50 Innovations in the Management of Temporomandibular Joint Disorders

Aaron D. Figueroa, Joseph W. Ivory, and Rishad Shaikh

Introduction

Temporomandibular joint (TMJ) surgery is one of the more difficult subspecialty fields within oral and maxillofacial surgery. This stems from the complexity of managing difficult patients with multifactorial problems, including chronic pain and the inability to provide curative treatment in most cases. In addition, many previously innovative surgical treatments were found to be unreliable in the long term, and some resulting in Food and Drug Administration (FDA) recall. Innovations have been few in this area, which may stem from the lack of financial reimbursement and a diminishing interest in managing these complex patients outside of large academic centers. Despite this, some of the major innovations in diagnosis and treatment planning have been integrating cone-beam computed tomography (CBCT), intra-oral scanning, and virtual surgical planning (VSP) into daily practice. In addition, computed tomographic angiography (CTA) has been shown to provide useful diagnostic information preoperatively and, combined with interventional radiology procedures, can decrease intra-operative blood loss. Though most non-surgical interventions have remained unchanged, addition of chemodenervation with onabotulinum toxin A or Botox® (Allergan, Madison, New Jersey) has shown some promising results. TMJ arthroscopy has gone through significant innovative changes in the surgical realm, making it an excellent minimally invasive intervention. Advances in open TMJ surgery have included the use of the Mitek anchor (DePuy Synthes, Raynham, Massachusetts) in discopexy procedures and new knowledge in managing discectomy patients when considering grafting materials. Finally, the use of custom alloplastic joint replacements has been widely accepted, along with the integration of CBCT, intra-oral scanning, and VSP. Management of temporomandibular joint dysfunction is a broad topic, and it is the goal of this chapter to help review some of the more recent innovations in diagnosis and management.

A. D. Figueroa
Oral and Maxillofacial Surgery, University of Iowa Hospitals and Clinics, Iowa City, IA, USA
e-mail: aaron-figueroa@uiowa.edu

J. W. Ivory (✉)
Oral and Maxillofacial Surgery, Dwight D. Eisenhower Army Medical Center, Fort Gordon, GA, USA
e-mail: sgtdabney@gmail.com

R. Shaikh
Midwest Oral Maxillofacial Surgery and Implant Center, Saint Louis, MO, USA
e-mail: rshaikh_omfs@icloud.com

Examination and Diagnosis

When managing patients with temporomandibular joint dysfunction (TMD), determining an accurate diagnosis is an important starting point in guiding appropriate treatment. From a diagnostic perspective, CBCT scanning has been one of the most important innovations for oral and maxillofacial surgery practice in recent years. Its application in the management of TMD ranges from its diagnostic value to its integration in treatment planning.

Though CBCT scanning can be an excellent adjunctive diagnostic tool, it is not a replacement for a thorough subjective evaluation and clinical examination. Questionnaires can help draw out subjective information in an organized manner from patients suffering from TMD (Fig. 50.1).

The subjective history and clinical examination should provide enough information for a working diagnosis. This diagnosis can then be confirmed or changed based on imaging findings.

Historically, an orthopantomogram served as an initial screening tool but provides a limited and distorted view of the TMJ complex's bony anatomy. It provides information on the overall shape and cortication of the condyle (Fig. 50.2). The position of the condyle within the glenoid fossa and joint space can also be evaluated. Many oral and maxillofacial surgery offices are equipped with CBCT scanners

M. R. Stevens et al. (eds.), *Innovative Perspectives in Oral and Maxillofacial Surgery*,
https://doi.org/10.1007/978-3-030-75750-2_50

Temporomandibular Joint Pain (TMJ) Questionnaire
Department of Oral and Maxillofacial Surgery

1. Do you have pain in your TMJ (jaw joint)? **Y/N**
   a. Is the pain on the (circle one):
   Left **Right** **Bilateral**
   b. Is the pain:
   Sharp **Dull**
   c. Is the pain:
   Constant **Occasional**
   d. Does anything make the pain worse?
   ____
   e. Does anything make the pain better? If so, What? **Y/N**
   ____
   f. Are you having pain today? **Y/N**
   g. On a scale of 1-10, what would you rate your pain?
   h. When is your TMJ pain the worse?
   Morning **Afternoon** **Evening** **No difference**
2. Do you have joint noise? **Y/N**
   a. Is the noise (circle one):
   Clicking **Popping** **Grinding**
   b. Is the pain associated with noise in your joint? **Y/N/NA**
   c. When does your joint noise occur (circle one)?
   On opening **On Closing** **Opening and Closing**
3. Do you get headaches? **Y/N**
   a. How bad are your headaches typically?
   Mild **Moderate** **Severe**
   b. When do you typically get headaches (cirle one)?
   Morning **Afternoon** **Evening** **No difference**
   c. How many headaches do you get a week? ____
   d. Where do your headaches typically occur (circle all that apply)?
   Left Forehead **Right Forehead** **Left Temple** **Right Temple**
   Back of Head **Top of Head** **Left Eye** **Right Eye**
4. Do you have pain elsewhere? **Y/N**
   a. If so, where?______________________
   b. Is the pain
   Mild **Moderate** **Severe**
5. Do you clech or grind your teeth? **Y/N**
   a. If so, do you clech or grind (circle one)
   Daytime **Nighttime** **Both** **Unsure**
6. Do you get earaches? **Y/N**
   a. If so, are they (circle one):
   Mild **Moderate** **Severe**
   b. Do they occur (circle one):
   Seldom **Frequently** **Constant**
   c. Do you get ringing in your ears? **Y/N**
   d. If so, is the ringing (circle one):
   Mild **Moderate** **Severe**
   e. Does it occur (circle one)"
   Seldom **Frequently** **Constant**
7. Have you tried any nonsurgical therapies for your jaw pain? **Y/N**
   a. If so, what were they (meidcations, bite splints, massage therapy, etc...)?
   ____
   ____
   ____
   b. Did they give you any relief? **Y/N**
8. Have you had anu surgeries on your TMJ? **Y/N**
   a. If so, please indicate how many surgeries you have had on each side:
   Right____ Left____
   b. Did any of these procedures help? **Y/N**
9. Do you have problems with other joints in your body? **Y/N**
   a. If so, please list which joints are affected below:
   ____
   ____
   ____
10. Do you have depression? **Y/N**
    a. If so, are you currently being treated? **Y/N**
11. Please list your medications below:
    ____
    ____
    ____
12. Does your TMJ pain affect your quality of life? **Y/N**
    a. Does it affect your daily activities? **Y/N**
    b. Does it limit your diet? **Y/N**
    c. List the foods you are typically unable to eat:
    ____
    ____
    ____

Fig. 50.1 An example TMJ examination questionnaire.

Fig. 50.2 Orthopantomogram showing bilateral severe degenerative joint disease

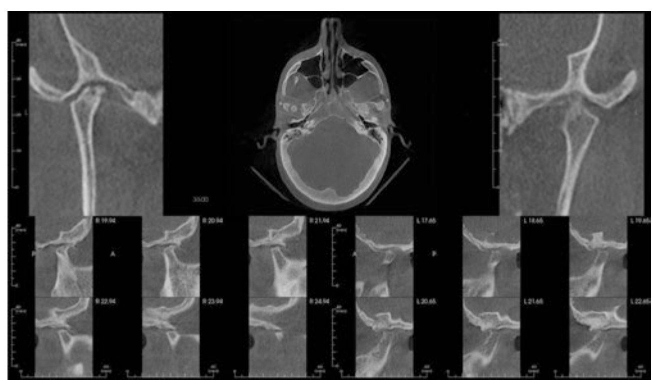

Fig. 50.3 CBCT of the same patient from Fig. 50.2, showing severe degenerative joint disease with coronal and sagittal image reconstruction

making three-dimensional data much more accessible to the surgeon in an office setting [1]. Prior to this, patients would be required to visit a hospital or radiology center to obtain a computed tomography (CT) scan.

The software available for viewing and manipulating the CBCT image data allows for very detailed evaluation and reconstruction of the images, including creating an orthopantomogram if desired (Fig. 50.3). TMJ viewing windows allow for a detailed view of the condyles in all planes providing much more diagnostic information regarding the cortication of the joint, presence of subchondral cysts, lipping, flattening, and the overall shape of the condyle, fibrous and bony ankylosis, and the presence of bony or cartilaginous pathology among others [2, 3].

Magnetic resonance imaging (MRI) is useful in evaluating soft tissue abnormalities within the joint and has not undergone a significant change but remains a useful tool in diagnosis (Figs. 50.4 and 50.5).

The use of CTA has become helpful in analyzing the vascular anatomy around the joint space and the course of the internal maxillary artery (Fig. 50.6). In some cases, consideration can be placed on embolization of certain vessels that may pose a significant bleeding risk at the time of surgery. This will help keep the surgical field dry and increase the ease of surgery while also lowering the risk of inadvertent vascular compromise for the patient.

Diagnostic nerve blocks and joint injections can be helpful adjuncts in diagnosis but have also been techniques in use for a long time. More recently, TMJ arthroscopy has become an excellent diagnostic tool in evaluating the temporomandibular joint's health.

Integration of standard examination methods with newer imaging and diagnostic protocols can help provide very accurate diagnoses that will help guide appropriate treatment.

Myofascial Pain

Myofascial pain is a condition caused by inflammation of the muscles that control the mandible or myalgia. It is defined by pain at rest, pain on palpation at three or more sites, and at least one palpable painful site on the same side that the patient perceives pain [4]. Many times, it is associated with intra-articular TMD, but it can also be found in isolation. Parafunctional habits like bruxism are commonly seen in patients with myofascial pain. Other contributing factors include hyperfunction, stress, and possibly lack of stable occlusion. Clinically, pain is typically not well localized to the articulation or pre-auricular region but is described as diffuse, involving a whole side of the face, jaw, and temporal regions. Treatments are aimed at reducing parafunction, hyperfunction, stress, and inflammation.

