Feasibility of Preplanned Computer Guided Gap-arthroplasty of Tempromandibular Joint Ankylosis

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Abstract
The surgical resection of the ankylosic mass remains the ultimate line of treatment for bony ankylosis. Resecting massive bone formations at the skull base in a distorted anatomic environment is difficult and runs the risks of life threatening complications. This complicates the uniform resection of the ankylosic mass and accordingly creating a uniform dimension gap. Computer-guided surgery (CGS) has not been a routine part of craniomaxillofacial surgery in bony ankylosis to date. This study investigates the use of Prefabricated computer guided cutting stent to promote the safe removal and uniform of ankylosed temporomandibular joint bone in the skull base. This study included 8 cases of temporomandibular ankylosis (7 unilateral and 1 bilateral). The patients underwent a surgical procedure of bony gap arthroplasty guided by a prefabricated cutting stent. It aided in a predetermined guiding the uniformity of the gap arthroplasty intraoperatively. The results showed that computer guided surgery resulted in an accurate presurgical determined osteotomies with subsequent safe and uniform surgical excision of the ankylosic mass. Conclusions: We regard Computer-guided release of an ankylosed temporomandibular joint as a valuable additional technique in creating a preplanned uniform gap yet the depth of resection still needs for studies to be made.

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1. Introduction

Temporomandibular joint (TMJ) ankylosis is a clinical disorder that leads to a restriction of the mouth opening from partial reduction to complete immobility of the jaw. It is most commonly associated with trauma (13% to 100%), local or systemic infection (0% to 53%), or systemic disease, such as ankylosing spondylitis, rheumatoid arthritis, or psoriasis (Kaban et al., 1997; Kaban and Perrott, 1990; Vasconcelos et al., 2006).

It interferes with mastication, speech, oral hygiene and normal life activities. However, it could be a potentially life threatening condition if an airway embarrassment is encountered (Tutak et al., 2011). TMJ ankylosis could be classified according to its location into (intra or extra articular), type of tissue involved (bony, fibrous or fibro-osseous) and extent of fusion (complete, incomplete). Any cause that originates from inside the joint is considered a true cause for ankylosis (Rowe, 1982). False ankylosis results from any cause that is outside the joint but restricting the movement of the jaw (Cunha et al., 2012). Diagnosis of TMJ ankylosis is usually made by clinical examination and imaging modalities, such as plain films, orthopantograms, computed tomography (CT) scans, MRI, and three dimensional reconstruction (Movahed and Mercuri, 2015; Kao and Chou, 1999). According to Long and De Bont, a tomographic image is the best imaging diagnosis tool to assess the type and extension of the ankylosis (Long et al., 2005; De Bont et al., 1993).

The main aim in the management of TMJ ankylosis is to increase the patient’s mandibular function, correct associated facial deformity, decrease pain, and prevent reankylosis. Multiple surgical modalities have been proposed to manage TMJ ankylosis which includes gap arthroplasty, interpositional arthroplasty, and total joint reconstruction (TJR) (Kaban and Perrott, 1990; Schmelzeisen et al., 2002).
Wide bone resection of the ankylosis mass remains the most important aspect in the surgical protocol to avoid relapse. However, the accurate placement of the superior and inferior osteotomies and resecting a massive bone formation at the skull base especially in a distorted anatomic environment is difficult and complicates the access and visualization of the medial aspect of the ankylosis mass and leads to an uneven gap while releasing the joint in addition to the risks of severe bleeding, nerve injuries, dura mater exposure, and cerebrospinal fluid leak (Kaban and Troulis, 2004; Susarla et al., 2014).

Computer-assisted planning and intraoperative guidance have recently advanced safety in skull base surgery (Al Sukkhun and Pentilla, 2013). Its applications involved different areas of craniomaxillofacial surgeries. This included accurate resection and reconstruction, trauma, dental implants and orthognathic surgeries. The merits of Computer assisted planning were highlighted by using software that enabled surgical simulation, planning and estimation of the results to be reached (Wang et al., 2009; Papadopoulos et al., 2002; Leiggener et al., 2009; Xia and Gateno, 2009; Bell, 2010).

