Contemporary Management of Temporomandibular Disorders

Surgical Treatment

S. Thaddeus Connelly
Gianluca Martino Tartaglia
Rebeka G. Silva
Editors

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Foreword

The majority of patients presenting with signs and symptoms of temporomandibular disorders (TMD) have extra-articular conditions which should be managed nonsurgically, as reviewed in Volume II.

The management of early definitive intra-articular TMD pathology often involves minimally invasive or open-joint surgical procedures. However, patients with compromised mandibular form and function resulting from end-stage joint disease are more appropriately managed with joint replacement or combined joint replacement and maxilla-mandibular orthognathic surgical procedures.

Volume III begins with a historical perspective of temporomandibular joint surgery. As the nineteenth-century American physician Alfred Stille wrote, "Medicine, like all knowledge, has a past as well as a present and a future, and in that past is the indispensable soil out of which improvement must grow."

The most important phase in the management of any disease is diagnosis. If a surgeon operates having made the right diagnosis, on the right patient, in the right way, using the right equipment, the outcome should be very predictable. However, a misstep at any of these stages will often lead to unexpected or adverse consequences.

Knowledge and mastery of surgical anatomy and the approaches to the temporomandibular joint and associated structures are critical. The important anatomical structures that occupy the region require constant review and reinforcement, since merely a casual understanding of the anatomy can have serious functional and esthetic consequences.

Minimally invasive temporomandibular joint procedures, such as arthrocentesis and diagnostic/arthroscopic surgery, have revolutionized the management of early intra-articular disease. They have also provided surgeons with a more comprehensive view of the pathophysiology of early TMJ disorders leading to a more profound understanding of the biology of the synovial, articular bone and fibrocartilage components of this joint.

Progression to invasive open reparative joint procedures such as arthroplasty, disc repositioning, and discectomy has definite diagnostic and performance criteria. For patients with form and functional end-stage joint disease, the option of total joint replacement utilizing autogenous tissue, alloplastic, or in the future bioengineered constructs should be based on the pathology, state of the host bone, and the experience of the surgeon.

Alloplastic total joint replacement, a biomechanical answer to a biological problem, has been successfully utilized in orthopedic surgery for over 50 years in the management of end-stage joint disease. In fact, the modern practice of orthopedic surgery would be impossible without the availability of these devices. There is now documented greater than 20 years success with TMJ alloplastic total joint replacement constructs and ever-increasing clinical and laboratory reports demonstrating their safety and efficacy.

Bioengineered tissue TMJ constructs, presently in the conceptual and laboratory stages of development, may one day provide another viable option for the management of end-stage TMJ disease. However, these basically autogenous tissue constructs may have the same disadvantages as transplanted autogenous tissue grafts when challenged by local or systemic bone-damaging diseases like high-inflammatory arthritis.

No one knows what advances in surgical techniques, equipment, and constructs lie ahead for TMJ surgeons. However, one thing is certain, as C. William Pollard has said, “The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow.” Therefore, it is up to future clinicians and researchers to “till the soil” that has been fertilized by the work of their predecessors.

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Preface

The invasive treatment of temporomandibular disorders is simultaneously challenging and rewarding. Whether the joint is appreciated through a scope or through open-joint surgery, the anatomy is beautiful, and one is always inspired by its intricacy, even in the advanced diseased state. It is through arthroscopy or surgery that the surgeon's steady hand and sharp eye holds the promise of decreased pain and improvement of function. Disease within the joint or a history of previous surgical intervention markedly disturbs normal anatomy; thus the surgeon must appreciate the proximity of the joint to many other critical structures and also understand every cell layer on the way to the joint.

In this volume, which focuses on the surgical treatment of temporomandibular disorders, respected surgeons from around the world teach us their craft and inform us of their research outcomes through the written word. There is an incredible wealth of information to learn. Most surgeons spend a lifetime refining skills and learning to operate from the focused, instinctive, and creative part of the brain. It is our hope that the reader uses these chapters as inspiration for their own development and gains an appreciation of the evolution of TMJ surgery, as well as its future.

In Part I, we begin by learning about the history of TMJ surgery. The following chapters take us through TMD diagnosis for surgical candidates and surgical pathways to the joint, which lays the groundwork for Part II. Part II delves into surgical procedures other than total joint replacement. This includes surgical arthroscopy, intraoral vertical ramus osteotomy, and discectomy and arthroplasty. Many of these procedures can be considered foundational surgeries that eventually led to extraordinary advances in total joint reconstruction. TMJ reconstruction for adults and children is the topic of Part III. In great detail, the reader will understand the step-by-step processes needed to successfully carry out the surgery, avoid complications, and manage complications should they occur. Many complex cases require virtual surgical planning, and this is especially important for those patients with comorbid diagnoses of craniofacial deformity, obstructive sleep apnea, cancer, osteoradionecrosis, or trauma. The chapters will give the reader a good understanding of the application of TMJ reconstruction in these special circumstances. Lastly, we reach the future of TMJ surgery with a fascinating look at what lies ahead in the domain of bioengineering. The volume ends with a discussion of how to educate the next generation of TMJ surgeons.

The editors and contributing authors of this comprehensive textbook humbly thank our readers for taking this journey to gain essential knowledge, to refine skills, to inform future research directions, and, above all, to treat our TMD patients.