The most recent innovation has been chemodenervation with Botox® (Allergan, Madison, New Jersey). Different approaches have been utilized, but all include injection of varying amounts of Botox® (Allergan, Madison, New Jersey) into the muscles of mastication (Fig. 50.7). When managing myofascial pain, simple injection into the masseter muscles and temporalis muscles seems to be an effective treatment modality. The analgesic effects of Botox® (Allergan, Madison, New Jersey) were first reported by

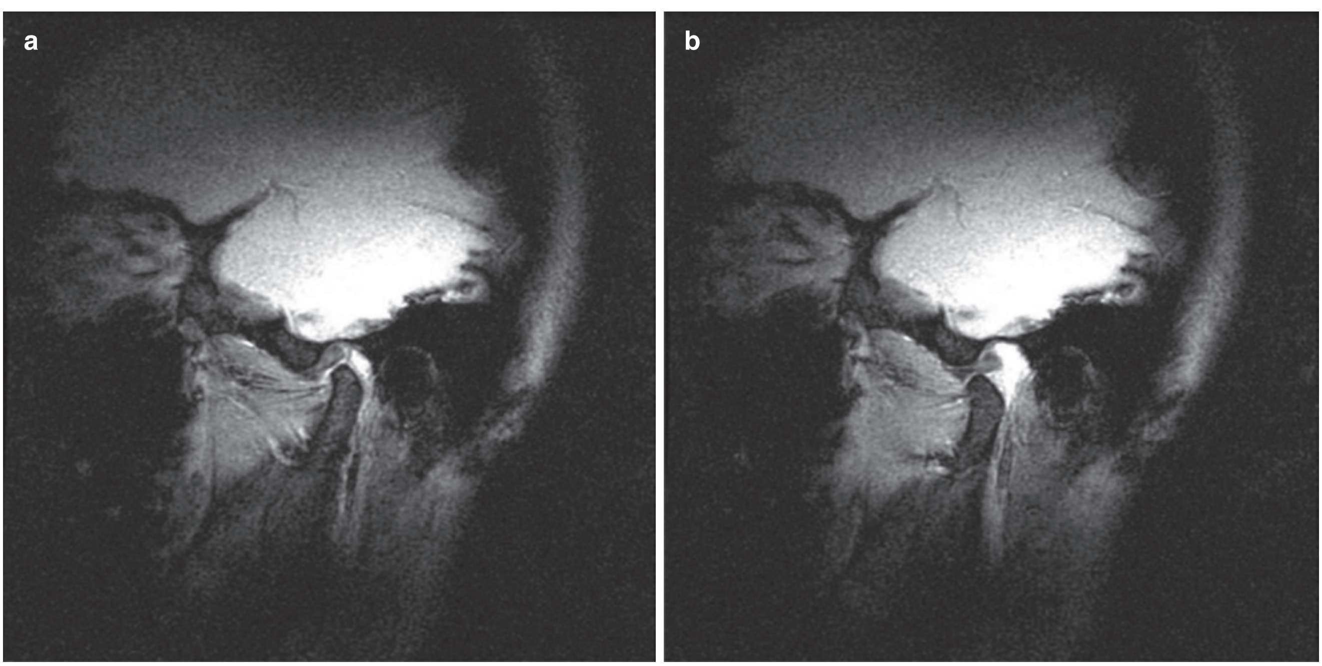

Fig. 50.4 (**a**) TMJ MRI in closed mouth view with normal anatomic position of the articular disc. (**b**) TMJ MRI in open mouth view with normal anatomic relationship between the articular disc, eminence, and condyle

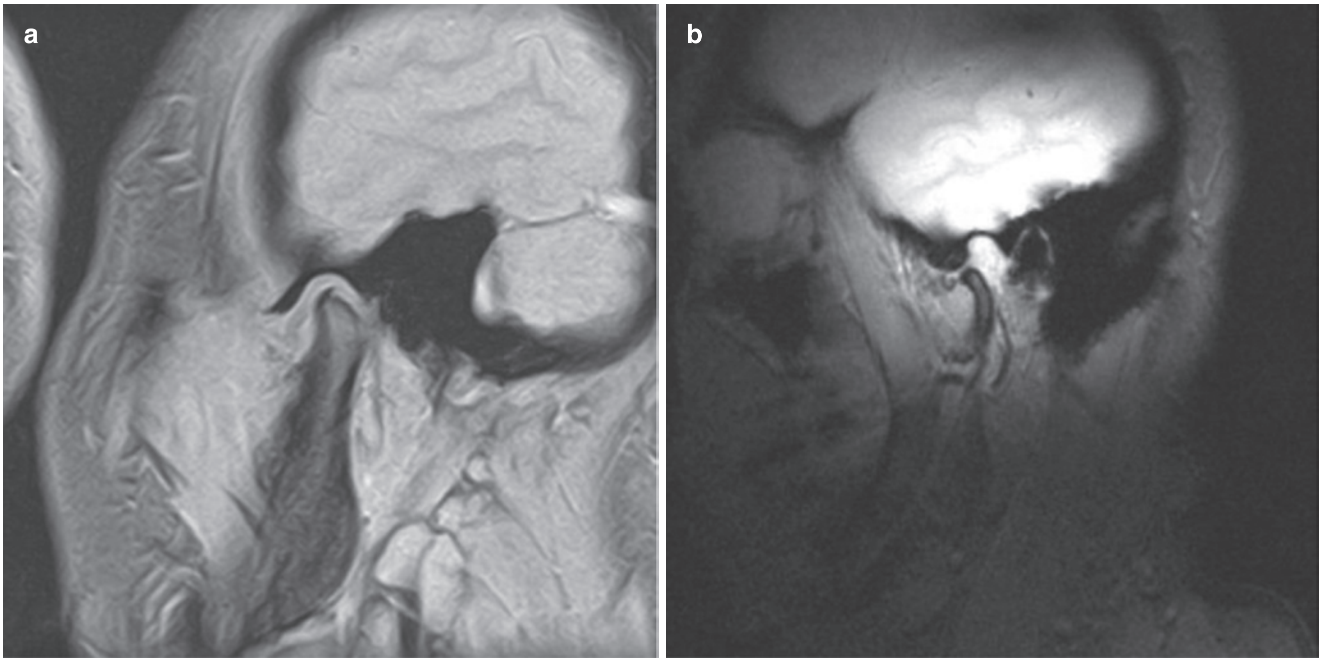

Fig. 50.5 (**a**) TMJ MRI in closed mouth view with anterior disc displacement. (**b**) TMJ MRI in open mouth views with anterior disc displacement without reduction

Binder in 2000, which may relate to the inhibition of the release of substance P and glutamate [5, 6]. Several subsequent studies have demonstrated the analgesic effects of intra-masseteric injections [7–10]. Researchers have reported Botox® (Allergan, Madison, New Jersey) to be superior to trigger point injections with normal saline as well as a local anesthetic with methylprednisolone [11, 12].

However, controversy remains as it has been pointed out that these studies are methodologically diverse, and the sample sizes are typically small. Also, there have been some studies that, though also having a small sample size (and in one case, a 30% dropout rate), failed to show statistically significant pain reductions [13, 14]. Milne reported a case series comparing the results of masseteric Botox® (Allergan, Madison, New Jersey) injections alone with patients receiving masseteric and temporalis injections. He reported that though both groups reported significant and similar reductions in pain scores, those receiving temporalis injections had a slight worsening of their maximum incisal opening (MIO). Therefore, he recommended Botox® (Allergan, Madison, New Jersey) be relegated to the use in the masseter only [15].

Botox® (Allergan, Madison, New Jersey) remains a promising non-surgical therapy to address myofascial pain. More randomized clinical controlled studies are needed to define the possible benefit further.

Internal Derangements

Internal derangements differ from myofascial pain in that they represent a true intra-articular problem. They are one of the more common problems seen within the TMJ. They occur in many individuals that remain asymptomatic, possibly forever. For some reason, they seem to bring on significant pain and dysfunction in other individuals. Internal derangements arise from a non-anatomic position of the articular disc within the joint capsule at rest and the mandible function. These derangements are divided into anterior disc displacement with reduction and without reduction.