Virtual surgical planning & stereolithography, as a preoperative technique, accurately measures, 3D prints and enables contouring of devices and hardware for the placement at the time of the surgery. It significantly decreases operating time and increases the surgeon’s option to manage complex reconstructions (White and Pharoah, 2010).

Computer-guided surgery (CGS) has not been a routine part of craniomaxillofacial surgery in bony ankylosis up to date. This study investigates the feasibility of Virtual Surgical Planning in determining planned gap arthroplasty with help of prefabricated computer guided cutting splint (CGCS) to promote the safe removal of ankylosed temporomandibular joint from the skull base.

2. Patients & Methods

Eight patients with TMJ ankylosis were treated at the department of Oral and Maxillofacial Surgery, Faculty of Oral and Dental medicine, Cairo University. All patients were treated by gap arthroplasty guided by a prefabricated computer guided cutting stent.

Preoperative assessment included the clinical history of the patient, physical and radiographic examination. The collected data included the cause and duration of the ankylosis, the affected side and occlusion, facial asymmetry and presence of micrognathia. Measurement of the maximal interincisal opening (MIO) was made before the surgical procedure. The radiographic examination included Orthopantograms and computerized topographic Scans (C.T Scans) to determine the anatomic boundaries and type of ankylosis (Figure 1, Figure 2, Figure 3, Figure 4).

2.1 Preoperative Planning & Simulation

All the C.T Scans of the TMJ and the maxillomandibular complex were viewed after fine slicing of less than 1.25 mm with no gantry tilt. The scans were processed to create an accurate three-dimensional model of the patient’s anatomy at 1:1 scale. These scans were imported as DICOM files into a virtual surgical planning software (Mimics Edition15, Materialise Innovations, Leuven, Belgium), to help in surgical planning for gap arthroplasty. The maxilla was then separated from the mandible. The area of interest in the mandible was delineated to include the TMJ, ramus and ankylosic mass up till the coronoid process. Virtual cutting planes were designed to simulate the position of the superior and inferior osteotomies needed to release the ankylosed joint (Figure 5). These virtual cutting planes will be placed guided by surgically planed gap arthroplasty dimension (10-15 mm), and safe removal of ankylosic bone from skull base and the uniform gap both medially and laterally and in cases with elongated coronoid process, the resection of the coronoid process was also planned by a third virtual cutting plane.

This was followed by exporting the surgical plan of gap arthroplasty to another specialized software 3-Matic software (Materialise Innovations, Leuven, Belgium) (Figure 6). This software was used in designing a surface template of a bone – borne cutting stent. The cutting stent was designed with resection slits that were used to mimic the direction and position of the virtual cutting planes and accordingly the osteotomies of the ankylosic mass and the coronoid process if elongated and indicated for coronidotomy.

This was followed by the 3D-printing of the mandibular ramus and ankylosic mass up till the coronoid process and bone – borne cutting stent that will dictate and guide the resection of the ankylosic mass needed to release the temporomandibular joint (Figure 7, Figure 8).

2.2 Surgical Procedure

All patients were treated under general anesthesia using nasal fiberoptic intubation. The TMJ approach was made by preauricular incision (Figure 9). Dissection was carried out through the superficial layer of temporal fascia, which was retracted anteriorly to protect the facial nerve and the periosteum over the zygomatic arch was incised. After exposing the joint and identification of the ankylosed joint, the prefabricated cuttingstent was placed on the ankylosic mass &
mandibular ramus and held in position (Figure 10, Figure 11). It was stable in place without any signs of rocking. The cutting stent was used to guide the positioning of the superior and inferior osteotomies. The initial cuts were made with rotary drills under copious amounts of saline irrigation (Figure 12, Figure 13). After which the stent was removed and arthroplasty was completed with rotary drills and chisels until complete release.

**Table 1:** Data of the patients

<table>
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**Table 2:** Statistical Analysis by Wilcoxon signed rank test. Postoperative showed higher value median 32.5 compared to preoperative median 10.5 (P value= 0.012).

