest points between 2 surfaces that were displaced with treatment. Quantification of surface distances by using closest points requires careful interpretation and comparisons with the semi-transparent overlays to determine areas of bone remodeling versus displacement (Figures 8 and 9), since closest point distances do not quantify vectorial magnitudes of 3D displacements and the closest points might not be homologous in both surfaces. For this reason, when changes over time are of interest, quantification with isolines provides absolute positive or negative values of displacements and aids assessment of the direction of displacement.

CONCLUSION

The present study indicates that from one to three years after surgery approximately one out of six patients who have mandibular advancement surgery will experience clinical changes (2 to 4mm) in the horizontal and vertical chin position. On average, small changes will occur in condylar position and adaptive bone remodeling.

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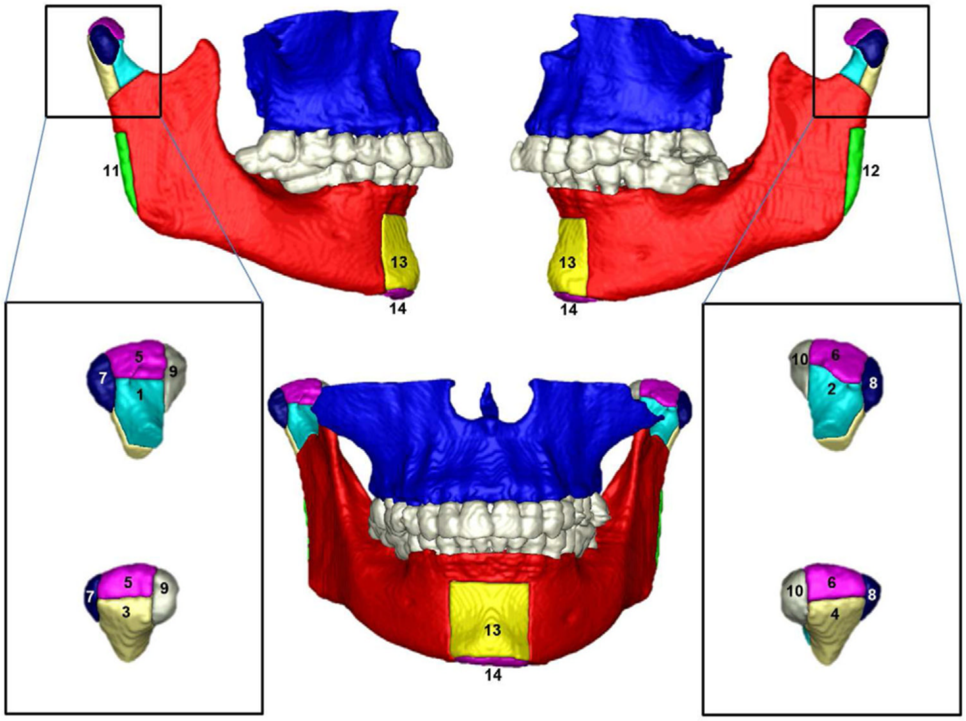

Figure 1.
Anatomic regions of interest: 1, right condyle anterior surface; 2, left condyle anterior surface; 3, right condyle posterior surface; 4, left condyle posterior surface; 5, right condyle superior surface; 6, left condyle superior surface; 7, right condyle lateral pole; 8, left condyle lateral pole; 9, right condyle medial pole; 10, left condyle medial pole; 11, right posterior border ramus; 12, left posterior border ramus; 13, anterior surface of the chin; and 14, inferior border of the mandible.