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Contents

Part I

Temporomandibular Joint Surgical Evolution, Diagnosis and Anatomic Pathways

1 Evolution of the Modern Surgical Management of Temporomandibular Disorders

MA Pogrel and Robert Hensher

Abstract

One of the authors (MAP) was fortunate enough to be a trainee to a very prominent British oral and maxillofacial surgeon many years ago. This gentleman was the only person who claimed to be able to cure all of his patients with temporomandibular joint problems. His technique was that if any patient complained of temporomandibular joint problems, he wired their jaws together for 6 weeks. At the end of 6 weeks, he released the fixation and asked how they were feeling. If they said everything felt okay, he counted them as a cure, and if they still complained of temporomandibular joint problems, he put them into intramaxillary fixation for another 6 weeks. At the end of the second 6 weeks, he asked them again, and only the occasional recalcitrant patient had to undergo three 6-week courses of intramaxillary fixation before they admitted that they were cured!

Unfortunately, we will never know how successful this treatment was. There is no doubt that a period of complete rest for a joint can be very helpful, and even curative, for a number of conditions, and this almost certainly applies to temporomandibular joints, but it is probably something short of 100%. Sometimes the success of the treatment depends on the personality of the treater.

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The temporomandibular joints (TMJs) are the most complex joints in the human body. They are the only joints that both hinge and slide and one of only three joints that has a meniscus dividing it into an upper and a lower joint compartment (the others being the knee and sternoclavicular joints). They are also the only joints which are fixed to each other so that if one moves the other has no choice but to move. Also, the way the teeth meet can determine how the joint moves. The occlusion may not always be optimal, and it is therefore not surprising that the temporomandibular joints are prone to problems. It is sometimes helpful to consider the three components, two joints, and the bite as one unit functioning together; the TMJ is also traditionally the only joint not managed by orthopedic surgeons but rather by dental surgeons.

It is estimated that today in the United States some 30 million people suffer, or have suffered, from temporomandibular joint problems, and at any one time, somewhere between 3 and 7% of Americans have TMJ problems [1]. It is estimated that one million new patients present every year, and the incidence is in some ways tied to lifestyle. The more highly developed the country, the higher seems to be the rate of temporomandibular joint problems. It may be responsible for up to 17.8 million days off work per 100 million full-time working adults per year in the United States [2]. All studies report a higher incidence of females presenting for treatment (1.5–35 times greater) though the incidence in the population at large may show a smaller gender difference [3].

Historically, reports of TMJ problems go back several hundred years. John Hunter, the surgeon/anatomist, mentions it in his book *A practical treatise on the diseases of the teeth* published in 1778 [4]. He noted the possible relationship of TMJ problems to the occlusion of the teeth, but he also describes the unpredictability of any treatment and concludes that "Sea bathing has been in some cases of singular service." There were isolated reports of attempted TMJ surgery in the nineteenth century [5] but little constructive thought. By the 1930s, however, more complex temporomandibular joint problems were being recognized, which today would fall into the categories of degenerative joint disease and internal derangement of the joints. Costen, an ENT surgeon from Washington University School of Medicine in St. Louis, in 1934 attempted to unite a disparate group of symptoms including deafness, tinnitus, vertigo, dizziness, joint clicking, joint locking, and joint pain, as well as stuffiness in the ears and burning throat, tongue, and the side of the nose [6]. His concept was that in some way the temporomandibular joint or its meniscus became displaced and put pressure on the external and middle ear as well as the Eustachian tube, causing a variety of symptoms. This concept has now been discarded, but nevertheless his description did focus thought on the problems of the temporomandibular joint. There were few attempts to operate on the temporomandibular joints in the 1930s and 1940s, but people like Reed O. Dingman were carrying out meniscectomies at that time for temporomandibular joint dysfunction with a high reported rate of success [7]. Interestingly enough, he carried these operations out under local anesthesia, even though lidocaine was not available at that time, so he presumably used procaine. However, he later stated that the meniscectomy patients did not uniformly do well, and he also started to use general

anesthesia [8]. It is now known that meniscectomy without replacement can give good results for many years but does tend to lead to later degenerative joint disease, and so most authorities now recommend repositioning or replacing the disc, preferably with autogenous material [9].

The problem of ankylosis continued to demand attention, and its causes ranged from birth trauma to complications of mastoiditis and middle ear infections, as well as later trauma. It was generally found that attempts to free up the joint locally seemed fraught with a high rate of recurrence of the ankylosis. A generation later, Robins attempted to explain this tendency to reankylosis by remembering that embryologically the present neo-TMJ is a late development, since the embryological jaw joint is between the malleus and the incus [10]. The current temporomandibular joint is embryologically similar to a cranial suture that never fuses, but it can have a tendency to fuse, like any other cranial suture, causing ankylosis. People like Terrance Ward recognized this tendency and advocated carrying out a gap arthroplasty lower down the ascending ramus of the mandible so that this became the new joint. He devised a metallic joint surface, and we are assured that the model for the size and shape of the new joint came from the old British penny [4].

In the 1960s, a number of procedures were advocated including closed condylotomy (performed blindly with a Gigli saw) to allow the condyle to reposition itself in a physiological position to increase the joint space [4], condylectomy [11] (which often caused deviation of the mandible), and high condylar shave [12] (which essentially increased the joint space and smoothed down the condylar head if it was irregular), often combined with meniscal surgery.

From the 1970s onward, it has tended to be imaging and technological advances which have led to new developments in TMJ investigation and surgery. Paul Toller developed a number of investigative techniques for the temporomandibular joint including transpharyngeal radiographs and arthrography [13, 14] and devised a capsular rearrangement operation which was designed to reposition a displaced disc and increase the joint space and provide for reinforcement for the capsule of the joint [15]. This was one of the first serious attempts to treat what we now know as internal derangement, where there is an in-coordination between the condyle head and the meniscus, leading to meniscal displacement. The actual procedure was based on Toller's preliminary work utilizing TMJ arthrography with plain films. The procedure itself involved entering the joint spaces from a lateral approach, freeing the attachments of the meniscus to allow it to reposition, severing branches of the auriculotemporal nerve to denervate the joint, and reconstructing and reinforcing the lateral capsule of the joint with a temporalis muscle and fascia flap turned down over the arch of the zygoma. When irregularities of the joint surface were diagnosed, a high condylectomy could be carried out. In many ways this procedure forms the basis of many of the contemporary temporomandibular joint surgical procedures.