<table>
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<tr>
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<th>Postoperative</th>
<th>P value</th>
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<tr>
<td>Median</td>
<td>10.5</td>
<td>32.5</td>
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<tr>
<td>IQR</td>
<td>6.25</td>
<td>8.25</td>
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**Figure 1:** Orthopantogram showing bilateral ankylosis secondary to subcondylar and parasymphseal mandibular fractures.
Figure 2: Coronal C.T Scan showing bilateral TMJ Ankylosis

Figure 3: Axial C.T Scan showing bilateral TMJ Ankylosis
Figure 4: 3D C.T Scan showing Bilateral TMJ Ankylosis

Figure 5: Virtual planning of the Superior and Inferior cutting planes of the ankylosic mass
Figure 6: 3D Surface template design for the Preplanned computer guided cutting stent in place showing the cutting slits for the superior and inferior osteotomies.

Figure 7: 3D printed model for the ankylosed joint and the ascending mandibular ramus.
Figure 8: The 3D printed model for the cutting stent

Figure 9: Preauricular incision

Figure 10: Exposure of the anklyotic mass at the right side
Figure 11: Outlining the superior and inferior osteotomies using rotary drills through the slits of the cutting stent

Figure 12: Superior and inferior grooves representing the proposed ostetomy positions

Figure 13: Gap arthroplasty after excision of the ankylotic mass
**Figure 14:** Maximum interincisal opening using a mouth gag

**Figure 15:** Bar chart representing the data of the patients

**Figure 16:** Resemblance of the excised ankylotic mass with the intermediate part between the slits of the cutting stent
and excision of the ankylotic mass (Figure 14). The resected ankylotic mass was equivalent to the pre-surgical virtual planned resection and equal to the space between the cutting resection slits. This was followed by the burring of the glenoid fossa and creating a gap between the roof of the fossa and the mandible. All patients underwent an ipsilateral pterygomasseteric sling release and coronoidotomy through the preauricular approach. A passive inter-incisal mouth opening of at 35mm was achieved (Figure 15). Contralateral coronoidotomy and sling release was performed when there still a resistant in attaining maximum mouth opening according to *Kaban’s protocol* (Kaban and Perrott, 1990).

After vigorous saline irrigation, suction drains were placed after the resection to avoid edema and infection. The incisions were closed and a pressure dressing was applied. The mouth opening was maintained immediately by custom-made resin block.

2.3 *Postoperative mouth opening exercises and follow up*

The physiotherapy began one day postoperatively with jaw exercises and orientation. The jaw exercises included opening and closing the jaws in active and passive forms. Patients were requested to undergo exercises 6 times daily, 10 min at each time. The times in between the exercises the mouth block was to be placed. This was maintained for
the entire follow up period. Regular follow up was carried out 3 times weekly for 2 months, then weekly for the rest of the follow up period. During the surgical procedure, the following data were collected: time of the operation, maximal mouth opening and amount of blood loss. Postoperatively, all patients were routinely administered antibiotics for 7-10 days. The patients started on a soft diet and during the next 3 to 4 weeks the diet was evolved to solid consistency. All patients were followed up for a minimum period of 6 months. Postoperative data included maximal mouth opening, facial nerve affection and recurrence. Data were presented by median and interquartile range (IQR). Wilcoxon signed rank test was used for comparison between preoperative and postoperative values. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics Version 20 for Windows.

3. Results

3.1 Preoperative Evaluation
Eight patients (4 males, 4 females) were included in this study with 9 involved TMJs (7 unilateral and 1 bilateral). The mean age was 22.6 (range 15 to 30 years). Etiology included Trauma (n=6) and others (n=2). (Figure 16, Table 1). The median of the preoperative MIO was 10.5 with an IQR 6.25. The results of the change in Maximum Inter-incisal Opening (MIO) were statistically significant ($P$ value $= 0.012$). Postoperative values showed higher value median 32.5 compared to Preoperative values median 10.5 and Interquartile range IQR values of 8.25 and 6.25 respectively. The Wilcoxon signed rank test showed significant difference between groups ($P$ value $= 0.012$) (Figure 18, Table 2).