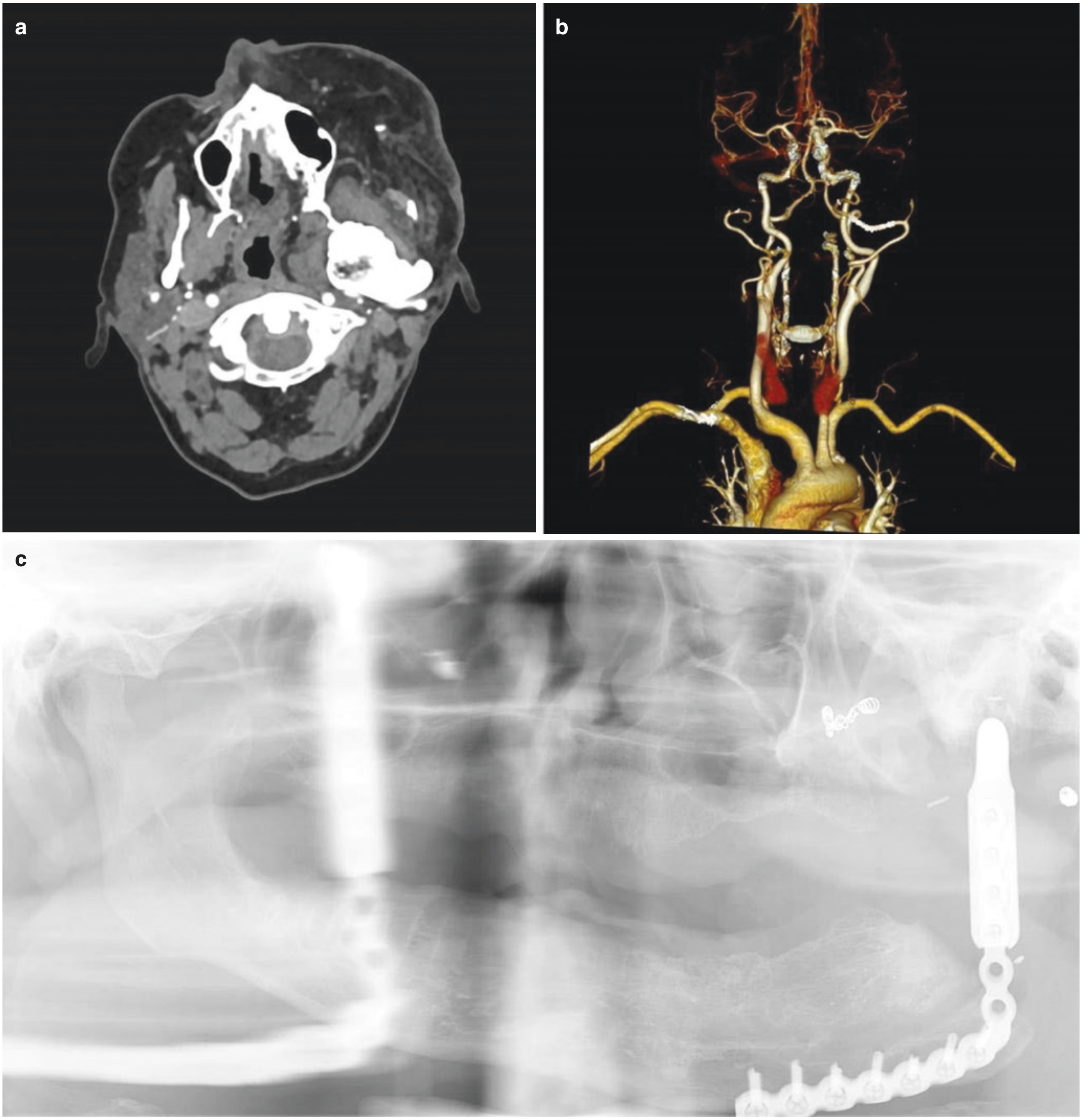

Fig. 50.6 (**a**) CTA in the axial view with the internal maxillary artery running just posterior to the large ankylotic bony mass. (**b**) Three-dimensional reconstruction of the vascular anatomy around the ankylosis. (**c**) Post-operative orthopantomogram showing stable position of temporary reconstruction hardware and coils from the pre-operative embolization procedure

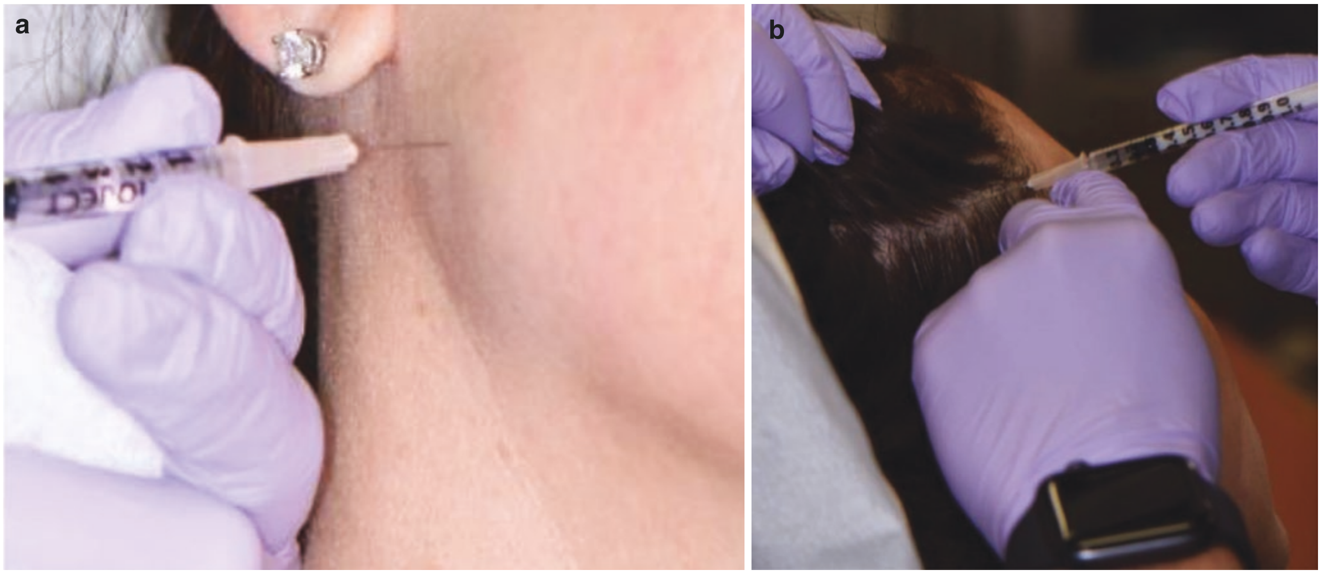

Fig. 50.7 (**a**) Botox® (Allergan, Madison, New Jersey) injection into the masseter muscle. (**b**) Botox® (Allergan, Madison, New Jersey) injection into the temporalis muscle

Traditionally, when speaking of the TMJ's internal derangements, clinicians have used the classification system devised by Wilkes to describe the severity of the derangement (Fig. 50.8).

Indications for Surgery

Absolute	Relative
Pathology Synovial chondromatosis Benign/malignant tumors Chondroma Osteochondroma Fibrous and bony ankylosis Severe traumatic injuries	Internal derangements Severe degenerative joint disease Idiopathic condylar resorption Juvenile and rheumatoid arthritis Pain and joint dysfunction refractory to non-surgical measures Hypermobility and dislocation refractory to non-surgical measures

The decision to move forward with surgical intervention to treat TMD should not be taken lightly. All procedures, including those that are minimally invasive, are associated with risks and morbidity and thus must be weighed against the amount of dysfunction and pain. Any TMJ surgery aims to eliminate pathology, decrease pain, and improve function. It should be noted that surgical intervention is unlikely to eliminate all pain in most cases. For this reason, the clinician must be certain of a diagnosis based on clinical exam, diagnostic imaging, and testing with a specific goal in mind before moving forward with surgery. Lysis and lavage procedures can be considered in patients with refractory pain and dysfunction without a definitive underlying cause and lack of improvement from non-surgical modalities.

If pain and dysfunction are improved to an acceptable level with non-surgical measures, a displaced disc or degenerative changes are not of surgical concern. Besides, patients who have failed non-surgical measures and lysis and lavage with no identified intra-articular pathology should not expect the more invasive surgical intervention to yield positive results. Finally, open interventions to the TMJ should be limited. The more the open interventions completed prior to alloplastic joint replacement, the more the chronic pain that should be expected after the final surgical treatment [18].

Non-surgical Treatment

There have been few innovations in non-surgical therapy in the management of TMD. It should be considered as a first-line treatment in most cases, but surgical intervention should not be delayed when clear pathology is present or in cases of severe degenerative joint disease associated with apertognathia, pain, and dysfunction. A study by Suvinen found that out of 37 patients treated conservatively, 81% of patients showed 50% or greater pain severity improvement at follow-up [19]. Most patients will have significant benefits from non-surgical treatment and may therefore not require further surgical intervention.

Stage	Clinical Findings	Radiographic Findings
I	No limitation of opening Painless clicking	Normal disc morphology Mild displacement with early reduction
II	Occasional painful click Intermittent lock	Mild disc deformity Moderate displacement with late reduction
III	Limited opening Frequent painful clicking Joint tenderness	Displaced, nonreducing disc
IV	Limited opening Chronic pain	Severe displacement without reduction Degeneratice bony changes
V	Variable joint pain Joint crepitus	Nonreducing disc with perforation Degenerative bony changes

Fig. 50.8 Wilkes classification of internal derangements [16, 17].

Non-surgical regimens should include splint therapy, pharmacotherapy, diet and habit modification, and physical therapy. Splints are not always benign prostheses, and they can result in worsening symptoms as well as tooth movement and occlusal changes. The goal of these devices is to decrease loading of the TMJ and create a neuromuscular balance that can reduce the reflexive activation of the muscles leading to parafunctional habits.

Flat plane stabilization splints should be the mainstay of treatment. They are permissive and should be fabricated in centric relation. These splints have little chance for significant dental movement and can be used long term. They should be periodically adjusted to ensure that even contact is always achieved [20–24]. Soft splints can also be considered. They are effective and often tolerated in patients who do not tolerate a rigid, flat plane stabilization splint. There is some evidence that they may offer comparable efficacy to that of hard splints in some patients [25, 26]. Regardless of the splint used, regular evaluation should be completed to ensure that no unwanted tooth movement occurs or worsens symptoms and function (Fig. 50.9).

Pharmacotherapy is aimed at controlling inflammation, parafunction, and pain. Typically, this includes the use of NSAIDs, muscle relaxants, and at times corticosteroids [27]. Other medications like tricyclic anti-depressant medications have more recently been shown to benefit from chronic facial pain and bruxism. However, further study is needed as the benefit is not clear [28–32]. Opioid medications are used in the management of acute post-surgical pain. Still, they do not play a role in managing the underlying etiology, and it is the author's opinion that should opioid medications be required for management of pain, it should be deferred to either the primary care provider or a pain specialist.

Concurrent treatment using all modalities may be more beneficial than each on their own. A course of therapy should be completed for at least 1 month before determining its effectiveness and for as long as 3 months.

Surgical Treatment

Innovations in TMJ surgery include the development of diagnostic and therapeutic arthroscopy, Mitek anchors (DePuy Synthes, Raynham, Massachusetts), and custom and stock alloplastic joint replacements. The integration of VSP, CBCT, and intra-oral scans has made planning more accessible and surgery more predictable, safe, and efficient. In addition, CTA, embolization procedures, and the advent of intra-operative CT guidance with systems like Stealth (Medtronic, Minneapolis, Minnesota), have helped to reduce risk and improve results.

