Maxillo-mandibular counter-clockwise rotation and mandibular advancement with TMJ Concepts® total joint prostheses

Part I - Skeletal and dental stability

Abstract. The purpose of this study was to evaluate skeletal and dental stability in patients who had temporomandibular joint (TMJ) reconstruction and mandibular counterclockwise advancement using TMJ Concepts total joint prostheses (TMJ Concepts Inc. Ventura, CA) with maxillary osteotomies being performed at the same operation. All patients were operated at Baylor University Medical Center, Dallas TX, USA, by one surgeon (Wolford). Forty-seven females were studied; the average post-surgical follow-up was 46.8 months. Lateral cephalograms were analyzed to estimate surgical and post-surgical changes. During surgery, the occlusal plane angle decreased 14.9° ± 8.0°. The maxilla moved forward and upward. The posterior nasal spine moved downward and forward. The mandible advanced 7.9 ± 3.5 mm at the lower incisor tips, 12.4 ± 5.4 mm at Point B, 17.3 ± 7.0 mm at menton, 18.4 ± 8.5 mm at pogonion, and 11.0 ± 5.3 mm at gonion. Vertically, the lower incisors moved upward −2.9 ± 4.0 mm. At the longest follow-up post surgery, the maxilla showed minor horizontal changes.
Temporal mandibular joint (TMJ) pathology can create clinical problems in the masticatory musculature, jaws, occlusion and other associated structures resulting in pain and jaw dysfunction. Many cases of TMJ dysfunction and symptoms can be managed with non-surgical therapies, but patients with irreversible TMJ damage, require surgical repair or reconstruction; traditionally with autogenous tissues. The use of autogenous grafts can lead to adverse outcomes in some TMJ conditions and pathology. These conditions include: multiply operated TMJs (2 or more previous operations); previous TMJ alloplastic implants containing Proplast/Teflon (PT; Vitek Inc., Houston, TX), Silastic (Dow Corning Inc, Midland, MO), acrylic, bone cements, metal-on-metal articulations or failed prostheses; inflammatory, infective, reactive or resorptive TMJ pathologies; connective tissue and autoimmune diseases; fibrous and bony ankylosis; absence of TMJ structures from pathology, trauma or congenital deformity; and tumors involving the fossa and/or condyle and mandibular ramus region. In these cases a custom-made total joint prostheses may be the best option. Using CAD/CAM (computer assisted design/computer assisted manufacture) technology, prostheses are designed and manufactured to fit the specific anatomical requirements for each patient.

TMJ pathology can affect patients of any age and both genders but, when these conditions occur in young patients, maxillo-mandibular growth alterations commonly occur resulting in dentofacial deformities and associated maloclusions. In adults, TMJ pathology (i.e. rheumatoid arthritis, psoriatic arthritis, reactive arthritis, condylar fractures) can cause dentofacial deformities. Degenerative pathological processes of the condyles may require TMJ reconstruction and orthognathic surgery to achieve optimal functional and esthetic results.

Surgical correction of co-existing TMJ pathology should be considered as part of the orthognathic surgical correction plan. WOLFORD et al., routinely perform concomitant TMJ and orthognathic surgery for correction in patients with co-existing dentofacial deformities and TMJ internal derangement, with a high success rate. Success rates for TMJ prostheses range from 60% to 100%. Risks and complications are associated with the use of TMJ total joint prostheses. A common problem in patients with previous PT and Silastic implants as well as bone cements, acrylic or metal-on-metal articulations, is the recurrent development of foreign body giant-cell reaction (FBGCR) and reactive bone that can cause limited jaw function as well as pain, fibrous and/or bony ankylosis. When reconstructing these patients with the TMJ Concepts total joint prostheses, packing autologous fat grafts around the articulating area of the prostheses decreases the FBGCR and minimizes excessive joint fibrosis and heterotopic calcification, consequently providing an improved range of motion in prosthetic TMJ reconstruction and decreased pain.

Many factors influence the success of total joint prostheses, such as biocompatibility and functionally compatible materials. The challenge is to minimize damaging factors such as metal hypersensitivity, prosthesis micro movement, loosening of the prosthetic components, material wear, break-down, and corrosion, prosthesis failure, bacterial contamination, and development of heterotopic/reactive bone around the prostheses.