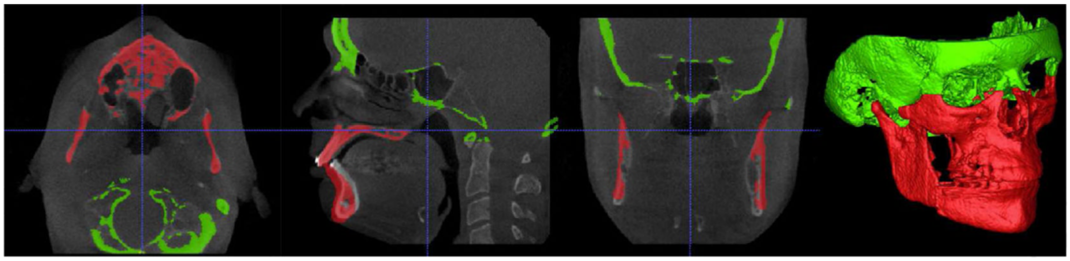

Figure 2.
Example of the result of the superimposition on the cranial base where the pre-surgery grey level image and the surface model 1 year post-surgery are shown. Note the registration in the cranial base in the 3 planes of space as indicated by green.

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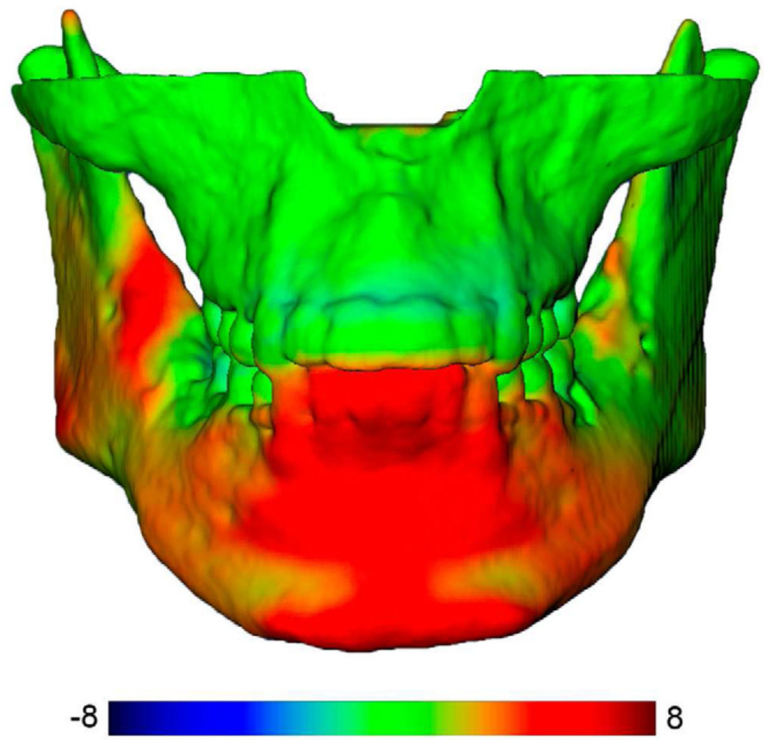

Figure 3.
Color-coded map of the surface distances between pre surgery and 1 year after mandibular advancement surgery. The virtual surface models were registered at the cranial base. Red represents the anterior displacement of the chin and inferior displacement of the inferior border of the mandible (color-code scale of −8 to +8 mm); green represents anatomic regions that did not present changes with treatment.