3.2 Intraoperative findings
In all the cases included in this study, the administration of anesthesia was made using nasal fiberoptic anesthesia due to the limited mouth opening. In two joints out of the nine, the splints that were used required intraoperative adjustment on the its margins to facilitate its fitting and adaptation. The rest of the fabricated splints were accurate. However, in the rest of cases any further adjustments made in the splint was made preoperatively and checked for accuracy by adapting it on the printed STL of the joint. This was evaluated by the stability of the splints when placed on the ankylosed joint without showing any rocking or need for any additional stabilization. The accuracy of the planned and printed splints was confirmed by the accurate resemblance between the excised ankylotic mass and the intermediate part of the splint between its two slits in all cases and the resected ankylotic mass was uniform in dimensions both medially and laterally as virtually planned and confirmed radiographically in the postoperative coronal cuts (Figure 17). A passive MIO of 35mm was achieved in all cases. The amount of intraoperative bleeding ranged between 150 – 220 cc.

3.3 Postoperative findings and follow up
All patients showed uneventful healing without complications such as postoperative hemorrhage or infection. Only transient postoperative pain and edema were encountered and were controlled by analgesics and corticosteroids. Postoperative temporary weakness of the facial nerve was encountered only in 2 patients (25%) in our study. However, it responded to steroid therapy and resolved completely within 3 months. The results of the change in Maximum Inter-incisal Opening (MIO) were statistically significant ($P$ value $= 0.012$). Postoperative values showed higher value median 32.5 compared to Preoperative values median 10.5 and Interquartile range IQR values of 8.25 and 6.25 respectively. The Wilcoxon signed rank test showed significant difference between groups ($P$ value $= 0.012$) (Figure 18, Table 2).

4. Discussion

Trauma is the major cause for the ankylosis in our study (75%). The traumatic cause of TMJ ankylosis is usually due to an old trauma causing condylar or subcondylar fracture. The main reason for the occurrence is mainly due to misdiagnosis and improper treatment for the fracture that occurred during childhood (Kaban and Perrott, 1990).

The sequence of occurrence follows the fracture that leads to intraarticular hemorrhage followed by organization and then fibrosis that becomes calcified. This results in the restriction of the joint movement and the ramal growth (Long et al., 2005; Casanova et al., 2006; Chossegros et al., 1997; Sarma et al., 1991). The calcification that occurs in a disordered fashion masks the normal joint anatomy. This complicates any kind of surgical approach that involves the TMJ and raises the procedure difficulty with risk of life threatening complications that may occur, such as haemorrhage or dural tear.

The administration of anesthesia to patients with TMJ ankylosis is one of the challenging conditions. This is attributed due to the limited mouth opening and restricted airway. It requires considerable expertise and meticulous monitoring facilities. The safest technique for general anesthesia is by securing the airway using nasal fiberoptic intubation. However, this was applied in 100% of the patients in this study.

Roychoudhury recommended a gap arthroplasty of at least 15mm between the glenoid fossa and the mandible to release the ankylosed joint. This is to be followed by an aggressive protocol of physiotherapy from the second day of surgery (Roychoudhury et al., 1999).
According to Kaban et al., gap arthroplasty involving aggressive bone removal is the ideal line of treatment for TMJ ankylosis. This is due to its simplicity and short operating time. However, disadvantages still stand due to the unplanned positioning for the superior and inferior osteotomy cuts that is difficult to place in a distorted anatomy as in ankylosis. This results in an unequal dimension in the created gap causing pseudoarticulation and shortening of ramus height due to the excessive, unplanned manual removal of the ankylotic mass (Kaban and Perrott, 1990; Vasconcelos et al., 2006; Kaban et al., 2009).

In addition to the risk of life threatening complications that could occur such as bleeding due to the injury of the maxillary artery and the risk of perforating the glenoid fossa into the middle cranial fossa causing neurological complications and dural tear.

In our study the Computer assisted planning was made using Virtual Surgical planning software (Mimics Edition 15, Materialise Innovations, Leuven, Belgium). It totally depended on the Preoperative C.T Scans of the patients, that were imported into the software as DICOM files.