It is considered a surgical success at long-term follow-up when the total joint prostheses provide TMJ and occlusal stability, improve function, decrease pain and have a long functional lifetime. Previous studies have shown that TMJ reconstruction with total joint prostheses resulted in a significant decrease in pain, and improvement in jaw function, diet and maximal interincisal opening. The present study evaluates the skeletal and dental stability of TMJ reconstruction and mandibular advancement in a counter-clockwise direction using TMJ total joint prostheses with maxillary osteotomies being performed at the same operation.

**Patients and Methods**

This retrospective study evaluated records of 50 consecutive patients from a single private practice, from 1990 through 2003, who underwent TMJ reconstruction and counter-clockwise rotation of the maxillo-mandibular complex. Criteria for study inclusion were: end-stage bilateral or unilateral TMJ reconstruction and mandibular advancement using custom-made TMJ total joint prostheses (TMJ Concepts system), and maxillary osteotomies for counter-clockwise rotation of the maxillo-mandibular complex and occlusal plane angle; all surgical procedures were performed by one surgeon (Wolford) at Baylor University Medical Center, Dallas, TX, USA; use of maxillary and mandibular rigid fixation; females at least 14 years of age and males at least 17 years of age; absence of post-surgical trauma; and minimum of 12-month post-surgery follow-up. Patients were rejected based on the following criteria: craniofacial syndromes; and records (radiographs) inadequate or poor quality. 49 patients (47 females, 2 males) met the criteria; one female patient was excluded because follow-up was less than 12 months. The two males were excluded from the study to make a homogeneous sample of 47 females (Table 1).

The custom-made total joint prostheses used in this study, were originally developed in 1989 by Techmedica Inc., Camarillo, CA, USA, and since 1997, have been manufactured by TMJ Concepts, Inc., Ventura, CA, USA. These prostheses are CAD/CAM devices, designed to fit the specific anatomical requirements for each patient.

43 patients had bilateral TMJ reconstruction and 4 patients had a unilateral prosthesis with a sagittal split osteotomy on the contralateral side. All patients had Le Fort I maxillary osteotomies, most with segmentation. All patients had coronoidectomies on the prosthesis side(s) at the reconstruction surgery or at a previous surgery. Mean patient age at the time of surgery was 34.5 years (range 14–57 years). Presurgical (T1) records were taken 1 day (range 1–6 days) before surgery; immediate post-surgical (T2) records were taken 5 days (range 2–16 days) after surgery; and longest follow-up (T3) records were taken at a mean of
40.6 months (range 12–143 months) after surgery.

**Imaging evaluation**

Two examiners were calibrated by repetition of the process until the method was considered adequate by a third examiner. Standardized lateral cephalometric radiographs (Quint Sectograph; American Dental Co, Hawthorne, CA) were randomly traced and digitized twice by one of the investigators approximately 1 week apart. Average values between the 2 replicates were used to decrease landmark technical errors.

16 landmarks were identified by one examiner and digitized using DFPlus software (Dentofacial Software Inc, Toronto, Canada). The following landmarks were used to compute 25 measurements (Table 2, Fig. 1): nasion, sella, Point A, anterior nasal spine, posterior nasal spine, Point B, pogonion, menton, gonion, and dental points. S–N minus 7 \( \frac{8}{9} \) was used as the horizontal reference plane (HRP) and a line perpendicular through sella as the vertical reference plane (VRP). Horizontal and vertical changes for each landmark were evaluated. Surgical changes were
computed as the differences between T2 and T1 values and post-surgical changes between T3 and T2 values.

**Null hypothesis**

Mandibular advancement with counter-clockwise rotation of the occlusal plane with total joint TMJ prostheses is an unstable procedure.

**Statistical method**

All data were transferred to SPSS (release 9.0; SPSS Chicago, IL) for statistical analysis. The skewness and kurtosis statistics showed normal distributions for all variables. Paired t-tests were performed to evaluate the surgical (T2–T1) and post-surgical changes (T3–T2). A significance level of \( p < 0.05 \) was applied. The reliability of tracing, landmark identification and analytical measurements had an intra-class correlation coefficient greater than 0.94.

Patients who received bilateral (n = 43) and unilateral (n = 4) TMJ prostheses were compared as separate groups. There were no statistically significant differences between those groups in post-surgical changes, therefore all the patients were analyzed as a single group. Patients were divided into two groups, with group 1 having 12–24 months post-surgical follow-up (n = 18) and group 2 having 25–143 months follow-up (n = 29). There were no statistically significant differences in any of the parameters evaluated between the two groups, so all 47 patients were analyzed as a single group.