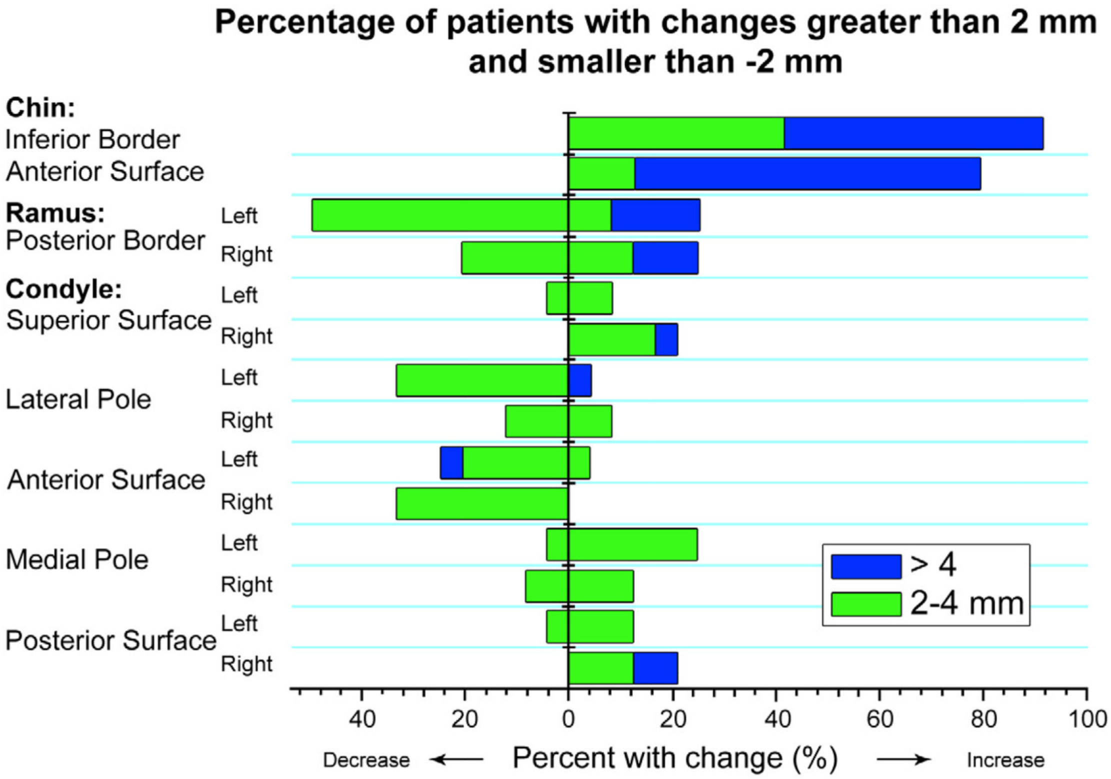

Figure 4.

Percentage of patients with changes greater than 2mm or less than −2mm for each of the anatomic regions of interest from presurgery to 1 year postsurgery. Patients with displacements between –2 and 2 mm are not represented. Note that positive or negative values of displacements represent different directional movements depending on the specific region of interest. Increase = anterior displacement for anterior surface of the chin and anterior surface of the condyles but posterior direction for posterior surface of the ramus and condyles; inferior displacement of the inferior border of the chin. Decrease = anterior displacement of posterior surface of the ramus and condyles; posterior direction in anterior surface of the chin and anterior surface of the condyles; superior displacement of the inferior border of the mandible.