TMJ arthroscopy was first described by a Japanese surgeon Ohnishi in 1975 [33]. It was further refined and studied by Murakami, Sanders, and McCain [34, 35]. TMJ arthroscopy has become much more versatile from a diagnostic prospective when compared to arthrocentesis alone. Indications include TMD with lack of improvement from non-surgical measures, continued pain after surgical intervention, internal derangements, and TMJ arthralgia. Contra-indications are TMJ ankylosis or fibrous ankylosis, overlying skin infection, or local factors limiting the success of entering into the joint space. Studies on the benefits of arthroscopy have shown

Fig. 50.9 (**a**) Frontal occlusion from chronic long-term use of an anterior repositioning splint resulting in malocclusion. (**b**) Right occlusion view. (**c**) Left occlusion view

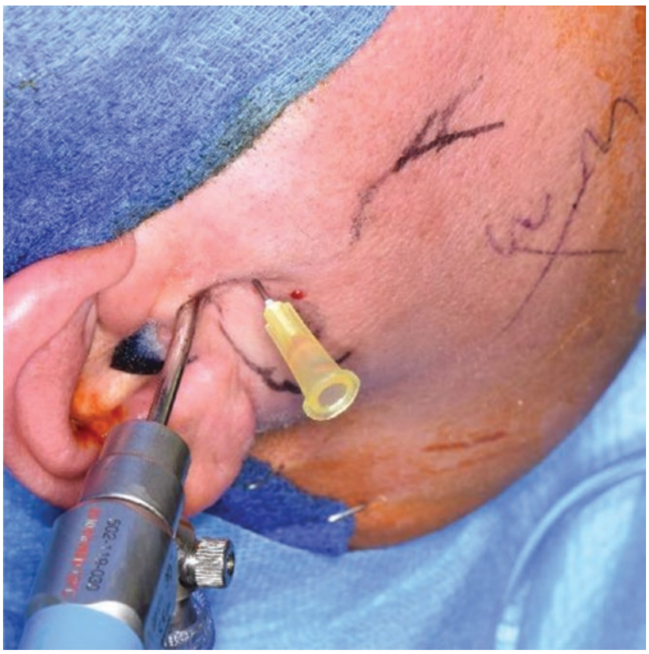

Fig. 50.10 Clinical edits of a 1.9 mm, 30-degree arthroscope (Stryker, Kalamazoo, Michigan) in the superior joint space with a second 20-gauge needle in place for lavage

improvement in pain and function in early- and late-stage diseases [36–38].

TMJ arthroscopy can provide diagnostic and therapeutic value. Typically, it is performed in the operating room under general anesthesia (Fig. 50.10). Zimmer Biomet has more recently come out with a very small arthroscopic camera called the OnePoint™ Scope System (Zimmer Biomet, Jacksonville, Florida) with a diameter of 1.2 mm that can be utilized in the oral and maxillofacial surgery office under intravenous sedation quite safely. This approach can be helpful diagnostically, but it will not offer the more versatile therapeutic interventions available with more standard-sized arthroscopes. Diagnostic evaluation allows visualization of key structures, including the medial synovial drape, pterygoid shadow, retrodiscal tissue, posterior slope of the articular eminence, articular disc, intermediate zone, and the anterior recess (Fig. 50.11) [35, 39–41].

Therapeutic plans can be made based on the diagnostic information obtained. McCain pioneered the two-puncture arthroscopy technique, which has allowed for introducing instrumentation into the joint, including blunt and sharp instruments, biopsy forceps, rotary instruments, monopolar and bipolar electrocautery, and lasers, among others [35]. Debridement can be completed to address adhesions not managed with lysis and lavage using either motorized instrumentation or electrocautery. Arthroscopic lysis and lavage and surgical arthroscopy are effective in managing internal derangements [42]. Surgical arthroscopy has shown to be successful in managing internal derangements showing significant reduction in pain and improvement in function [36–38, 43, 44]. Though open approaches may achieve similar results, the minimally invasive nature of the arthroscopic approach makes it attractive and innovative [45].

Some have advocated that lysis and lavage alone are adequate, though arthroscopic techniques may yield better results [46, 47]. Arthrocentesis alone does not provide the diagnostic value that arthroscopy does, but it may be technically less demanding and accessible given that it can be completed under local anesthesia with procedural sedation in an office setting. Additionally, it does not require costly arthroscopic equipment. Data suggest that it is also effective in improving pain and dysfunction [47].

Therapeutic medicaments can also be injected into the joint space. Examples have included corticosteroids, hyaluronic acid, morphine, and local anesthetic. More recently, platelet-rich plasma (PRP) injection, platelet-rich growth factor, and platelet-rich fibrin have been newer innovations. A study by Kutuk et al. compared the use of PRP, hyaluronic acid, and corticosteroid and found PRP to be more effective in reducing pain [48]. There have been promising results from other studies as well. However, a clear benefit over current treatments has not been established [49–52].

TMJ arthrotomy and arthroplasty are considered open-joint interventions and have not changed drastically in recent years. Arthrotomy involves surgery within the joint space,

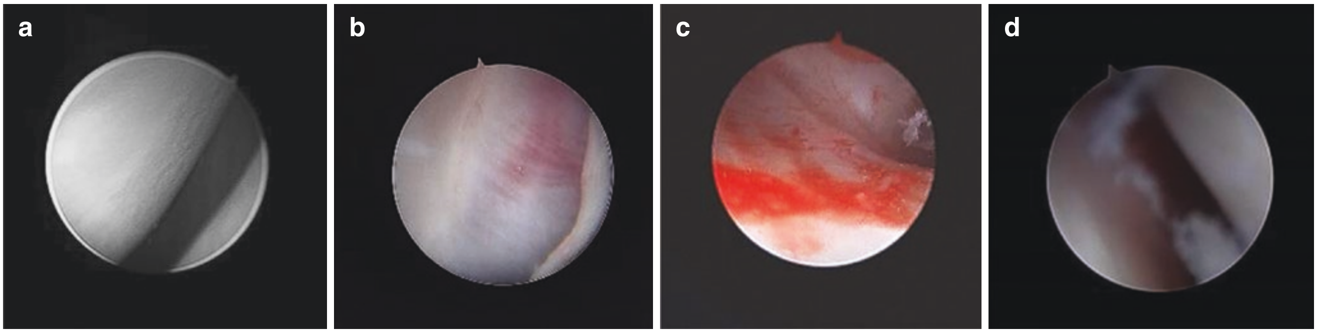

Fig. 50.11 (**a**) Intermediate zone. (**b**) Pterygoid shadow. (**c**) Retrodiscal tissue with creeping synovitis and hyperemia. (**d**) Fibrillation of the fibrocartilage

while arthroplasty will include alteration to the bony anatomy. Disc repositioning and discectomy are the most commonly performed procedures with an open approach. Indications for disc repositioning include anterior disc displacement with or without reduction, failure of conservative therapy, and arthroscopic procedures failure. Indications for discectomy include disc displacement with or without reduction, perforation, and fragmentation. Both procedures are undertaken by either a pre-auricular or endaural surgical approach. The Al-Kayat extension can be considered superior to improve access, though it is usually not necessary [53]. Once the superior joint space is accessed, the disc is then visualized for its position and inspected for perforations or tears. Should it be found to be healthy, then repositioning can be considered.

Wolford pioneered the use of Mitek anchors (DePuy Synthes, Raynham, Massachusetts) in TMJ surgery [54, 55]. The technique involves using a small titanium anchor with nickel-titanium wings that are drilled into the condylar neck and used as a fixation point for posterior and lateral repositioning of the articular disc (Fig. 50.12). In a study by Wolford and Mehra, they provide a description for the procedure and found that out of the 105 patients evaluated, 74% of patients had no pain, 13% of patients had mild pain, 8.5% patients had moderate pain, and 3% of patients still had severe pain at the longest follow-up [54]. Another study by Montgomery et al. showed that although in about 80% of patients the disc position did not seem to change significantly on imaging, pain was improved in 89% of patients [56]. Regardless, the decision to repair or reposition the articular disc should be approached with caution in order to minimize open procedures in the future.

If the disc is found to be damaged, fragmented, or torn, then a discectomy procedure may be more beneficial. Studies have shown that when the disc and/or articular cartilage is removed, there are morphological changes that occur to the condyle [57]. The incidence and severity of condylar remodeling seem to be much more extensive in patients who received additional condylar surgery in addition to discectomy, such as a high condylar shave or debridement of the fibrocartilage [58]. Surgeons have long sought an adequate material to place in the joint space after discectomy procedures. Alloplastic materials like silastic and Proplast-Teflon (Vitek, Inc, Houston, Texas) were used, though they ultimately fell out of favor, with the latter being recalled by the FDA [59]. Various autografts from different anatomic locations such as costal cartilage, auricular cartilage, dermis, fat, dermis–fat, fascia, and temporal muscle have been used with mixed results [60]. While an acceptable technique, auricular cartilage grafting has a high failure rate and does not prevent degenerative changes [61]. While providing adequate tissue in close proximity to the TMJ, the temporalis muscle flap has been shown to result in pain, restricted mouth opening, and cosmetic defects [62]. Of the various autogenous materials available, fat and the dermis-fat grafts are the most promising. Placement of fat within the joint space after discectomy is thought to prevent organized clot formation, leading to ankylosis. Dimitroulis has published several case series on the technique, touting very low rates of ankylosis, significant improvements in quality of life, and the formation of interpositional material between the condyle and the fossa [63–65]. However, there are concerns about donor site morbidity.