**Surgical Technique**

Seven patients required a preliminary surgical stage to remove previously placed, failed total joint prostheses that contained metal (i.e. Vitek total joint prostheses, Vitek Inc., Houston, TX; Christensen total joint prostheses, TMJ Implants Inc., Golden, CO), so that an accurate CT scan could be taken. Metal in the TMJ and/or ramus can interfere with the imaging data, and significantly distort the 3-dimensional (3D) plastic model on which the custom-made total joint prostheses are made. CT scans were taken on all patients extending from supero-posterior to the TMJ to anterior to the chin, maxilla and nasal bones. The 3-D plastic model was then created using stereolithography technology (Fig. 2A). A surgical prediction tracing was developed from a presurgical lateral cephalometric radiograph to determine the desired final position of the maxilla and mandible. The 3D model was mounted on an anatomical articulator and precise model surgery performed to reposition the mandible to the desired post-surgical position relative to the maxilla that remained in its original position on the model. Once the mandibular position was achieved, the mandible was secured to the maxilla by placing quick-cure acrylic inter-occlusally to lock-in the position of the mandible. The condyles were cut off and if indicated, bony recontouring of the fosse and lateral aspect of the rami was completed. Any recontouring on the 3D model had to be duplicated accurately on the patient at the time of surgery.

The custom-made total joint prostheses were then manufactured using CAD/CAM technology.
technology on the 3D model to fit the patient’s specific anatomical requirements (Fig. 2B). Immediately prior to surgery, the mandibular movements done on the 3D model were duplicated accurately on anatomically mounted dental models, and an intermediate splint constructed to aid in repositioning the mandible. The maxillary model was then repositioned and sectioned, if necessary, to achieve the best occlusal relationship. A final splint was constructed when indicated.

At surgery, an endaural or preauricular approach was used to perform the condylectomy, joint debridement, coronoidectomy to release the temporalis muscle, and if indicated, accurate bony recontouring of the fossa as dictated by the recontouring done on the 3D model. Through a submandibular approach, the masseter and medial pterygoid muscles were reflected off the mandibular ramus and lateral recontouring completed as indicated from the 3D model. The mandible was then mobilized and repositioned using the intermediate splint and inter-maxillary fixation applied. The fossa component was inserted through the endaural / preauricular incision and stabilized to the zygomatic arch with 3–4, 2 mm diameter bone screws. The mandibular prosthetic component was inserted through the submandibular incision and stabilized to the ramus with 8–12, 2 mm diameter bone screws. Following stabilization of the prostheses, most patients had fat grafts (usually harvested from the abdomen) packed around the articulating area of the prostheses to help prevent fibrosis and heterotopic/reactive bone formation post-surgery. The incisions were closed.

Multiple maxillary osteotomies were performed to establish the best possible functional and esthetic result, since pre-surgery the maxilla was usually AP retruded as well as having anterior vertical maxillary excess and/or posterior vertical maxillary deficiency with a high occlusal plane angulation. The maxilla was stabilized with bone plates and porous block hydroxyapatite grafts (PBHA, Interpore 200, Interpore Inc., Irvine, CA).

When indicated, genioplasty, turbinectomies, nasoseptoplasty or rhinoplasty were performed at the same surgery. Many of the patients, particularly those with significant retroglossia, had moderate to severe presurgical symptoms of sleep apnea because of the decreased oropharyngeal airway. The suprapharyngeal muscles were not deliberately detached from the genial tubercles in any of the cases. Alloplastic materials such as PBHA or hard tissue replacement (HTR; Walter Lorenz Inc, Jacksonville, FL) were used for augmentation genioplasties, although some patients had osseous genioplasties.

Post-surgery, no maxillo-mandibular fixation was used in any cases, but light interarch elastics were applied routinely to help support the mandible, since the muscles of mastication were reflected from the mandible and were initially non-functional. Postoperative elastics were generally discontinued following adequate functional return of the pterygomasseteric musculature (usually 2–4 weeks post-surgery), unless required for finishing orthodontic mechanics. Passive physical therapy was used on all patients beginning approximately 6–8 weeks post-surgery. Patients were instructed to open and close their jaws and begin shifting their jaws from side to side for 4–5 sessions per day for 10–15 minutes each session. Patients were maintained on a puree to soft diet for 4 months post-surgery to allow the maxilla to complete the initial bone-healing phase. Patients were then encouraged to begin working up to a normal diet. Orthodontic appliances were usually maintained for at least 6 months post-surgery and then removed at the discretion of the orthodontist.