In the early 1970s, CT scanning of the temporomandibular joints became a practical proposition, and although these would show the morphology of the condyle head and the glenoid fossa, it did not show the disc itself unless combined with arthrography.

For some years this was the definitive imaging technique, although it was time-consuming and uncomfortable. Nevertheless, it was utilized for diagnostic purposes [16]. It did start to show that many of the problems with the temporomandibular joints appear to be due to anterior dislocation at the meniscus, and considerable efforts were made to try and reposition the discs both nonsurgically and surgically [17, 18].

In 1980, the first commercial magnetic resonance imaging (MRI) scanner became available, and by the early 1980s, MRI scans were becoming more widely available. When coupled with surface coils, images of the temporomandibular joints showed the meniscus without the need for arthrography.

The presence of an anteriorly and medially displaced disc was often diagnosed and felt to be the cause of the patient's symptoms, and considerable efforts were made both with splint and other nonsurgical therapy to cause the disc to reposition [19] (almost always unsuccessfully), and surgical procedures were employed to either remove the disc and replace it or surgically reposition and fix the displaced disc [20]. Unfortunately, these procedures proved to be as unpredictable as previous procedures, and moreover, MRI studies on normal asymptomatic individuals actually showed an incidence of disc displacement of around 30%, even though they had never had any TMJ problems. Thus, it would appear that discal position was not as important as previously thought [21, 22].

One consequence of this regime of meniscectomy and replacement of the disc was the utilization of a Proplast/Teflon disc replacement in the late 1970s, which was shown to fragment during function causing degeneration in the joint and the typical giant cell inflammatory reaction. It lead to many more temporomandibular joint problems and was very difficult to treat [23]. This particular episode led to the initial involvement of the FDA in device approval and monitoring.

When the joints were so badly affected by disease that they were no longer functional and were better replaced (either for agenesis as in hemifacial microsomia, severe degenerative disease, resorption, or sometimes ankylosis), attempts were made to replace the joints with autogenous tissue. Costochondral grafts have probably been the most popular and were described by Gillies in 1920 [24]. It is relatively easy to obtain grafts from the sixth or seventh ribs with a cartilage cap which can realistically replace the temporomandibular joint. Long-term studies have shown that these grafts can be very successful and the ribs are incorporated into the mandible and become functional [25]. They have been used to replace the temporomandibular joints in children, where on occasion there can be growth of the condyle from the cartilage cap. However, this is unpredictable, and in some cases, there was actually overgrowth of the neocondyle [26]. Other autogenous sites have included a metatarsal [27, 28] and the sternoclavicular joint [29], but since the advent of more successful alloplasts, these have tended to fall out of favor.

The miniaturization of fiber-optic arthroscopes and instrumentation allowed arthroscopy of the temporomandibular joint to become a practical proposition in the 1980s. The techniques originated in Japan [30] and started to be practiced in the United States in the mid-1980s [31, 32]. Arthroscopy is normally performed in the

superior joint compartment but can be extended to the inferior compartment, although this is more difficult. Arthroscopy can be diagnostic or therapeutic. Diagnostic arthroscopy can reveal many interesting features in the temporomandibular joint compartments, but many of them are of academic interest only and can also be diagnosed less invasively on an MRI scan. It is possible to detect meniscal perforations which may not be shown by other imaging techniques. As far as therapeutic arthroscopy is concerned, lavage and instillation of steroids and other medications into the joint have proved beneficial in many cases, but these can often be performed blindly without the use of an arthroscope [33]. Arthroscopic surgery itself, performed with miniaturized instruments to smooth the joint surface and remove irregularities and also to reposition and even suture the disc back in position, has been performed with relatively limited success. The results have been less satisfactory than arthroscopic surgery on larger joints such as the knee because of the limitations imposed by the size of the joint and the consequent size of instruments utilized, as well as the fact that the TMJ can only be approached from the lateral and with more difficulty from the anterior and posterior approach, the latter via the external auditory meatus. The inability to access the joint from the medial side obviously limits access.

On the heels of the relative success of hip replacement surgery, attempts were made from 1970 onward to make a functional alloplastic temporomandibular joint. The early Christensen joints became available in 1973 (the fossa only was available from 1960). These were later withdrawn, to be reintroduced later with modifications. Vitek produced a replacement temporomandibular joint in 1972. Failures occurred due to the early types having a plastic fossa which wore easily. This was largely remedied by substituting a high molecular weight polyethylene. However, the prostheses utilized Proplast on the fitting surfaces. This material had been combined with Teflon in an interpositional (post-discectomy) discal implant, a device associated with a severe giant cell reaction and high incidence of early failure with tissue destruction [34]. This added to the confusion, and after professional and governmental concern, the total joint alloplasts were often removed, and the device was withdrawn from the market.