Amniotic membranes and amniotic cords have been gaining more and more popularity in oral and maxillofacial surgery. They have been applied to implant surgery, complex intraoral reconstruction, vestibulopathy, and TMJ surgery [66]. A rat model showed that they were biocompatible and prevented adhesion formation in abdominal wall reconstruction [67]. Tuncel showed that they prevented adhesions and osteophytes formation when used as an interpositional arthroplasty material in the treatment of fibrous ankyloses in rabbit models [68]. Akhter presented a case study of 13 patients who were treated for bony ankyloses using a layered amniotic membrane in which all patients demonstrated improved pain and mobility at 1-, 6-, and 12-month intervals [69]. Nardini hypothesized that the antimicrobial, anti-inflammatory, low immunogenicity, and analgesic properties of amnion membranes would make

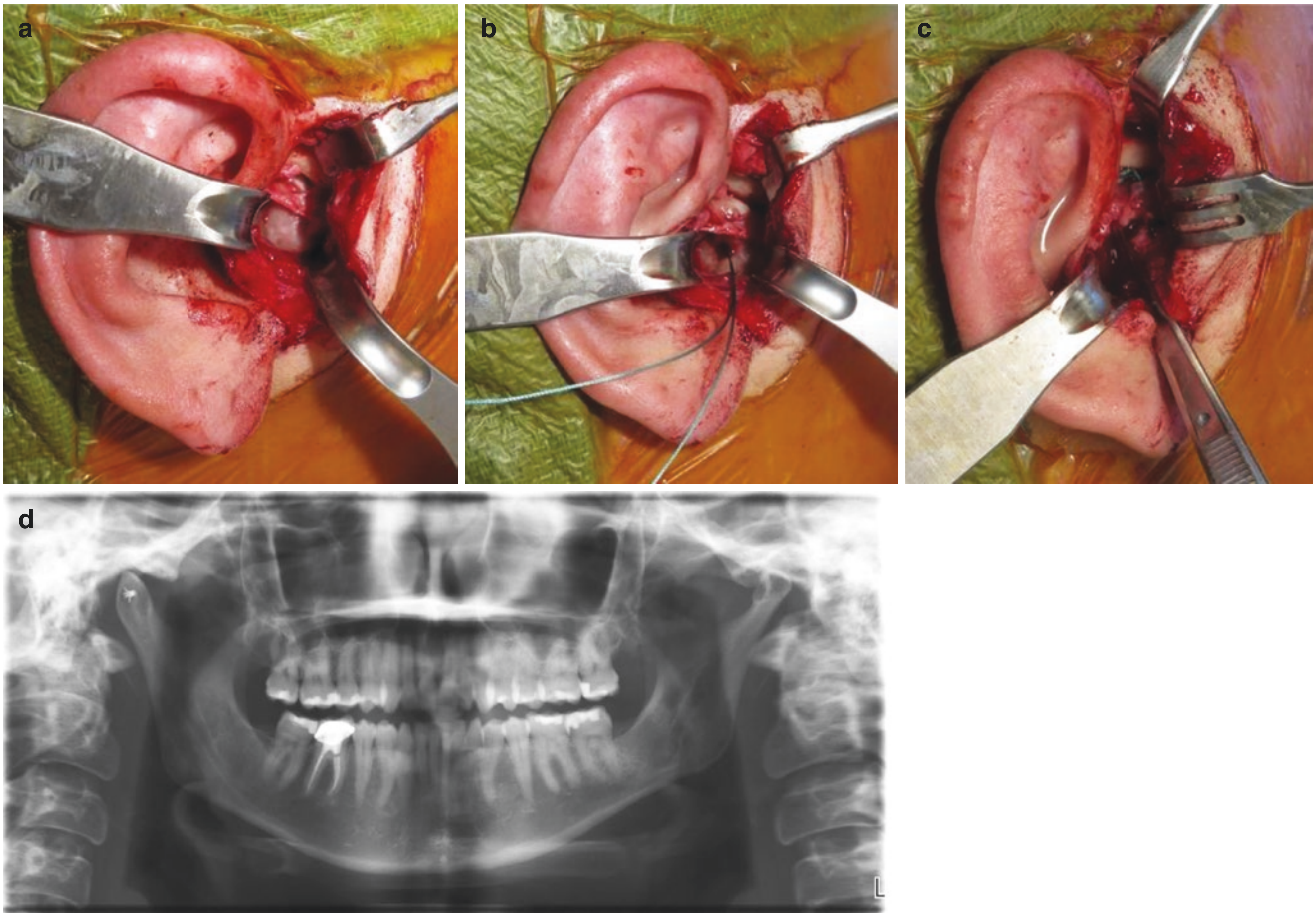

Fig. 50.12 (**a**) Isolation of the articular disc. (**b**) Placement of the Mitek anchor (DePuy Synthes, Raynham, Massachusetts). (**c**) Articular disc repositioned and sutured in place. (**d**) Post-operative orthopantomogram showing the Mitek anchor within the condylar neck

them an ideal interpositional material within the TMJ [70]. Investigators recently presented a case series that involved discectomy followed by implantation of cryopreserved viable osteochondral allograft combined with a viable cryopreserved umbilical cord tissue allograft. The reported outcomes suggest that the interpositional implantation of osteochondral allograft and umbilical cord tissue graft after TMJ discectomy could be a solution for reducing TMJ-related pain and restoring TMJ function, though longer follow-up and prospective multicenter studies are warranted. It should be noted that most patients experienced an improvement in symptoms but decreased MIO [71].

Consideration can also be given to discectomy without replacement (Fig. 50.13). A study by Homlund et al. reports an 83% success rate at 1 year after discectomy procedures [72]. Miloro et al. also showed a success rate of discectomy without replacement of around 83%. They also advocate that given the success rate and reduction in success with multiple operations, discectomy can be considered an initial intervention rather than a procedure of last resort after unsuccessful discopexy procedures [18, 73, 74].

Though both disc repositioning and discectomy are valid surgical interventions that are shown to be successful, care should be taken to decide on which intervention is pursued. The Mitek anchor (DePuy Synthes, Raynham, Massachusetts) may make disc repositioning more predictable in the long term. Discectomy with and without replacement seems to be a safe surgical option in many cases.

Total joint replacement (TJR) has become much more common in the last 20 years due to the emergence of stable long-term results with the prostheses available for use [18, 75–78]. Many different prostheses, such as the Christensen fossa and various TMJ replacement devices were engineered over many years of development and study with various degrees of success. These gave rise to the modern patient-fitted prosthesis from TMJ Concepts (Ventura, California) and the stock prostheses from Walter Lorenz Surgical Inc. now Zimmer Biomet (Jacksonville, Florida) [79, 80]. Indications for TJR include ankylosis, severe degenerative joint disease, pathology, failed previous surgery, failed previous autogenous joint replacement, condylar agenesis, avascular necrosis, developmental abnormalities, and traumatic injury.

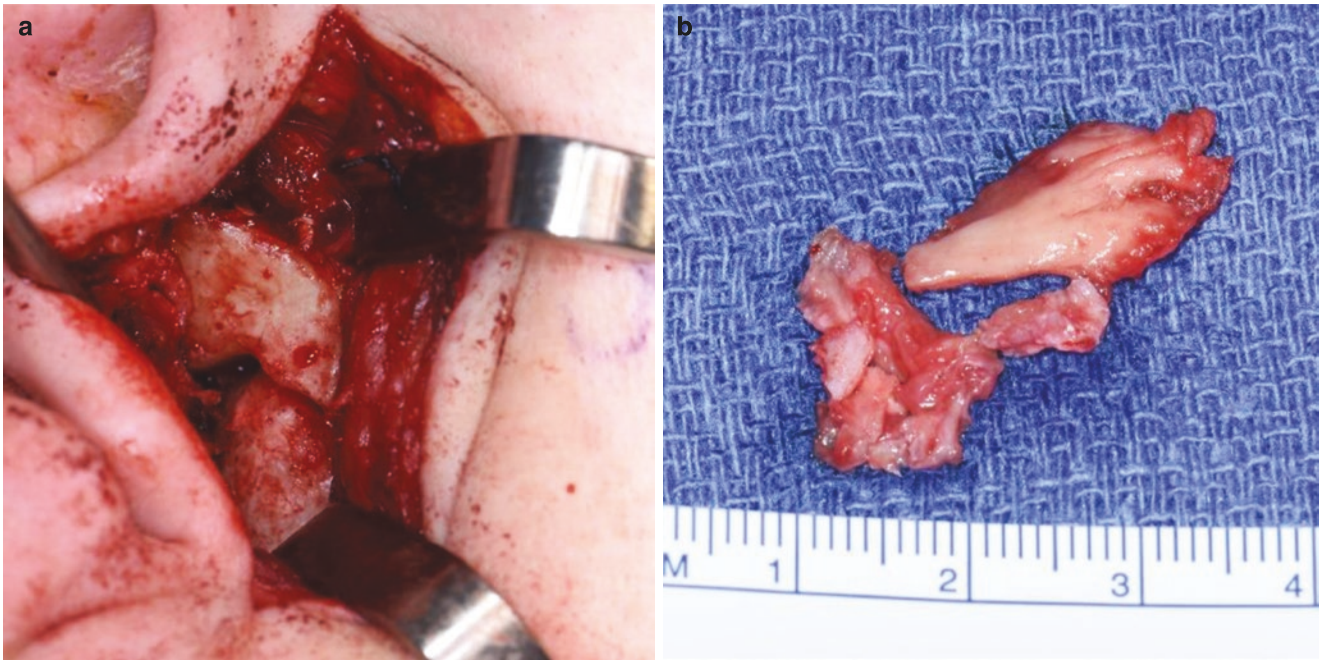

Fig. 50.13 (**a**) Clinical image of TMJ after disc removal without replacement. (**b**) Fragmented residual articular disc

Currently, a stock prosthesis is available from Zimmer Biomet (Jasksonville, Florida) as well as a patient-fitted prosthesis from TMJ Concepts (Ventura, California). The indications for use are similar for both. The advantages of the stock device include potentially lower cost and immediate availability. Patients with more severe bony deformities or those requiring concomitant movement of the mandible in a significant manner will be better suited for a patient-fitted prosthesis. The disadvantages of the patient-fitted prosthesis are cost and time required for fabrication.

Both the stock and patient-fitted prostheses have good long-term outcome data supporting their use as safe and effective [76, 77]. It is the author's opinion that the patient-fitted prosthesis may be easier to place if more immediate surgery is not needed. The stock prosthesis is excellent in the management of traumatic injuries [81].

In addition to the advent of these prostheses, the integration of CBCT into planning has been significant innovation in treatment. A patient may no longer require a medical-grade CT scan in the planning stages, which makes obtaining the DICOM data simpler and more cost-effective. In addition, with the use of the TMJ concepts (Ventura, California), patient-fitted prosthesis integration with VSP is more straightforward and accurate. Movahed describes the traditional approach and the computer-assisted approach that allows for complex movement of the mandibular position in combination with maxillary orthognathic procedures [82, 83]. With the advent of intra-oral scanners, the use of stone dental models and impressions is not necessary, and a fully digital workflow can be utilized in contrast to Movahed's initial description.