Results

Surgical changes (T2–T1)

Initial values, surgical and longest follow-up changes are listed in Table 3. The mean surgical changes showed upward and forward movement of the maxillary anterior region (Fig. 3). The horizontal movement of anterior nasal spine (ANS) was 1.3 mm. (range –7.3–7.1 mm), and point A was 2.5 mm (range –6.0–6.8 mm). In the horizontal direction, positive values indicate forward movement, negative values indicate posterior movement. The vertical movement (positive values indicate downward movement, negative values indicate upward movement) of the ANS was –0.6 mm (range –4.0–3.4 mm) and point A was –1.0 mm (range –4.2–3.3 mm). The posterior nasal spine (PNS) was displaced downward by 5.5 mm (range 1.8–14.3 mm) and forward by 2.9 mm (range –3.9–10.9 mm). The upper incisor tip (UIT) moved forward 5.6 mm (range –0.6–1.3 mm) and vertically –1.3 mm (range –5.7–2.6 mm).

All the anterior mandibular measurements were advanced in a horizontal direction with lower incisor tip (LIT) 7.9 mm (range 0.9–14.3 mm), point B 12.4 mm (range 1.7–22.5 mm), pogonion (Pog) 18.4 mm (range 2.1–42.1 mm), and menton (Me) 17.3 mm (range 2.6–32.8 mm). In the vertical direction, LIT showed a superior movement of –2.9 mm (range –16.5–2.3 mm). Minimal vertical change was seen at Point B with –0.1 mm (range –8.4–5.8 mm) and Pog showed no movement. Me showed an inferior movement of 2.6 mm (range –6.7–12.5 mm). Gonion (Go) moved downward 18.4 mm (range –1.5–43.4 mm) and forward 11.0 mm (range 2.8–25.6 mm). The occlusal plane angle (OPA) relative to HRP decreased by a mean –14.9° (range –37.0 to –2.3°) and the SNA-Pog angle increased 9.1° (range 1.0–20.1°).

There was a surgical increase in the SNA angle of 2.3° (range –6.5–6.4°) and in that of SNB of 6.9° (range 1.0–
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Table 3. Initial values (T1), surgical changes (T2–T1) and post-surgical changes (T3–T2) (n = 47).

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1</th>
<th>T2–T1</th>
<th>T3–T2</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<td>Horizontal (mm)</td>
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<td></td>
<td></td>
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<tr>
<td>ANS</td>
<td>65.7</td>
<td>4.7</td>
<td>1.3</td>
</tr>
<tr>
<td>PNS</td>
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<td>4.3</td>
<td>2.9</td>
</tr>
<tr>
<td>A</td>
<td>67.5</td>
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<tr>
<td>B</td>
<td>52.0</td>
<td>8.3</td>
<td>12.4</td>
</tr>
<tr>
<td>Pog</td>
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<td>10.7</td>
<td>18.4</td>
</tr>
<tr>
<td>Me</td>
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<td>17.3</td>
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<tr>
<td>Go</td>
<td>−8.4</td>
<td>6.1</td>
<td>11.0</td>
</tr>
<tr>
<td>U1T</td>
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<td>6.3</td>
<td>5.6</td>
</tr>
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<td>L1T</td>
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<td>OJ</td>
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<td>Vertical (mm)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ANS</td>
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<td>3.3</td>
<td>−0.6</td>
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<tr>
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<td>5.5</td>
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<tr>
<td>A</td>
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<td>4.2</td>
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</tr>
<tr>
<td>B</td>
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</tr>
<tr>
<td>Pog</td>
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<tr>
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<td>2.6</td>
</tr>
<tr>
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<tr>
<td>U1T</td>
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<td>4.8</td>
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<tr>
<td>L1T</td>
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</tr>
<tr>
<td>OJ</td>
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<td>4.1</td>
<td>1.6</td>
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<tr>
<td>Angle (deg)</td>
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<tr>
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</tr>
<tr>
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<tr>
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<tr>
<td>OPA</td>
<td>25.1</td>
<td>8.2</td>
<td>−14.9</td>
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</table>

See Table 2 for an explanation of the abbreviations.
Horizontal vector: Positive values = forward movement; negative values = posterior movement.
Vertical vector: Positive values = downward movement; negative values = upward movement.
* $p < 0.05$.
** $p < 0.01$.