In 1989, Techmedica introduced its custom temporomandibular joint. It is currently marketed through TMJ Concepts [35] and has proved to be quite successful for over 20 years. In the early years of the twenty-first century, a number of other prosthetic temporomandibular joints have become FDA approved and are marketed, both as custom joints and stock joints. Most incorporate the same principles as hip replacements and feature a metal condyle (usually titanium) and a high-impact plastic (usually polyethylene) fossa component. Although only approved by the FDA to last for 15 years, it does appear that they may survive longer than this. With their current success, there does seem to be a move toward earlier use of a totally prosthetic device, although one must take into account the fact that these are often younger patients and long-term survival is important. It appears from the experience in orthopedic surgery that the smaller the joint, the harder it is to make a successful alloplastic one [36].

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2 The Diagnosis of Temporomandibular Disorders Leading to Surgical Intervention

Vincent E. DiFabio

Abstract

The ability to make a "clinical diagnosis" for temporomandibular disorders and advance to the conclusion that there is the medical necessity for a surgical correction is not an easy task. This involves many potential avenues and modalities. These would include years of clinical and/or surgical experience, a complete clinical medical and dental evaluation and examination, elimination of minor and major overlapping maladies, undergoing conservative nonsurgical care for a period of time when medically indicated, obtaining specific imaging of the hard and soft tissues of the TMJ area, using the Wilkes Classification when appropriate for internal derangements of the TMJ, and following good, sensible medical and dental ethical practices to assure that the patient comes first. Using the correct "clinical diagnosis" when medically indicated can point us to a surgical correction at a future date.

2.1 Introduction

The ability to make a "clinical diagnosis" for temporomandibular disorders and advance to the conclusion that there is the medical necessity for a surgical correction is not an easy task. This involves many potential avenues and modalities. These would

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include years of clinical and/or surgical experience, a complete clinical medical and dental evaluation and examination, elimination of minor and major overlapping maladies, undergoing conservative nonsurgical care for a period of time when medically indicated, obtaining specific imaging of the hard and soft tissues of the TMJ area, using the Wilkes Classification when appropriate for internal derangements of the TMJ, and following good, sensible medical and dental ethical practices to assure that the patient comes first. Using the correct "clinical diagnosis" when medically indicated can point us to a surgical correction at a future date.

To make the correct "clinical diagnosis," you will still need to be flexible and able to juggle multiple problems in the air at one time. These problems relate to initial presenting problems, associated problems, and disorders that encompass many symptoms, signs, pathologies, and other related associated issues that the patient brings to the consultation table. To reduce this voluminous amount of data to specific entities that will lead us to a surgical solution means that we start at a point in time when some or most of the "other problems" have been excluded and eliminated from consideration. That would be ideal but that usually does not happen in real life. These "other problems" would fall under the preview of the general dentist, physical therapist, primary care physician, and many, many others. Unfortunately, the real "clinical diagnosis" may be missed, and there can still remain the overriding problem of "overlap" in most, if not all, of these cases. It is this "overlap" that can cause difficulty in picking the correct course or courses of action to be followed. This is true even in the initial stage of diagnosis by some that do not see surgery as a solution and hence will try many splints, therapies, and medications to "try" to affect a treatment that is helpful to the patient. The difficulty is that most of the time these treatments are only partially successful, and this is owed to the overlap of the problems, diagnosis, and hence treatments offered as we shall see. The title statement above for this chapter, "Diagnosis of Temporomandibular Disorders Leading to Surgical Correction," has been chosen specifically so that we can move to a "surgical" approach when this approach is indicated, medically necessary, and in the best interest of the patient. The thrust of this chapter is how to make the correct "clinical diagnosis" and how, when medically necessary, to propose a "surgical correction" to the patient and thus obtain the "final diagnosis."

2.2 In the Beginning

All medical, surgical, and dental conditions have a beginning or presenting "problem(s)" commonly called the "chief complaint" (CC) and will be defined in the history of present illness. There may be more than one chief complaints or additional "problems" to consider, and thus the pleural is used frequently in the more complicated cases, such as TMJ patients. It is from these presenting "problem(s)" that we can learn more about the "diagnosis" and hence the proper "treatment" of that problem. We address the "presenting problem(s)" in the TMJ area as we would for any other illness, disease, or pathology. We ask the patient to state why they are here in our office to see us, and then we listen to their answers. This can also be performed via forms that the patient fills out. There are many forms of paperwork

out there, and we would suggest that these forms comply with being short and not complicated. What is the chief complaint (CC) of the patient? We want to know the reason why they are here and not at a neurologist or primary care physician. We ask about other issues related to their CC. Is there other signs or symptoms that accompany the CC? Are there problems in other related areas? As we go forward, we will see how these "other problems" can be related or not related to the CC and perhaps show the way to the correct "clinical diagnosis."