The authors use a similar workflow described below.

1. CBCT data and intra-oral scan data are sent to both TMJ Concepts (Ventura, California) and KLS Martin (Jacksonville, Florida).
2. Using Individualized Patient Solutions (IPS) software with KLS Martin (Jacksonville, Florida) engineers, the final occlusion is set from the intra-oral scan data (Fig. 50.14).
3. The LeFort procedure and position of the maxilla are determined in all planes (Fig. 50.15).
4. The mandible is set to meet this position based on the final occlusion.
5. Gap arthroplasty and coronoidectomy, if desired, are marked and completed digitally.
6. This planning data is used to create an intermediate and final splint.
7. The data is shared with TMJ Concepts (Ventura, California) to fabricate the patient-fitted prosthesis (Fig. 50.16).

Another added benefit of this workflow is creating cutting guides for planned osteotomies and bone reduction if desired.

This workflow has helped to improve the accuracy of planning and surgical outcomes while decreasing the difficulty of surgery.

When managing large ankylotic bony masses, pathology, or multi-operative joints, bleeding can pose a signifi-

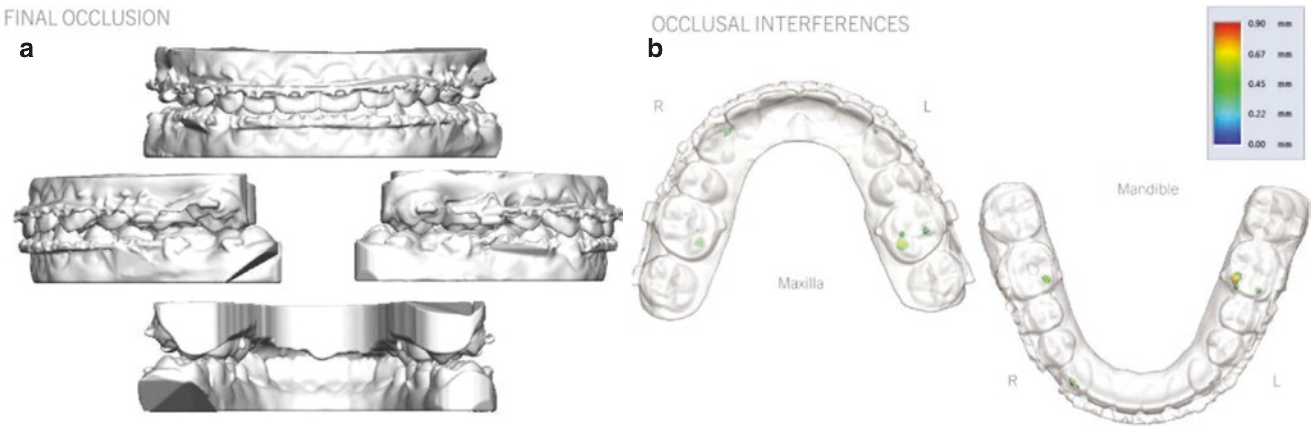

Fig. 50.14 (**a**) Final occlusion set digitally using intra-oral scan data. (**b**) Pressure map revealing points of contact and adjustments for planned final occlusion

cant risk. The use of CTA can be helpful in analyzing the vascular anatomy around the joint space and the course of the internal maxillary artery. In some cases, embolization of the vessels that may pose a significant bleeding risk at the time of surgery should be considered. This will help keep the surgical field dry and increase the ease of surgery while also lowering the risk of inadvertent vascular compromise for the patient. A case series by Susara et al. evaluated five cases of ankylosis and found a decrease in blood loss on the embolized side, and the ease of surgery improved [84]. Hossameldin et al. evaluated 14 patients with ankylosis and found that all patients suffered less than 250 mL of blood loss [85]. Should embolization not be possible, the anatomic information obtained remains valuable to the surgeon to help avoid vascular compromise and decrease blood loss.

Finally, in cases of pathology or large bony ankylotic masses, intra-operative CT guidance can help avoid complications. These systems offer surgical probes that allow the surgeon to translate the probe's position to an anatomic location on the CT scan, helping the surgeon to avoid damaging anatomic structures which are medial to the surgical field. In cases requiring significant recontouring of the temporal bone, CT guidance can help prevent inadvertent entrance into the middle cranial fossa as well [86, 87].

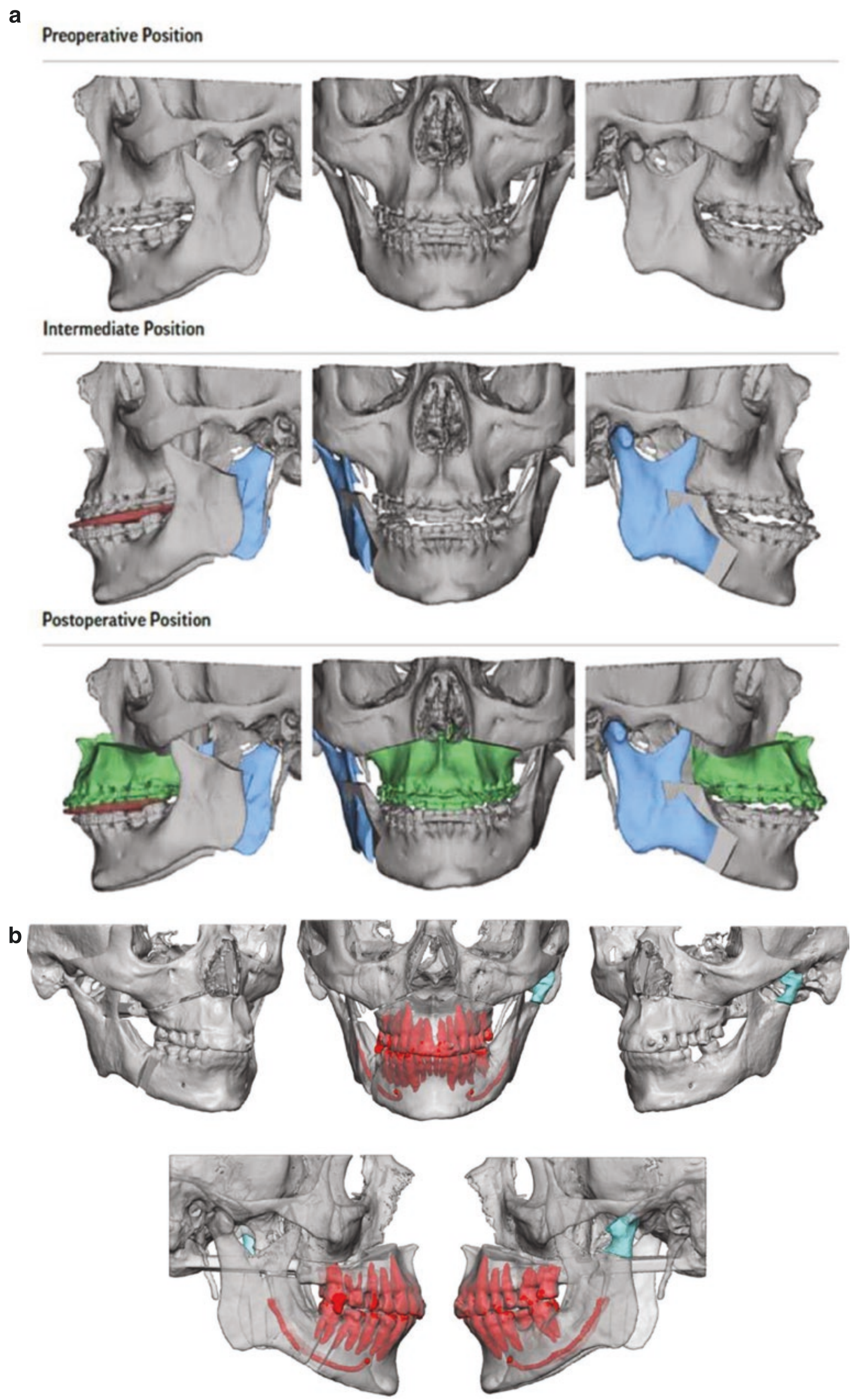

Fig. 50.15 (**a**) VSP plan including the preoperative state, the intermediate position after digital gap arthroplasty and sagittal split osteotomy, and final position with LeFort I osteotomy and final occlusion. (**b**) Final data showing LeFort I, sagittal split osteotomy, and gap arthroplasty to be shared with TMJ Concepts (Ventura, California)

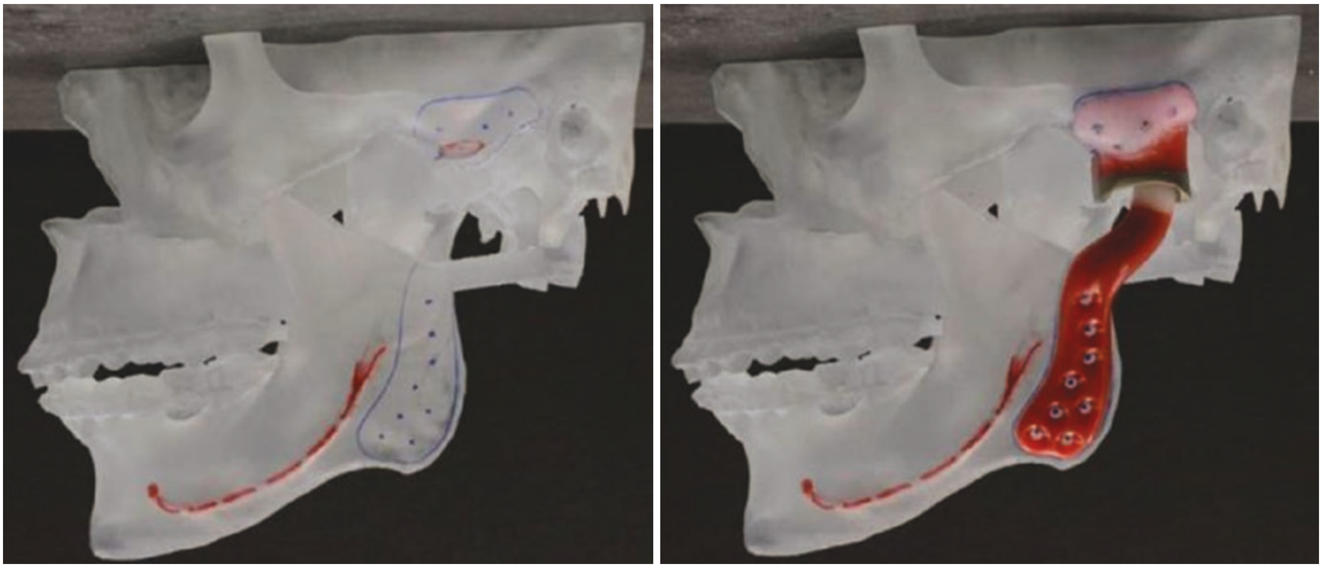

Fig. 50.16 Pre-operative TMJ Concepts (Ventura, California) plan with 3D printed models created from data shared by IPS. (KLS Martin, Jacksonville, Florida)