Fig. 3. Superimposition of pre- and post-surgical lateral cephalograms demonstrate the surgical changes achieved.
12.8°). The ANB angle decreased −4.6° (range −10.5–2.2°) because of the greater increase of the SNB value compared with SNA. Overjet (OJ) decreased −2.2 mm (range −7.4–1.8 mm). Overbite (OB) increased by 1.6 mm (range −14.7–3.9 mm).

Post surgical stability (T3–T2)
Point A and posterior nasal spine (PNS), in their horizontal direction only, showed a backward change of −0.4 mm (range −2.8–5.0 mm) and −0.8 mm (range −8.4–3.9 mm), respectively; they were considered statistically significant (p < 0.05). The remaining maxillary landmarks remained stable. All the anterior mandible measurements (L1T, B, Pog, Me) showed no statistically significant change at long-term follow-up (p < 0.05). Neither OPA nor SNPog angles had significant changes long-term post-surgery. All horizontal and vertical mandibular measurements remained stable during follow-up (Table 3).

Case 1 (CT patient no. 41)
This 27-year-old female presented 4 years after trauma that involved multiple mandibular fractures including bilateral subcondylar fractures, comminution of the right condyle, a symphysis fracture with loss of a central incisor, as well as fracture of the anterior maxilla resulting in the loss of 7 teeth from the left lateral incisor through the right second bicuspid. The missing teeth had been replaced with 5 osseo-integrated dental implants and a prosthesis. She had one previous surgery on her right TMJ with no improvement. Her diagnoses included: right TMJ severe arthritis; anterior open bite; transverse occlusal plane angle and transverse asymmetry. (C, D) The patient is seen 79 months post-surgery following right TMJ reconstruction and mandibular advancement with custom-made TMJ total joint prostheses, left mandibular ramus sagittal split for advancement, and maxillary osteotomies. (E, F) The patient was recently evaluated at 18 years post-surgery showing the maintenance of good facial balance.

Following orthodontic preparation, surgery was performed (Fig. 6B) in one operation including: right TMJ reconstruction and mandibular counter-clockwise advancement (right ramus was lengthened and advanced 26 mm) with a custom-made TMJ total joint prosthesis (Techmedica - TMJ Concepts system); right coronoidectomy; left mandibular ramus sagittal split osteotomy; and multiple maxillary osteotomies to down graft the posterior aspect, advance it, and transversely level the occlusal plane. The AP occlusal plane was decreased 16°. The patient’s longest follow-up at completion of the study was 79 months post-surgery showing good stability (Figs. 4C,D; 5D–F), with elimination of TMJ pain, headaches and myofascial pain; improved jaw function, occlusion and facial esthetics. The patient recently returned for a follow-up evaluation at 18 years post-surgery (Figs. 4E,F; 5G–I; 6C). She remains pain free with good jaw stability (Fig. 6D),

Fig. 4. Case 1 (CT, patient no. 41) (A, B) This 27-year-old female is seen 4 years after trauma with multiple mandibular fractures and loss of 7 maxillary teeth. She presents with right TMJ severe arthritis and pain. The mandible and maxilla are significantly retruded with a high occlusal plane angle and transverse asymmetry. (C, D) The patient is seen 79 months post-surgery following right TMJ reconstruction and mandibular advancement with custom-made TMJ total joint prostheses, left mandibular ramus sagittal split for advancement, and maxillary osteotomies. (E, F) The patient was recently evaluated at 18 years post-surgery showing the maintenance of good facial balance.
esthetics and function with an incisal opening of 42 mm.

Case 2 (TW, patient no. 47)

This 24-year-old female was referred after failed previous bilateral TMJ surgery, maxillary osteotomies and genioplasty (Figs. 7A,B; 8A–C; 9A). She reported problems with other joints and a rheumatology evaluation diagnosed a non-specific connective tissue/autoimmune disease. MRI showed severe condylar resorption and a reactive pannus surrounding the TMJ articular discs. Her surgical diagnoses included: severe bilateral condylar resorption and a reactive pannus surrounding the TMJ articular discs; maxillary AP and posterior vertical hypoplasia; severe AP mandibular hypoplasia; Class II occlusion with severe apertognathia (7 mm); decreased oropharyngeal airway (AP dimension 2 mm, where normal is 11 ± 2 mm) causing severe sleep apnea; severe masticatory dysfunction; and severe TMJ and myofascial pain.