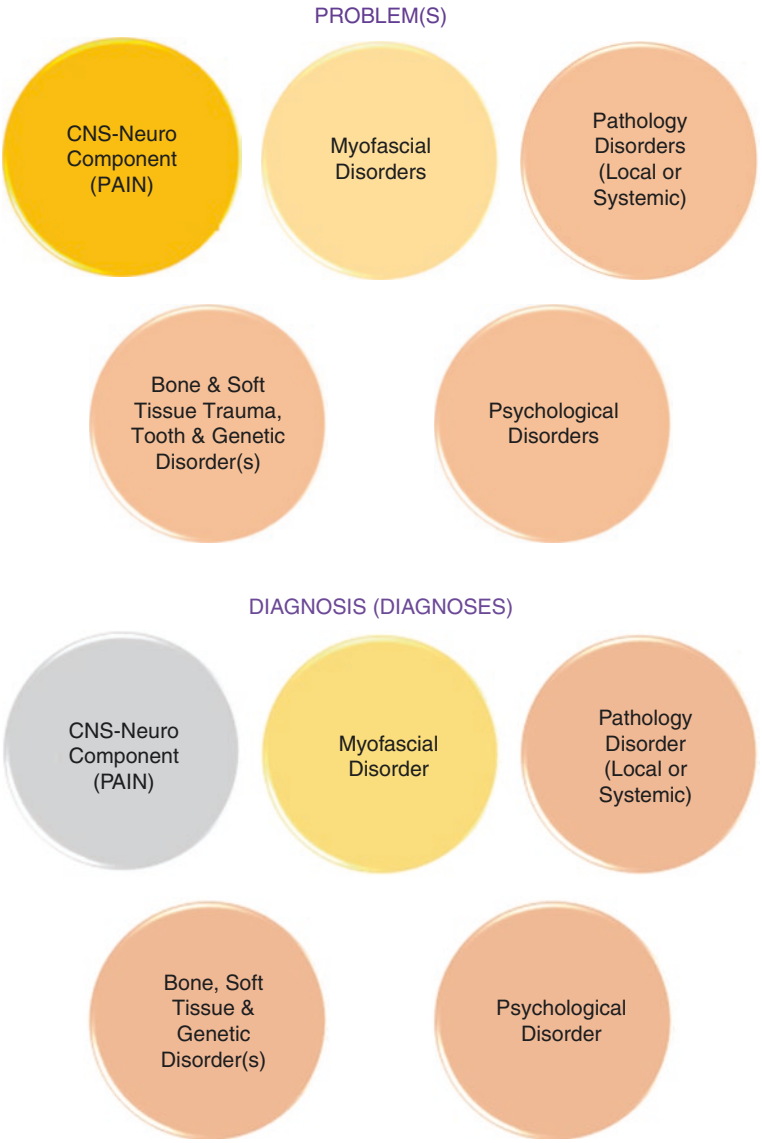
2.2.1 The Comprehensive Consultation

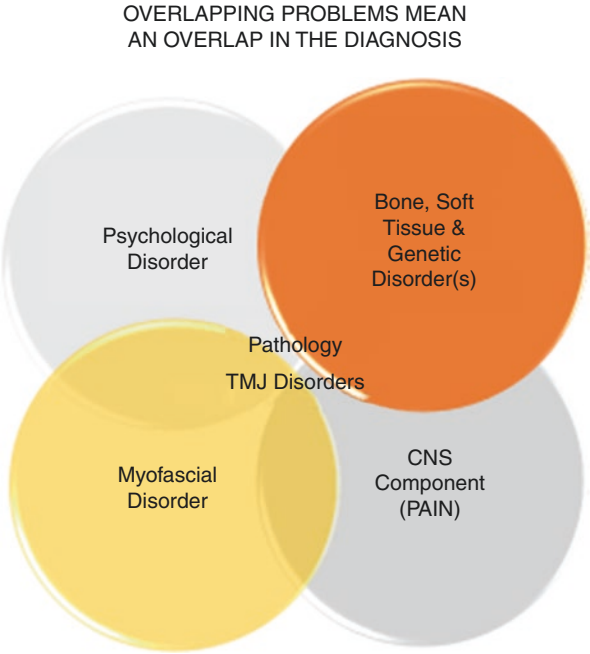
The first approach to defining the problem(s) is to accurately find the problem(s) and then accurately make the correct diagnosis. This sounds easy but not so fast! To accomplish this we will need to perform an evaluation and examination of the patient and thus come up with a management or treatment plan. This evaluation and examination of the patient falls under the heading of what is called in medicine or dentistry a comprehensive consultation. We use the medical model as it is more detailed and exacting in description. Using the American Medical Association's Current Physician Terminology (CPT), this evaluation and examination will be at a level 4 or 5 (99244 or 99245). This evaluation and examination will take about 60–80 min and will include many issues and steps. It will involve gathering medical and dental information (past medical history and past dental history, a physical evaluation of the patient) and obtaining old records from other treating providers and obtaining new radiographs and any laboratory information that may be needed from the past medical history information. Because of the potential for overlap with other modalities, this aspect of "problem" will require a stealth inquiry into these problems to lead to the "correct diagnosis" and hence to the proposed proper treatment.

Typically, in a consultation for TMJ disorders, as there is not a specific model or template for TMJ disorders per se, we will use the Centers for Medicare and Medicaid (CMS), ENT Model for the TMJ consultation. This is a comprehensive general physical exam of medical systems to include cardiac, pulmonary and a general head and neck evaluation, but in addition there is also the need for a very specific examination of the TMJ area for additional data. This information is then used and brought together for a review and discussion with the patient, parents, and others as needed.

The chief complaint is the "primary problem" but may have secondary problems associated with this primary problem. Some of these secondary problems may actually be medical issues noted by the patient on the past medical history or in the review of systems. As the medical issues may overlap with the presenting problem, these medical issues may need to be resolved or corrected before any surgical intervention, such as psychological problems to include stress, migraine headaches (CNS pain), severe hypertension, uncontrolled diabetes, etc. This group of presenting problems will have a moderate to high severity level to ferret through and will take considerable time and effort in coming up with the "clinical diagnosis" and then the "treatment" for the malady. It is in this area of problems and complaints that we have to add "diagnostic information" called ICD (International Classification of Disease)-10 codes that describe the signs and symptoms of specific pathologies,

diseases, and illnesses. These ICD-10 codes are imperative to justify the need for surgical intervention. The "final diagnosis" will be saved for any biopsy of the soft tissues and bone of the offending joint and observed by a pathology service rendering a microscopic diagnosis. This diagnosis can perhaps be accomplished by arthroscopic intervention for diagnosis and biopsy prior to any additional surgery of the TMJ. Typically most patients are female (80%) and between the ages of 20 and 40 years old. However, these facts should not lead us away from the quest to gather all the information presented. In the circles of problems, diagnosis, and overlapping problems presented below, we see the potential complexity and the need to be stealth in our investigation as many false avenues can appear.