Conclusion

Patients with TMD can be difficult to manage, but with the integration of recent innovations into management protocols, outcomes can be improved. Integrating CBCT imaging data and diagnostic arthroscopy can help form very accurate diagnoses that will help guide patients and surgeons to appropriate interventions. Innovations in TMJ arthroscopy have helped to provide a minimally invasive management option to many patients and surgeons. This has included the introduction of different therapeutic medications into the joint. Additionally, the use of Botox® (Allergan, Madison, New Jersey) in the management of myofascial pain seems to be showing promising results, though more investigations are needed. Traditional open arthroplasty and arthrotomy procedures have moved toward using adjuncts like the Mitek Anchor (Dupuy Synthes, Raynham, Massachusetts), amniotic membranes, and tissue grafts in discectomy procedures. And finally, one of the most innovative changes in the field has been the stable and predictable use of patient-fitted and stock alloplastic joint replacements. This treatment has been further refined with the integration of digital workflows in planning. Some of the risks have been decreased with the use of intra-operative CT navigation as well as pre-operative CTA and embolization. As we look to the future, tissue engineering may provide a more stable graft in discectomy procedures, and digital platforms will likely continue to evolve rapidly, making surgery more predictable while decreasing risk.

References

1. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. Int J Oral Maxillofac Surg. 2009;38:609.
2. Barghan S, Tetradis S, Mallya S. Application of cone beam computed tomography for assessment of the temporomandibular joints. Aust Dent J. 2012;57(Suppl 1):109.
3. Zain-Alabdeen EH, Alsadhan RI. A comparative study of accuracy of detection of surface osseous changes in the temporomandibular joint using multidetector CT and cone beam CT. Dentomaxillofac Radiol. 2012;41:185.
4. Fallah HM, Currimbhoy S. Use of botulinum toxin A for treatment of myofascial pain and dysfunction. J Oral Maxillofac Surg. 2012;70:1243.
5. Binder WJ, Brin MF, Blitzer A, Schoenrock LD, Pogoda JM. Botulinum toxin type A (BOTOX) for treatment of migraine headaches: an open-label study. Otolaryngol Head Neck Surg. 2000;123:669.
6. Aoki KR. Review of a proposed mechanism for the antinociceptive action of botulinum toxin type A. Neurotoxicology. 2005;26:785.
7. Acquadro MA, Borodic GE. Treatment of myofascial pain with botulinum A toxin. Anesthesiology. 1994;80:705.
8. Freund B, Schwartz M, Symington JM. The use of botulinum toxin for the treatment of temporomandibular disorders: preliminary findings. J Oral Maxillofac Surg. 1999;57:916.
9. von Lindern JJ, Niederhagen B, Bergé S, Appel T. Type A botulinum toxin in the treatment of chronic facial pain associated with masticatory hyperactivity. J Oral Maxillofac Surg. 2003;61:774.
10. Ali R, Webster K, Kennedy D. A review of treatment outcomes for patients receiving intra-masseteric botulinum toxin-A for the management of facial myofascial pain. Br J Oral Maxillofac Surg. 2017;55:e146.
11. Kurtoglu C, Gur OH, Kurkcu M, Sertdemir Y, Guler-Uysal F, Uysal H. Effect of botulinum toxin-A in myofascial pain patients with

or without functional disc displacement. J Oral Maxillofac Surg. 2008;66:1644.
12. Porta M. A comparative trial of botulinum toxin type A and methylprednisolone for the treatment of myofascial pain syndrome and pain from chronic muscle spasm. Pain. 2000;85:101.
13. Nixdorf DR, Heo G, Major PW. Randomized controlled trial of botulinum toxin A for chronic myogenous orofacial pain. Pain. 2002;99:465.
14. Ernberg M, Hedenberg-Magnusson B, List T, Svensson P. Efficacy of botulinum toxin type A for treatment of persistent myofascial TMD pain: a randomized, controlled, double-blind multicenter study. Pain. 2011;152:1988.
15. Milne S, Carter L, Cooper T. An audit of the efficacy of botulinum toxin for myofascial pain. Br J Oral Maxillofac Surg. 2016;54:e124.
16. Wilkes CH. Internal derangements of the temporomandibular joint. Pathological variations. Arch Otolaryngol Head Neck Surg. 1989;115:469.
17. Wilkes CH. Surgical treatment of internal derangements of the temporomandibular joint. A long-term study. Arch Otolaryngol Head Neck Surg. 1991;117:64.
18. Mercuri LG. Subjective and objective outcomes in patients reconstructed with a custom-fitted alloplastic temporomandibular joint prosthesis. J Oral Maxillofac Surg. 1999;57:1427.
19. Suvinen TI, Hanes KR, Reade PC. Outcome of therapy in the conservative management of temporomandibular pain dysfunction disorder. J Oral Rehabil. 1997;24:718.
20. Carraro JJ, Caffesse RG. Effect of occlusal splints on TMJ symptomatology. J Prosthet Dent. 1978;40:563.
21. Tsuga K, Akagawa Y, Sakaguchi R, Tsuru H. A short-term evaluation of the effectiveness of stabilization-type occlusal splint therapy for specific symptoms of temporomandibular joint dysfunction syndrome. J Prosthet Dent. 1989;61:610.
22. Türp JC, Komine F, Hugger A. Efficacy of stabilization splints for the management of patients with masticatory muscle pain: a qualitative systematic review. Clin Oral Investig. 2004;8:179.
23. Dimitroulis G, Gremillion HA, Dolwick MF, Walter JH. Temporomandibular disorders. 2. Non-surgical treatment. Aust Dent J. 1995;40:372.
24. Greene CS, Menchel HF. The use of oral appliances in the management of temporomandibular disorders. Oral Maxillofac Surg Clin North Am. 2018;30:265.
25. Pettengill CA, Growney MR, Schoff R, Kenworthy CR. A pilot study comparing the efficacy of hard and soft stabilizing appliances in treating patients with temporomandibular disorders. J Prosthet Dent. 1998;79:165.
26. Wright E, Anderson G, Schulte J. A randomized clinical trial of intraoral soft splints and palliative treatment for masticatory muscle pain. J Orofac Pain. 1995;9:192.
27. Heir GM. The efficacy of pharmacologic treatment of temporomandibular disorders. Oral Maxillofac Surg Clin North Am. 2018;30:279.
28. Sharav Y, Singer E, Schmidt E, Dionne RA, Dubner R. The analgesic effect of amitriptyline on chronic facial pain. Pain. 1987;31:199.
29. Plesh O, Curtis D, Levine J, McCall WD. Amitriptyline treatment of chronic pain in patients with temporomandibular disorders. J Oral Rehabil. 2000;27:834.
30. Rizzatti-Barbosa CM, Nogueira MT, de Andrade ED, Ambrosano GM, de Barbosa JR. Clinical evaluation of amitriptyline for the control of chronic pain caused by temporomandibular joint disorders. Cranio. 2003;21:221.
31. Raigrodski AJ, Christensen LV, Mohamed SE, Gardiner DM. The effect of four-week administration of amitriptyline on sleep bruxism. A double-blind crossover clinical study. Cranio. 2001;19:21.
32. Mohamed SE, Christensen LV, Penchas J. A randomized double-blind clinical trial of the effect of amitriptyline on nocturnal masseteric motor activity (sleep bruxism). Cranio. 1997;15:326.
33. Onishi M. Aarthroscopy of the temporomandibular joint (author's transl). Kokubyo Gakkai Zasshi. 1975;42:207.
34. Murakami K. Rationale of arthroscopic surgery of the temporomandibular joint. J Oral Biol Craniofac Res. 2013;3:126.
35. McCain JP. Arthroscopy of the human temporomandibular joint. J Oral Maxillofac Surg. 1988;46:648.
36. Breik O, Devrukhkar V, Dimitroulis G. Temporomandibular joint (TMJ) arthroscopic lysis and lavage: outcomes and rate of progression to open surgery. J Craniomaxillofac Surg. 2016;44:1988.
37. Al-Moraissi EA. Arthroscopy versus arthrocentesis in the management of internal derangement of the temporomandibular joint: a systematic review and meta-analysis. Int J Oral Maxillofac Surg. 2015;44:104.
38. Kaneyama K, Segami N, Sato J, Murakami K, Iizuka T. Outcomes of 152 temporomandibular joints following arthroscopic anterolateral capsular release by holmium: YAG laser or electrocautery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2004;97:546.
39. Holmlund A. Diagnostic TMJ arthroscopy. Oral Surg Oral Diagn. 1992;3:13.
40. Murakami KI, Lizuka T, Matsuki M, Ono T. Diagnostic arthroscopy of the TMJ: differential diagnoses in patients with limited jaw opening. Cranio. 1986;4:117.
41. Murakami K, Ono T. Temporomandibular joint arthroscopy by inferolateral approach. Int J Oral Maxillofac Surg. 1986;15:410.
42. González-García R, Rodríguez-Campo FJ. Arthroscopic lysis and lavage versus operative arthroscopy in the outcome of temporomandibular joint internal derangement: a comparative study based on Wilkes stages. J Oral Maxillofac Surg. 2011;69:2513.
43. McCain JP, Hossameldin RH, Srouji S, Maher A. Arthroscopic discopexy is effective in managing temporomandibular joint internal derangement in patients with Wilkes stage II and III. J Oral Maxillofac Surg. 2015;73:391.
44. McCain JP, Sanders B, Koslin MG, Quinn JH, Peters PB, Indresano AT, Quinn JD. Temporomandibular joint arthroscopy: a 6-year multicenter retrospective study of 4,831 joints. J Oral Maxillofac Surg. 1992;50:926.
45. Al-Moraissi EA. Open versus arthroscopic surgery for the management of internal derangement of the temporomandibular joint: a meta-analysis of the literature. Int J Oral Maxillofac Surg. 2015;44:763.
46. Indresano AT. Surgical arthroscopy as the preferred treatment for internal derangements of the temporomandibular joint. J Oral Maxillofac Surg. 2001;59:308.
47. Nitzan DW, Dolwick MF, Martinez GA. Temporomandibular joint arthrocentesis: a simplified treatment for severe, limited mouth opening. J Oral Maxillofac Surg. 1991;49:1163.
48. Gokçe Kutuk S, Gökçe G, Arslan M, Özkan Y, Kütük M, Kursat Arikan O. Clinical and radiological comparison of effects of platelet-rich plasma, hyaluronic acid, and corticosteroid injections on temporomandibular joint osteoarthritis. J Craniofac Surg. 2019;30:1144.
49. Bousnaki M, Bakopoulou A, Koidis P. Platelet-rich plasma for the therapeutic management of temporomandibular joint disorders: a systematic review. Int J Oral Maxillofac Surg. 2018;47:188.
50. Cömert Kiliç S, Güngörmüş M. Is arthrocentesis plus platelet-rich plasma superior to arthrocentesis plus hyaluronic acid for the treatment of temporomandibular joint osteoarthritis: a randomized clinical trial. Int J Oral Maxillofac Surg. 2016;45:1538.
51. Chung PY, Lin MT, Chang HP. Effectiveness of platelet-rich plasma injection in patients with temporomandibular joint osteoarthritis: a