The surgical procedures performed (Fig. 9B) included: bilateral TMJ reconstruction and mandibular advancement in a counter-clockwise direction utilizing the TMJ Concepts/Techmedica custom-made total joint prostheses with the rami lengthened 17 mm and the chin (pogonion) advanced 24 mm; bilateral coronoidectomies; multiple maxillary osteotomies with the maxillary incisor tips advanced 7 mm and the posterior maxilla inferiorly positioned 5 mm, stabilized with bone plates and PBHA grafts; and osseous chin augmentation (Fig. 9B). The mandibular occlusal plane was surgically decreased 19°. At 6 years post-surgery, the patient maintained a stable facial balance and occlusion (Figs. 7C,D; 8D–F; 9C,D). Incisal opening improved from 24 mm pre-surgery to 42 mm post-surgery. Pain levels decreased from 9 at T1 to 1 at T3. The sleep apnea was resolved, and the patient could eat relatively normally.

Discussion

TMJ reconstruction with total joint prostheses is indicated in specific TMJ conditions and pathology with irreversible joint damage. Some of those progressive TMJ disease conditions (i.e. rheumatoid arthritis, psoriatic arthritis, reactive arthritis, idiopathic condylar resorption, ankylosis, multiply operated joints) are predominantly found in females and can result in malocclusion, facial disfigurement, TMJ dysfunction, and pain7,9–15,23,29.

The demographic data from this study revealed that the need for maxillo-mandibular surgery with total joint TMJ prostheses reconstruction involves a relatively younger patient population (many under the age of 40 years, including teenagers), which means that the longevity of the prosthesis is an important variable. Longevity and stability of any implanted joint prosthesis is based on the proper indication for its use, correct placement and maintenance of the prosthesis, the properties and biocompatibility of the materials used, the recipient’s biological acceptance of the device, the implant’s stability in situ, and the ability of the recipient to understand the limitations involved with having a prosthesis in place. TMJ Concepts custom-made total joint prosthesis system was designed with these factors in mind9.

Previous studies have shown that TMJ reconstruction with this specific total joint prosthesis system resulted in a significant improvement in pain, function, diet and increase in maximum interincisal opening9–13,23,28,29. There are only a few studies on the stability of maxillo-mandibular surgery associated with total joint prostheses13,29. The present study evaluated this aspect of TMJ prostheses using the
TMJ Concepts custom-made total joint prostheses.

In this study, surgical changes showed upward and forward movement of the anterior region of the maxilla, while the posterior region was displaced downward and forward; thus the palatal plane angle also rotated in a counter-clockwise direction. The amount and direction of the surgical movement of the maxilla was directly related to the mandibular movement.

The post-surgical stability of upward maxillary repositioning by Le Fort I osteotomy is relatively stable\textsuperscript{3,17,18}. The stability of the surgical movement of the maxilla (in the vertical and horizontal planes) was stable with counter-clockwise rotation of the maxillo-mandibular complex in the presence of healthy TMJs\textsuperscript{4,22}.

In the present study, Point A showed a post-surgical mean change of $-0.4$ mm in the horizontal plane, and although clinically insignificant, it was statistically significant. This alteration can be explained in part by post-surgical bone remodeling or by post-surgical orthodontic movement. Point A is considered a dento-alveolar point, being subject to alteration of incisor position. With retraction of maxillary incisors, Point A can move posteriorly, and soft tissue tension created by maxillary advancement can cause remodeling of Point A. The PNS showed a clinically minimal post-surgical mean horizontal movement of $-0.8$ mm, which was statistically significant. This change can be associated with bone remodeling. Most of the cases studied received three pieces of maxillary segmentation with a midline split in the palate that could affect the posterior nasal spine anatomy with consequential bony remodeling.