2.2.2 The Importance of the Medical and Dental History and Review of Systems

As part of the comprehensive consultation, the history and physical evaluation begins with the review of the **past medical history (PMH)** and **systems review (ROS)** as noted by the patient or parent filling out information that is usually preprinted. In the PMH and ROS, we can include allergies to medications, medicines (routine and past), brain (neuro-trauma, stroke, epilepsy, early onset of dementia, etc.), pancreas (diabetes or diabetes in the family), head and neck (tumors, injury, etc.), other endocrine (thyroid, adrenals, etc.), cardiac (angina, coronary artery disease, hypertension, arrhythmias, etc.), pulmonary (asthma, COPD, emphysema, etc.), kidney, gastrointestinal, vascular (coronary or other arterial occlusions), bones and joints, surgery, sleep, cancer, family, and social history. Any positive answers by the patient or guardian must be investigated. Likewise the patient or guardian may miss one of the specific topics and so all of these items must be addressed by the examiner to verify the medical status of the patient.

After gathering the information on ROS and PMH, we then move to document the history of present illness as noted above. This is the start of our quest for determining the correct "clinical diagnosis." The history of present illness (HPI) or the very reason the patient is coming to see you today will give us a checkoff list of the patient's complaints and problems. What is the chief complaint (CC)? In this review we want to know the past history of any facial, neck, or head trauma and the cause, any past surgical history, when and why, where is the problem, etc. also when doing the HPI using the chart below which are helpful and have the patient

place a value number on certain problems. As will be noted later, there is a cross-over with the etiology of TMJ disorders which will be added to all the information gathered in the HPI.

2.2.3 The Chief Complaint or the History of Present Illness

The history of present illness (HPI) speaks to the very reason for the evaluation and gives some insight into the patient as well.

This can be described by the WHO—the patient is a … *year old, male or female,* presenting with the symptom or chief complaint of:

Location of the symptom:	WHERE: facial, TMJ, right vs. left, others
Intensity of the symptom:	HOW GREAT: scale of 1–10
Quality of the symptom:	WHAT AND HOW MUCH: burning, pulsating, others scale 1–10
Onset of the symptom:	WHEN AND HOW MUCH: time line, precipitating factors, others
Symptom radiates:	WHERE: right temple area, left angle of the mandible, etc.
Associated symptoms:	WHAT AND WHERE: pain behind the eye, numbness, etc.
Alleviating factors:	WHAT AND HOW: not eating certain foods, ice, heat, etc.
Aggravating factors:	WHAT AND HOW: eating, chewing hard food, talking, etc.
Evolution of symptoms:	WHEN, HOW LONG: started 3 years ago, yesterday, unknown, etc.
Treatment by others:	WHAT, WHEN, & WHO: exam, surgery, dentists, PCP, PT, etc.

2.2.4 The Examination

As noted, the TMJ examination is based on using the CMS ENT model for the examination. This model can be found on the CMS Web site: http://www.entnet.org/sites/default/files/1997-Documentation-Guidelines-for-Evaluation%20(3).pdf.

The examination is complete for all systems to include a complete evaluation of the head and neck. But remember we seek to evaluate the TMJ and must do even more! The ENT model looks like other specialty models but is concentrating on the head and neck more than, say, a neurology or podiatric examination. TMJ examination will have some overlap with the ENT model and this should be noted.

Elements of the exam will start by measuring the seven vital signs, and CMS notes that any three of these elements need to be measured. These include sitting or standing blood pressure, supine blood pressure, pulse rate with regularity and with ECG, respiration rate, temperature, height, and finally weight + calculation of the BMI. In the ENT examination, note that the measurements of vital signs can be performed and recorded by ancillary staff members. Also note the general appearance of the patient (development, nutrition, body habitus, deformities, attention to grooming). Also assess the ability to communicate with the patient (use of sign language or other aids and quality of voice). Note the limited evaluation of the head and neck. This part includes inspection of the head and face (appearance, scars, lesions, and masses), palpation and/or percussion of the face with notation of the presence or absence of sinus tenderness, examination of salivary glands, and

assessment of facial strength. Examine the eyes and test for ocular motility including primary gaze alignment. In the ENT exam these are the most comprehensive parts: ears, nose, mouth, and throat. Otoscopic examination of external auditory canals and tympanic membranes (TM) includes:

- Pneumatic otoscopy with notation of mobility of the TMs
- Assessment of the nasal mucosa, septum, and turbinates hearing with tuning forks and clinical speech reception thresholds (e.g., whispered voice, finger rub)
- External inspection of the ears and nose (overall appearance, scars, lesions, and masses). Inspection of the nasal mucosa, septum and turbinates using a nasal speculum
- Inspection of the lips, teeth, and gums. Examination of the oropharynx: oral mucosa, hard and soft palates, tongue, tonsils, and posterior pharynx (asymmetry, lesions, hydration of mucosal surfaces)
- Inspection of pharyngeal walls and pyriform sinuses (pooling of saliva, asymmetry, lesions)
- Examination by mirror of the larynx including the epiglottis, false vocal cords, true vocal cords, and mobility of the larynx
- Examination by mirror of the nasopharynx including the appearance of the mucosa, adenoids, choanae, and eustachian tubes

In the ENT exam, more attention is paid to the ear, nose, and throat and not to the oral cavity and corresponding areas. In the neck, examination of the neck for masses and overall appearance are to be noted. Additionally, note the symmetry, tracheal position, and crepitus and examine the thyroid for any enlargement, tenderness, masses, nodules, deviation, etc.