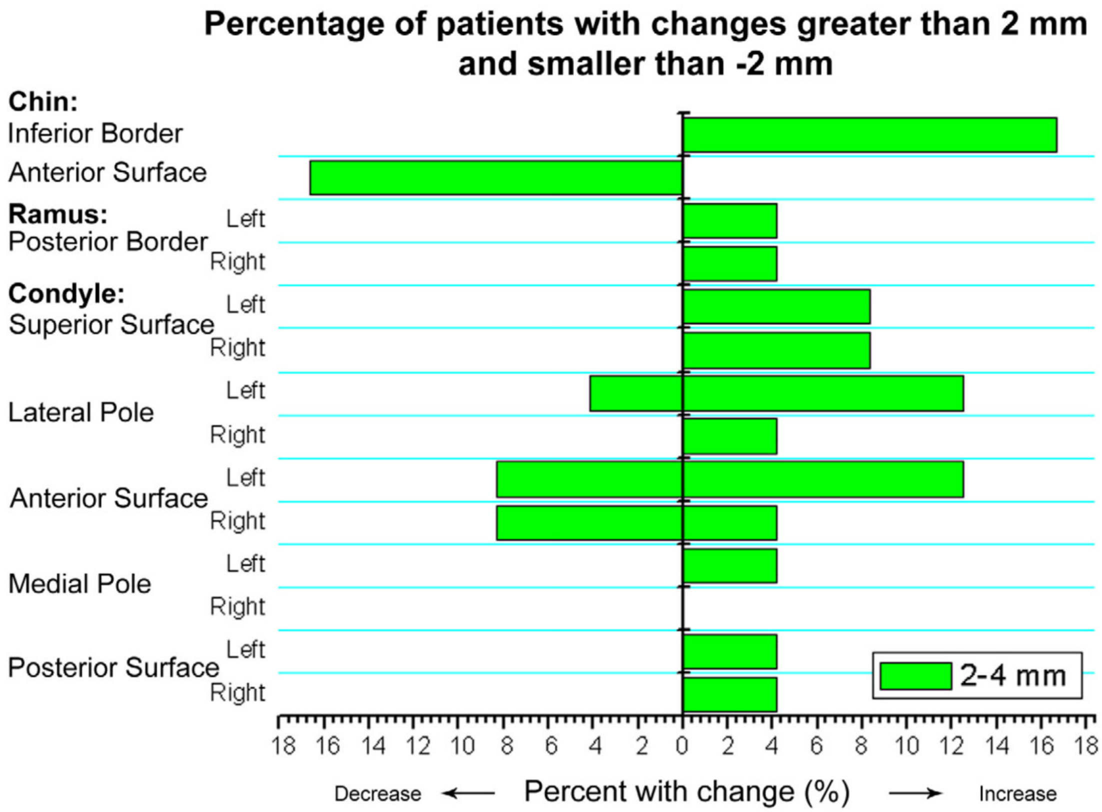

Figure 5.

Percentage of patients with changes greater than 2mm or less than −2mm between 1-year and 3-year follow-up. Patients with displacements between –2 and 2 mm are not represented. Note that positive or negative values of displacements represent different directional movements depending on the specific region of interest. Increase = anterior displacement for anterior surface of the chin and anterior surface of the condyles but posterior direction for posterior surface of the ramus and condyles; inferior displacement of the inferior border of the chin. Decrease = anterior displacement of posterior surface of the ramus and condyles; posterior direction in anterior surface of the chin and anterior surface of the condyles; superior displacement of the inferior border of the mandible.