In reference to the counter-clockwise rotation and advancement of the mandible, all of the anterior points of the mandible remained stable in the post-surgical long-term follow-up period. The mean mandibular advancement at the incisor tips was 7.9 mm, Point B was 12.4 mm, and the pogonion substantially greater with 18.4 mm, as a result of the counter-clockwise rotation of the maxillo-mandibular complex. The counter-clockwise rotation resulted in the pogonion advancing 6.0 mm more than Point B and 10.5 mm more than the lower incisor tips. This demonstrates the advantage of counter-clockwise rotation in advancing the mandible and chin in patients with a high

Fig. 6. Case 1 (A) The pretreatment cephalometric analysis shows a retruded maxilla and mandible, anterior open bite, steep occlusal and mandibular plane angles, vertical facial asymmetry and significant degenerative changes in the right condyle. (B) The STO (prediction tracing) demonstrates the TMJ and orthognathic procedures required to achieve a good functional and esthetic result including right TMJ reconstruction and mandibular advancement with custom-made TMJ total joint prostheses, left mandibular ramus sagittal osteotomy, right coronoidectomy, and maxillary osteotomies for counter-clockwise rotation and transverse leveling of the maxillo-mandibular complex. (C) Cephalometric analysis at 18 years post-surgery demonstrates good facial balance. (D) Superimposition of the immediate post-surgery (red lines) and 18 year follow-up (black lines) cephalometric tracings demonstrate the treatment stability achieved for this patient.
occlusal plane angle. Decrease in the occlusal plane and mandibular plane angles was correlated with the anterior movement of the mandible. These clinical results, confirm WOLFORD et al.’s22 previous supportive research and philosophy that maxillo-mandibular counter-clockwise rotation, in high occlusal plane facial types, may improve function and esthetics with a stable occlusion4,22.

In the vertical plane, the counter-clockwise rotation of the mandible resulted in an upward movement of the anterior points of the mandible except for menton. The mean menton surgical movement was in a downward direction as a result of geometrically up-righting the anterior aspect of the mandible (L1T to Me) causing the menton to rotate downward and forward compared with the lower incisor tips. Gonion showed a major downward surgical movement, due to reorientation of the mandibular ramus in that direction.

The long-term post-surgical mandibular stability in this study was found to be comparable with the results of CHEMELLO et al.4, with counter-clockwise rotation of the maxillo-mandibular complex and occlusal plane in patients with healthy TMJs. These results are significantly better than those found by other authors such as MOORE et al.14 and ARNETT and TAM-BORELLO1, in which mandibular surgical advancement (without counter-clockwise rotation) was performed on patients without regard to the presence or absence of TMJ pathology, nor was any appropriate TMJ surgical intervention provided for any of the patients with TMJ pathology in those studies. This allowed post-surgical relapse related to condylar remodeling and resorption to occur in some of their patients.

One of biggest changes with the surgery in the present study occurred in the occlusal plane angle. According to RICKETTS15, the normal occlusal plane angle is $8 \pm 4^\circ$ and is defined as: a line tangent to the occlusal plane. Decrease in the occlusal plane and mandibular plane angles was correlated with the anterior movement of the mandible. These clinical results, confirm WOLFORD et al.’s22 previous supportive research and philosophy that maxillo-mandibular counter-clockwise rotation, in high occlusal plane facial types, may improve function and esthetics with a stable occlusion4,22.

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lower bicuspids cusp tips through the second molar buccal groove and the angle formed with the Frankfort horizontal plane. In the present study, the T1 occlusal plane angle was a mean of 25.1° and was surgically decreased at T2 to a mean of 10.2° with a mean change of 14.9°. The alteration of this angle is significantly influential on the horizontal and vertical menton position. With a decrease in the occlusal plane angulation, there is an increase of the horizontal projection of the menton compared with the lower incisor tips. Counter-clockwise rotation of the maxillo-mandibular complex with mandibular advancement has inherent risks to the healthy as well as the TMJ with untreated pathology. The mandibular lever arm is lengthened so the soft tissues including skin, muscles and periostium are stretched, increasing the load to the TMJs. This can create or exacerbate TMJ problems.

Post-surgical increased loading of the joints occurs until the TMJs, soft tissues, muscles, skeletal structures and occlusion reach a state of equilibrium and adaptation to the new position, which could take several months. Although advancement of the maxillo-mandibular complex in a counter-clockwise direction may increase the loading of the TMJ by stretching the associated soft tissues, it is a very stable procedure in the presence of healthy TMJs. According to WOLFORD et al., patients with co-existing TMJ dysfunction undergoing mandibular advancement without surgical correction of the TMJ pathology, are likely to have significantly increased signs and symptoms of TMJ dysfunction and pain.