1. **Respiratory examination** includes inspection of the chest including symmetry, expansion and/or assessment of respiratory effort (intercostal retractions, use of accessory muscles, diaphragmatic movement), and auscultation of the lungs (breath sounds, rubs, and adventitious sounds). In the ENT exam, we have duplication with our additional head and neck exam and these are ok. Note that the auscultation of the lungs should be in the front and back and in all areas of the lobes (three right and two left).
2. **The cardiovascular examination** begins with auscultation of the heart with notation of abnormal sounds and murmurs. Additional examinations of the peripheral vascular system are by observation (swelling and varicosities) and palpation (pulses, edema, pitting edema, tenderness, temperature, etc.). Note the auscultation of the heart and document.
3. **Lymphatic system** examination of the neck with notation of nodes and tenderness.
4. **Neurologic and psychological** evaluation and examination: Test all cranial nerves II–XII and note deficits. For the psychological evaluation, note orientation to person, place, and time. Also assess mood and affect, and note depression, anxiety, agitation, etc. Pain and is this real or imagined?

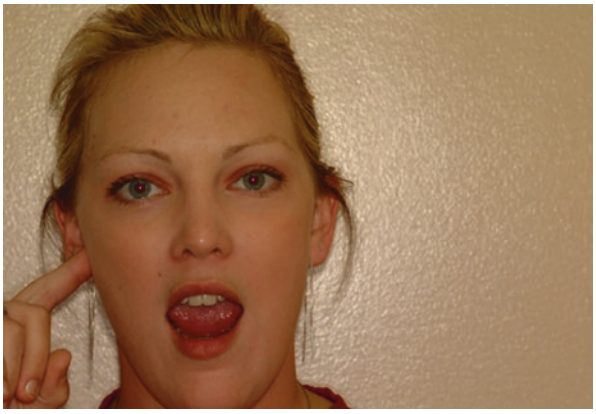
After following the CMS ENT model as a guide, we will need additional information which is very specific for the TMJ area. As noted before these consultations follow CPT guidelines, and thus we use **evaluation and management (E and M)** levels (1–5), and the criteria relates to **history** (one key), **examination** (one key), **medical decision making** (one key), and others that include counseling and coordination of care, nature of the problem, and time. Adding this together we still are missing the specifics of the TMJ per se exam. So now we have the past medical history, the review of systems, the history of present illness, and now the ENT model examination. We still need the additional information to assess the TMJ disorders, and thus we will move to the additional examination of the patient. Note that the essentials of a comprehensive consultation as above (by AMA CPT and CMS) are necessary to qualify for that level of E and M. Thus to complete this, we not only need the additional head and neck examination but also the element of medical decision as a key and additional information to be gained by (1) counseling and coordination of care and (2) nature of the problem (etiology) and time (how much time did you spend face to face with this patient for all of the above?). All of this information added together will advance us to the level of consultation in the office for a new or established patient: note in CPT CODE 99224 with attention paid to the fifth number "4." But we still need additional information, which will now follow.

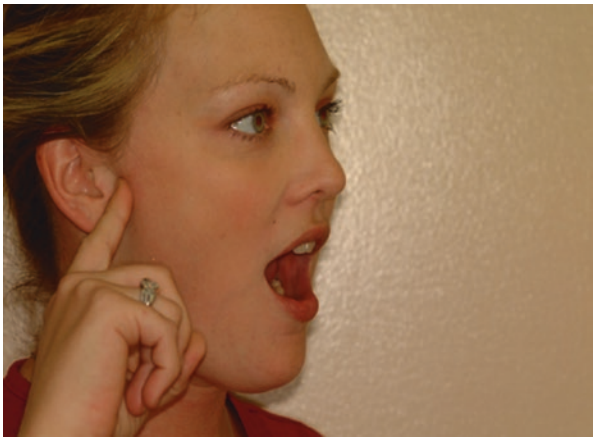
2.2.5 Additional Head and Neck Evaluation for the TMJ

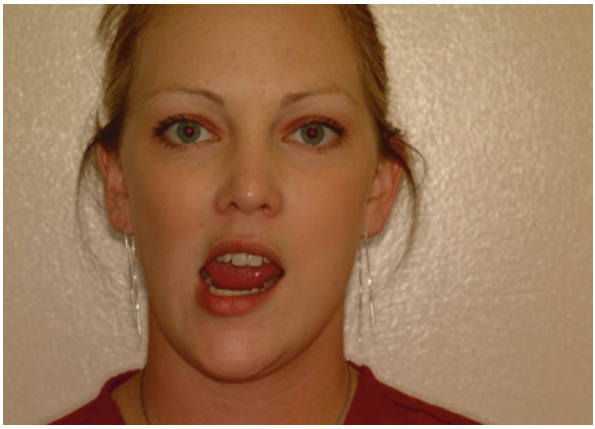
As noted this is a very long and complicated exam and is based on the CMS ENT model, but in addition we will need very current vital signs to include blood pressure, pulse, SPO_2, ECG, temperature, weight, and BMI-specific information relating to the TMJ, if this was not performed in the ENT exam. Evaluation of the mental status is always a part of any consultation, and the TMJ is no exception, if this mental assessment has not been performed in the ENT exam. The initial psychological evaluation should involve mood, affect, and ability to identify time, person, and place. Since pain is usually the initiating symptom, the ability to know that the pain is a real symptom and not imagined can be a real extra problem. If the mental evaluation is uncertain, then referral to the primary care provider for a psychological evaluation would be the most appropriate especially if no real TMJ pathology can be determined.