systematic review and meta-analysis of randomized controlled trials. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019;127:106.
52. Haigler MC, Abdulrehman E, Siddappa S, Kishore R, Padilla M, Enciso R. Use of platelet-rich plasma, platelet-rich growth factor with arthrocentesis or arthroscopy to treat temporomandibular joint osteoarthritis: systematic review with meta-analyses. J Am Dent Assoc. 2018;149:940.
53. Al-Kayat A, Bramley P. A modified pre-auricular approach to the temporomandibular joint and malar arch. Br J Oral Surg. 1979;17:91.
54. Mehra P, Wolford LM. The Mitek mini anchor for TMJ disc repositioning: surgical technique and results. Int J Oral Maxillofac Surg. 2001;30:497.
55. Mehra P, Wolford LM. Use of the Mitek anchor in temporomandibular joint disc-repositioning surgery. Proc (Bayl Univ Med Cent). 2001;14:22.
56. Montgomery MT, Gordon SM, Van Sickels JE, Harms SE. Changes in signs and symptoms following temporomandibular joint disc repositioning surgery. J Oral Maxillofac Surg. 1992;50:320.
57. Abdala-Júnior R, Cortes ARG, Aoki EM, Ferreira S, Luz JGC, Arita ES, de Oliveira JX. Impact of temporomandibular joint discectomy on condyle morphology: an animal study. J Oral Maxillofac Surg. 2018;76:955.e1.
58. Dimitroulis G. Condylar morphology after temporomandibular joint discectomy with interpositional abdominal dermis-fat graft. J Oral Maxillofac Surg. 2011;69:439.
59. McKenna SJ. Discectomy for the treatment of internal derangements of the temporomandibular joint. J Oral Maxillofac Surg. 2001;59:1051.
60. Dimitroulis G. A critical review of interpositional grafts following temporomandibular joint discectomy with an overview of the dermis-fat graft. Int J Oral Maxillofac Surg. 2011;40:561.
61. Ioannides C, Freihofer HP. Replacement of the damaged interarticular disc of the TMJ. J Craniomaxillofac Surg. 1988;16:273.
62. Lam D, Carlson ER. The temporalis muscle flap and temporoparietal fascial flap. Oral Maxillofac Surg Clin North Am. 2014;26:359.
63. Dimitroulis G. The interpositional dermis-fat graft in the management of temporomandibular joint ankylosis. Int J Oral Maxillofac Surg. 2004;33:755.
64. Dimitroulis G, McCullough M, Morrison W. Quality-of-life survey comparing patients before and after discectomy of the temporomandibular joint. J Oral Maxillofac Surg. 2010;68:101.
65. Dimitroulis G, Trost N, Morrison W. The radiological fate of dermis-fat grafts in the human temporomandibular joint using magnetic resonance imaging. Int J Oral Maxillofac Surg. 2008;37:249.
66. Kesting MR, Wolff KD, Nobis CP, Rohleder NH. Amniotic membrane in oral and maxillofacial surgery. Oral Maxillofac Surg. 2014;18:153.
67. Akhter M, Ahmed N, Arefin MR, Sobhan MU, Molla MR, Kamal M. Outcome of amniotic membrane as an interpositional arthroplasty of TMJ ankylosis. Oral Maxillofac Surg. 2016;20:63.
68. Kesting MR, Wolff KD, Mücke T, Demtroeder C, Kreutzer K, Schulte M, Jacobsen F, Hirsch T, Loeffelbein DJ, Steinstraesser L. A bioartificial surgical patch from multilayered human amniotic membrane-in vivo investigations in a rat model. J Biomed Mater Res B Appl Biomater. 2009;90:930.
69. Tuncel U, Ozgenel GY. Use of human amniotic membrane as an interpositional material in treatment of temporomandibular joint ankylosis. J Oral Maxillofac Surg. 2011;69:e58.
70. Guarda-Nardini L, Trojan D, Paolin A, Manfredini D. Management of temporomandibular joint degenerative disorders with human amniotic membrane: hypothesis of action. Med Hypotheses. 2017;104:68.
71. Connelly ST, Silva R, Gupta R, O'Hare M, Danilkovitch A, Tartaglia G. Temporomandibular joint discectomy followed by disc replacement using viable osteochondral and umbilical cord allografts results in improved patient outcomes. J Oral Maxillofac Surg. 2020;78:63.
72. Holmlund A, Lund B, Weiner CK. Discectomy without replacement for the treatment of painful reciprocal clicking or catching and chronic closed lock of the temporomandibular joint: a clinical follow-up audit. Br J Oral Maxillofac Surg. 2013;51:e211.
73. Miloro M, Henriksen B. Discectomy as the primary surgical option for internal derangement of the temporomandibular joint. J Oral Maxillofac Surg. 2010;68:782.
74. Miloro M, McKnight M, Han MD, Markiewicz MR. Discectomy without replacement improves function in patients with internal derangement of the temporomandibular joint. J Craniomaxillofac Surg. 2017;45:1425.
75. Mercuri LG. Alloplastic temporomandibular joint reconstruction. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;85:631.
76. Wolford LM, Mercuri LG, Schneiderman ED, Movahed R, Allen W. Twenty-year follow-up study on a patient-fitted temporomandibular joint prosthesis: the Techmedica/TMJ concepts device. J Oral Maxillofac Surg. 2015;73:952.
77. Granquist EJ, Bouloux G, Dattilo D, Gonzalez O, Louis PJ, McCain J, Sinn D, Szymela V, Warner M, Quinn PD. Outcomes and survivorship of biomet microfixation total joint replacement system: results from an FDA postmarket study. J Oral Maxillofac Surg. 2020;78:1499.
78. Granquist EJ, Quinn PD. Total reconstruction of the temporomandibular joint with a stock prosthesis. Atlas Oral Maxillofac Surg Clin North Am. 2011;19:221.
79. De Meurechy N, Mommaerts MY. Alloplastic temporomandibular joint replacement systems: a systematic review of their history. Int J Oral Maxillofac Surg. 2018;47:743.
80. Mercuri LG, Wolford LM, Sanders B, White RD, Hurder A, Henderson W. Custom CAD/CAM total temporomandibular joint reconstruction system: preliminary multicenter report. J Oral Maxillofac Surg. 1995;53:106.
81. Giannakopoulos HE, Quinn PD, Granquist E, Chou JC. Posttraumatic temporomandibular joint disorders. Craniomaxillofac Trauma Reconstr. 2009;2:91.
82. Movahed R, Teschke M, Wolford LM. Protocol for concomitant temporomandibular joint custom-fitted total joint reconstruction and orthognathic surgery utilizing computer-assisted surgical simulation. J Oral Maxillofac Surg. 2013;71:2123.
83. Movahed R, Wolford LM. Protocol for concomitant temporomandibular joint custom-fitted total joint reconstruction and orthognathic surgery using computer-assisted surgical simulation. Oral Maxillofac Surg Clin North Am. 2015;27:37.
84. Susarla SM, Peacock ZS, Williams WB, Rabinov JD, Keith DA, Kaban LB. Role of computed tomographic angiography in treatment of patients with temporomandibular joint ankylosis. J Oral Maxillofac Surg. 2014;72:267.
85. Hossameldin RH, McCain JP, Dabus G. Prophylactic embolisation of the internal maxillary artery in patients with ankylosis of the temporomandibular joint. Br J Oral Maxillofac Surg. 2017;55:584.
86. Yu HB, Shen GF, Zhang SL, Wang XD, Wang CT, Lin YP. Navigation-guided gap arthroplasty in the treatment of temporomandibular joint ankylosis. Int J Oral Maxillofac Surg. 2009;38:1030.
87. Gui H, Wu J, Shen SG, Bautista JS, Voss PJ, Zhang S. Navigation-guided lateral gap arthroplasty as the treatment of temporomandibular joint ankylosis. J Oral Maxillofac Surg. 2014;72:128.