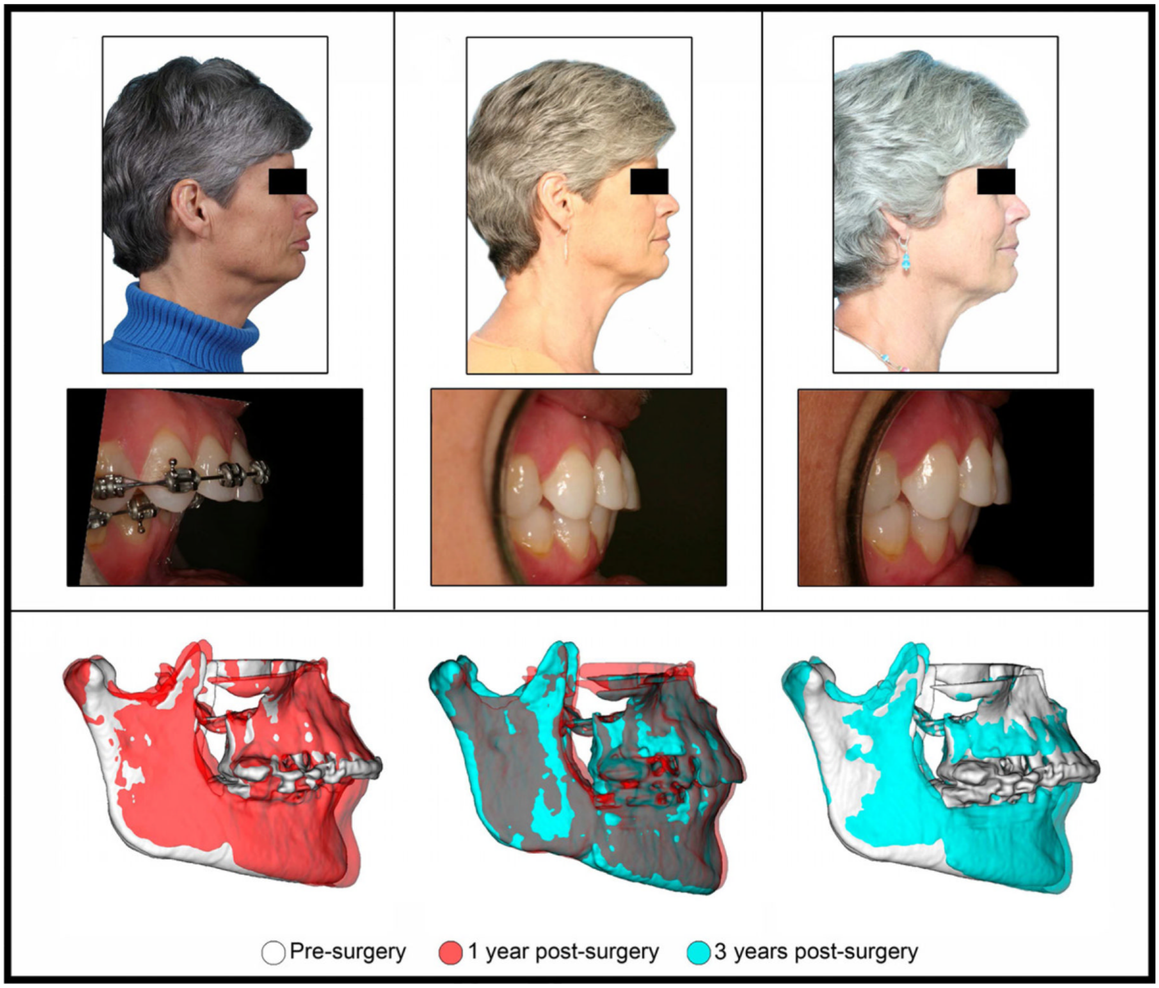

Figure 6.
Facial profile and intra-oral photos of patient who showed stability of the mandibular advancement when we compared pre-surgery, 1 year post-surgery and 3 years post-surgery 3D models. The bottom row shows lateral views of the semitransparency superimpositions. Note that small changes in chin position were observed between 1 and 3 years post-surgery, and the condylar position and morphology remained stable.