Several studies have noted that after surgery, the condyles tend to move posteriorly and superiorly in the fossa following mandibular advancement. VAN SICKELES et al. noted this phenomenon with wire osteosynthesis and rigid fixation from 8 weeks to 2 years after surgery. This posterior movement may be an adaptive response to mandibular advancement and change in the fulcrum arm length of the mandible, related to TMJ disc position change pre- and post-surgery, and/or soft tissue tension related to the advancement.

In this study, the joints were replaced by TMJ total joint prostheses (TMJ Concepts system), making it possible to get highly predictable functional, aesthetic and stable results, since the TMJ prostheses are not affected by muscle adaptation, disc position or physiological loading of the joints.

The Techmedica custom-made total joint prostheses (now manufactured by TMJ Concepts) were previously evaluated by Henry and WOLFORD, to determine the outcomes in patients with a history of PT TMJ implants. 26 patients (43 joints) were evaluated, with a follow-up of 4–24 months. The prosthesis provided an 86% success rate relative to stability and function, with a level of residual pain rated as good in 46%, fair in 38% and poor in 16% of the patients. The residual pain was mainly related to the multiply operated patients, pre-surgical irreversible pain, and continued FBGCR from failed previous TMJ alloplastic implants and prostheses containing PT.

The main problems associated with TMJ total joint reconstruction are related to wear at the articular surfaces, foreign body reaction, mobility of the implant with displacement and implant fracture, caused by the use of inappropriate alloplastic materials. WOLFORD and KARRAS conducted a comparative study on patients who had Techmedica total joint prostheses; 22 patients had fat grafts and were compared with 37 patients without fat grafts. Statistically significant improvement was found for maximum interincisal opening and excursive movements in the fat-grafted joints compared with the non-grafted joints. 35% of the non-grafted joints required additional surgery for the removal of heterotopic/reactive bone or severe fibrosis, whereas none of the fat-grafted joints required secondary joint surgery.

TMJ patients are often relatively young (mean age in this study was 34.5 years), therefore a total TMJ prosthesis must have a long lifetime; once the prosthesis is implanted there is no way to return to the previous anatomy. The present follow-up period ranged from 12 to 143 months, with a median of 40.6 months. Only 10 patients had been followed for 5 years or more. It will be important to continue to monitor these patients. SPECULAND et al. stated that it is not possible to determine the lifetime of this type of TMJ prostheses. WOLFORD demonstrated that custom-made total joint prostheses, constructed with materials used as the gold standard for orthopedic joint devices, work well for TMJ reconstruction. Total joint prostheses using appropriate materials are the only predictable alternative for many patients. During the 19 years that these prostheses have been available, the senior author (LMW) has placed over 540
prostheses and has not replaced any because of wearing out. The longevity of the prostheses remains unknown.

The current study demonstrates that the TMJ Concepts total joint prostheses work well with good stability at the longest follow-up (12–143 months), and is a viable technique for TMJ reconstruction, with mandibular advancement and counter-clockwise rotation of the maxillo-mandibular complex and occlusal plane angle, and osseous genioplasty. (C) Cephalometric analysis at 6 years post-surgery demonstrates good facial balance. (D) Superimposition of the immediate presurgery (red lines) and 6 year post-surgery follow-up (black lines) cephalometric tracings demonstrate the treatment changes achieved for this patient, including the significant increase in the oropharyngeal airway.

Fig. 9. Case 2 (A) The pretreatment cephalometric analysis shows a retruded maxilla and mandible, anterior open bite, steep occlusal and mandibular plane angles, and severely decreased oropharyngeal airway. (B) The STO (prediction tracing) demonstrates the TMJ and orthognathic procedures required to achieve a good functional and esthetic result including bilateral TMJ reconstruction and mandibular advancement with custom-made TMJ total joint prostheses (TMJ Concepts system®), bilateral coronoidectomies, maxillary osteotomies for counter-clockwise rotation of the maxillo-mandibular complex and occlusal plane angle, and osseous genioplasty. (C) Cephalometric analysis at 6 years post-surgery demonstrates good facial balance. (D) Superimposition of the immediate presurgery (red lines) and 6 year post-surgery follow-up (black lines) cephalometric tracings demonstrate the treatment changes achieved for this patient, including the significant increase in the oropharyngeal airway.

References


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