The use of C.T Scans was very important in detailed assessment of the ankylotic mass in coronal, axial and sagittal dimensions (Long et al., 2005; De Bont et al., 1993; Yan et al., 2011). This greatly helped in evaluating the difficulty of the surgery, making an accurate simulation for the position and direction of the osteotomies and measuring the amount of the gap to be created. C.T scans helped in evaluating the thickness of the glenoid fossa to avoid its perforation during the surgery.

The software enabled the immediate comparison with the normal side in unilateral cases. It helped in separating the maxilla from the mandible and delineating the area of interest as a form of virtual surgical simulation.

This was followed by designing the computer guided cutting splint (CGCS) by using the 3 Matic software (Materialise Innovations, Leuven, Belgium). This was made to guide in uniform removal of the ankylotic mass and coronidotomy in indicated cases. The standard amount of 15 mm gap arthroplasty was not applied, to avoid the excessive removal of bone and accordingly the undesirable loss of ramal and posterior facial height.

The 3D printed splint needed intraoperative adjustment of its margins the first two cases to facilitate its fitting. This was improved by printing a 3D model for the ankylotic mass and area of interest to make preoperative adjustment of the splint and guarantee its maximum adaptation.

The accuracy of the preoperative planning was assured by the resemblance between the size of the actual resected ankylotic mass and the intermediate part in the cutting splint. The Gap created was uniform in dimension from its outer and inner sides, thus clarifying the uniformity of the shape of the resected ankylotic mass.

According to the literature, the gap arthroplasty was always made in an unplanned fashion starting with a small gap created which turned to 15 mm by rounding of the gap edges created. This arises the variation that may occur between operators and the sensitivity of the technique. In addition to the excessive bone removal that will result in more loss of posterior facial height and accordingly postoperative deformity. This in turn may lead to pseudoarticulation and makes any future reconstruction or corrective orthognathic surgery more difficult.

Temporomandibular joint gap arthroplasty has always been physiotherapy mediated surgical procedure (Roychoudhury et al., 1999). This was demonstrated by studies made by Hlawitschka et al. and Eckelt et al. (Hlawitschka and Loukota, 2005; Eckelt et al., 2006).

Accordingly, this confirms the importance for an aggressive postoperative physiotherapy protocol, to avoid any recurrence rather than a standard amount of unnecessary excessive bone removal. The viability of undergoing coronidotomy from an extraoral approach, and ipsilateral pterygomasseteric sling release was facilitated. By reviewing literature our study is the only one undergoing pterygomasseteric sling release from an extraoral approach. This avoided an additional intraoral incision to be made. However, this required stripping of masseter muscle from its insertion. This could be the reason for the bleeding that occurred in the surgery. In addition to, extensive dissection through the fascial planes that was made to enable sufficient retraction and accessibility.

Accordingly, this required more retraction to be made for the tissues which explains the occurrence of the temporary weakness of the temporal branch of the facial nerve.

In our study only 2 patients experienced this complication and responded to steroid therapy. It resolved completely within 3 months.

**Conclusion**

The use of Computer Guided Cutting Splints (CGCS) in gap arthroplasty of TMJ ankylosis has
shown its feasibility and increased the standards of safety and accuracy of the procedure. In addition to reducing the operative time and risk for complications. It aids in accurate, uniform positioning and direction of the osteotomy cuts. However, it still needs modification to guide the depth of cuts.

**Research Highlights**

Describe the problems faced in managing the Temporomandibular joint ankylosis and its management.

Highlight the difficulties in managing the gap arthroplasty and the risks encountered while performing it regarding the distorted anatomy due to the increased risks of life threatening complications. In addition to the difficulty in placing a standardized superior and inferior osteotomy and thus making a uniform sized gap to release the joint.

Introducing the computer guided planning and surgery in performing the gap arthroplasty for the first time, for it has never been introduced in the TMJ ankylosis management up to date.

Demonstrate the feasibility of using a preplanned computer guided cutting stent to guide and facilitate an accurate placement of osteotomies in a uniform dimension.

**Limitations**

The inability to confine a depth guide through the cutting stent, to enable a uniform depth in addition to an accurate width of the created gap.

**Authors declare no any conflict of interest.**

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**References**