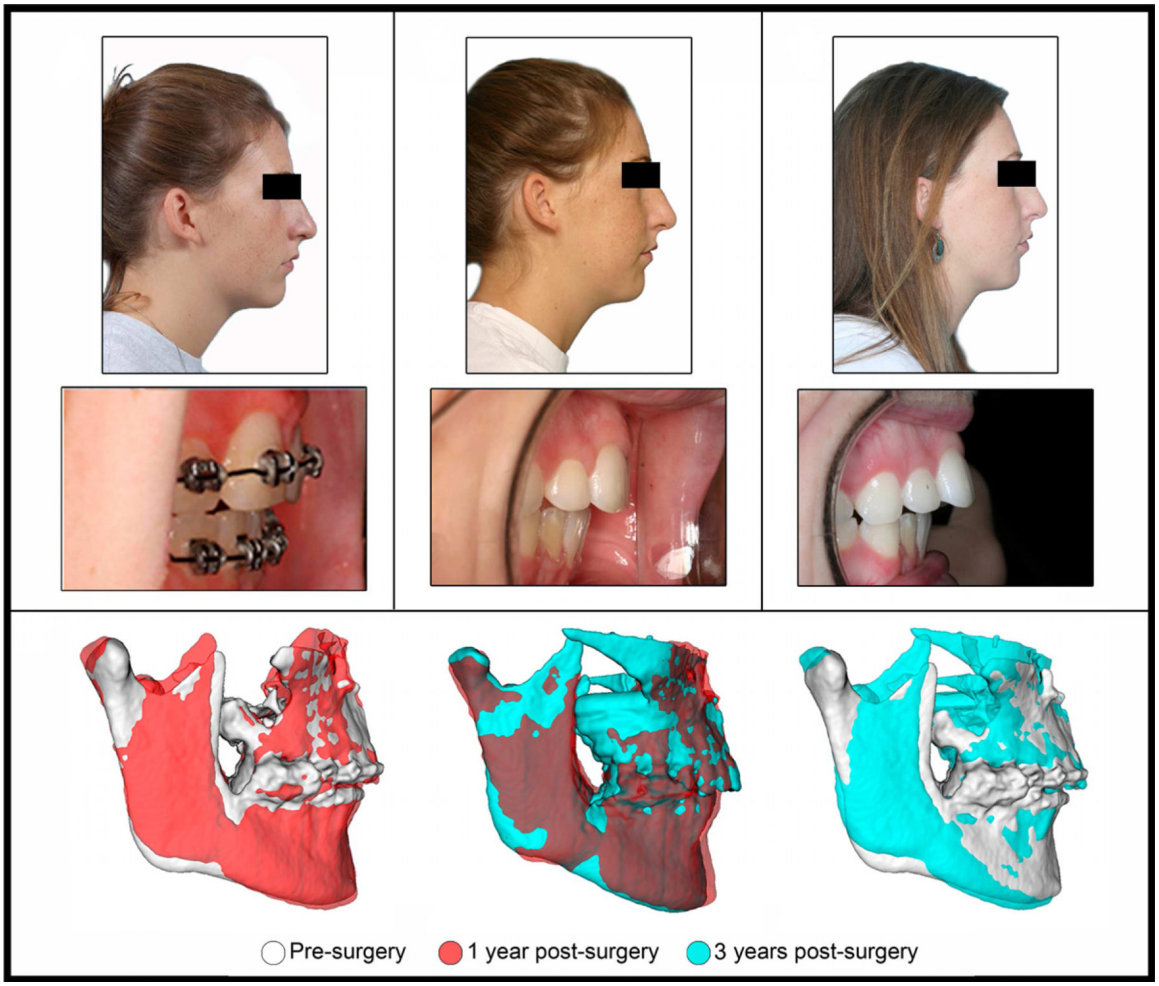

Figure 7.

Facial profile and intra-oral photos of patient who showed stability of the mandibular advancement when we compared pre-surgery, 1 year post-surgery and 3 years post-surgery. The bottom row shows lateral views of the skeletal semitransparency superimpositions of same patient. Note that at 1 year post-surgery the chin advancement had returned to its original position. Between 1 year and 3 years post-surgery the downward and backward displacement of the mandible progressed, compromising the surgical outcome.

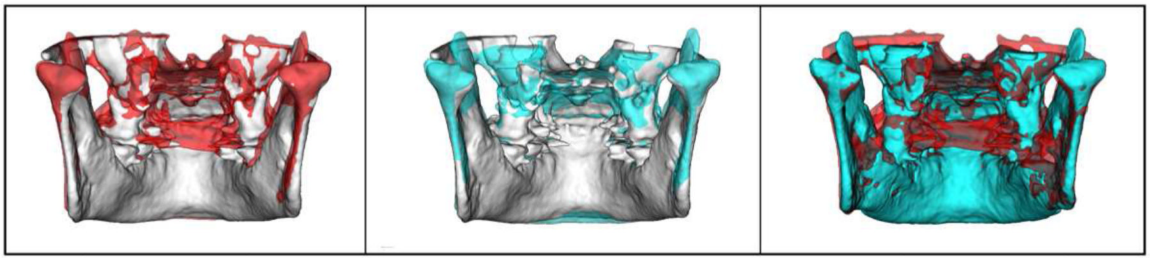

Figure 8.

Posterior view of semi-transparent superimpositions of patient in Fig. 6. Overlays of pre-surgery (white), 1 year post-surgery (red) and 3 years post-surgery (blue) surface models are shown. Note the stability of condylar position and morphology in the long-term follow up.

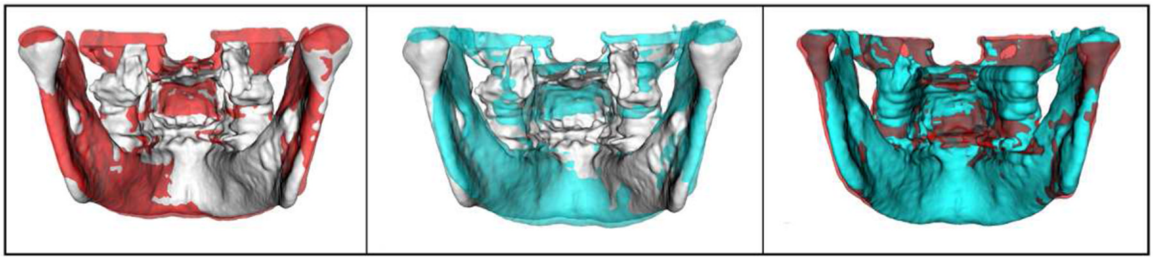

Figure 9.

Posterior view of semi-transparent superimpositions of patient in Fig. 7. Overlay of pre-surgery (white) and 1 year post-surgery (red) surface models shows superior displacement and bone remodeling of the condyles. Overlay of pre-surgery (white) and 3 years post-surgery (blue) surface models shows superior displacement and further bone remodeling of the condyles. Overlay of 1 year post-surgery (red) and 3 years post-surgery (blue) surface models shows the progression of bone remodeling in the condyles.

Table 1

Descriptive statistics for the greatest displacement/and or bone remodeling at each anatomic region from presurgery to 1 year postsurgery and 1 year to 3 years postsurgery.

Region	Presurgery to 1 Year postsurgery Mean +− SD (mm)	1 Year to 3 Year postsurgery Mean +− SD (mm)
Ramus		
Rt Posterior Border Ramus	−0.32 +− 2.56	0.39 +− 1.16
Lf Posterior Border Ramus	−0.44 +− 3.02	0.18 +− 1.32
Chin		
Horizontal (anterior surface)	5.48 +− 3.53	−0.63 +− 1.33
Vertical (inferior surface)	5.53 +− 3.49	1.16 +− 1.03
Condyle		
Rt Posterior Surface	1.27 +− 1.75	0.29 +− 0.99
Lf Posterior Surface	0.72 +− 1.28	0.15 +− 1.14
Rt Medial Pole	0.17 +− 1.63	−0.26 +− 0.91
Lf Medial Pole	0.42 +− 1.50	−0.11 +− 1.15
Rt Anterior Surface	−1.50 +− 1.04	−0.46 +− 1.27
Lf Anterior Surface	−1.43 +− 1.61	−0.34 +− 1.50
Rt Lateral Pole	−0.61 +− 1.66	0.19 +− 1.02
Lf Lateral Pole	−0.91 +− 1.80	0.26 +− 1.18
Rt Superior surface	0.95 +− 1.72	0.39 +− 1.26
Lf Superior Surface	0.48 +− 1.26	0.33 +− 1.14

Table 2

Adjusted mean change from 1 to 3 years post-surgery

Region	adjusted mean +− SE (mm)	P value
Ramus		
Rt Posterior Border Ramus	0.38 +− 0.31	0.23
Lf Posterior Border Ramus	0.12 +− 0.34	0.72
Chin		
Horizontal (Anterior Surface)	−0.42 +− 0.32	0.20
Vertical (Inferior surface)	1.11 +− 0.22	<.0001
Condyle		
Rt Posterior Surface	0.19 +− 0.26	0.47
Lf Posterior Surface	0.02 +− 0.28	0.95
Rt Medial Pole	−0.19 +− 0.21	0.38
Lf Medial Pole	−0.07 +− 0.30	0.81
Rt Anterior Surface	−0.32 +− 0.33	0.34
Lf Anterior Surface	−0.27 +− 0.33	0.43
Rt Lateral Pole	0.29 +− 0.25	0.27
Lf Lateral Pole	0.34 +− 0.30	0.26
Rt Superior surface	0.12 +− 0.29	0.70
Lf Superior Surface	0.19 +− 0.30	0.54