Continuing to the additional head and neck evaluation would be to evaluate the cranial nerves II–XII, if not already performed in the ENT exam. Check the eyes, pupils, and eye movements and record any abnormalities. Next perform an evaluation of the entire range of mandibular motion to include measurements (using a millimeter ruler or gage) and notation of any deviation of the mandible to the right or left and also note any decreased opening in a vertical direction (normal vertical

opening is 40–50 mm, lateral and protrusive movements are 7–11 mm). Next will be an auscultation of the right and left TMJ on the vertical opening (note any noises on the opening and closing, the mm of the noise for both opening and closing, and also any noises on lateral excursions, loudness, and mm if possible. Noises come in different varieties: soft, loud, clicking, grating, and grinding. Note the intensity of the noise and the kind of noise. At this time in the exam, we can also use the stethoscope and listen to the right- and left-external carotid arteries and note any noises, bruits, or decreased sounds. Palpate all the head, neck, and shoulder muscles, and note any pain and where in these muscles and the degree of pain elicited by the patient. Check for hyperplasia of the masseter and temporalis muscles by having the patient bite their teeth together while palpating those muscles. If there is a dramatic size increase in the contracted muscle, then note the size increase. If pain or tenderness to muscular palpation is negative, then mark at zero, if mild then mark at 1/4, if moderate then mark at 2/4, if moderate to severe then mark at 3/4, and if barely touching the muscle producing severe pain, then mark at 4/4. Also note where on the muscle mass the pain occurs. Palpate the areas of the sinus, both the frontal and maxillary, and note any tenderness. Palpation and inspection of the ear, ear canal, and preauricular area should begin by inspecting the ear and the ear canal with an otoscope. Note any external ear wounds, scraps, infections and condition of the tympanic membrane, ossicles and any inner ear infections, or other pathologies. At this point palpation of the preauricular area is begun, and note any pain or tenderness in the area. It is best to have the patient open as wide as possible and to place the index finger in the "preauricular depression" created, and note any pain produced. Negative response would be 0/4, mild pain would be 1/4, moderate pain would be 2/4, moderate to severe pain would be 3/4, and barely touching the area and eliciting severe pain would be 4/4. Using a nasal speculum, examine each nostril, note any inflammation of the nasal mucosa and size of the turbinates, and note the nasal septum and any deviation or other abnormalities, if not already performed in the ENT exam. In the neck examine the thyroid, and note any enlargement in the right and left side and any nodules present, if not already performed in the ENT exam. Also in the neck, examine the lymph nodes, and note any increase in size and tenderness, if not already performed in the ENT exam. An oral exam is performed next and last. This involves the soft and hard tissue examination and is also performed noting the mucosa status; gingival and periodontal status; missing teeth and general dental health status; dental abrasion and abnormal wear facets of incisal areas (bruxism and clenching); if third molars (maxillary and mandibular) are present, erupting, inflamed, or infected; the dental occlusion and classification; cranial bone classification; tongue size; tonsils if present and its status; parotid and submaxillary size and flow of saliva, if not performed in the ENT exam; and finally the Mallampati classification I–IV relating to oral volume, tongue size, and pharyngeal airway patency.







Photos 1, 2, and 3 are prompted by asking the question "where does it hurt?," and this information will help determine to a great extent if the problem or problems are specific to the muscles or the TMJ proper or both. Follow-up evaluation and palpation by the surgeon are always necessary to elicit the symptoms of pain in muscles and/or the TMJ proper. Neuromuscular pain can overlap with the pain and dysfunction of the TMJ and disc pathology and needs to be separated out, if possible. Photo 4 includes a clinical evaluation of the preauricular area especially by palpation, and inspection is important, and of course auscultation of the joint for noises in the range of motion is also important. In Photo 5 we ask the patient to open as wide as possible, and note any deviation from the midline. Checking for any deviation and consistency in that deviation in the mandibular movement is critical and perhaps pathognomonic of an internal derangement of the TMJ meniscus. If this is encountered, then verification with a MRI of the TMJ soft tissues is necessary. Confirmation of an anterior, medial, or lateral displacement of the disc will be noted and verified by the MRI to help identify the disc position and importantly give justification to any surgical intervention. Integration of this clinical material with MRI material can then be compared to the Wilkes classification and present to the patient and other necessary entities for verification of disease and for the surgical intervention.

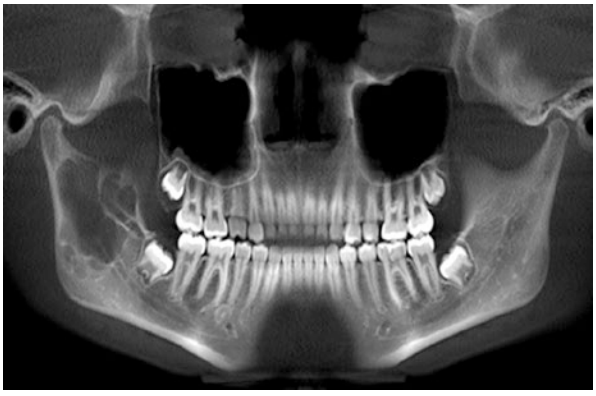
Clinical evaluation of the sub-anatomic area of the TMJ is critical to note the masseteric hypertrophy as well as any parotid pathologies. Palpation of this area and noting swelling not related to muscle activity are critical. Additional information is also gained by checking the parotid flow during the intraoral examination. Observation of the inner ear and canal is also a critical step to make sure there is no ear-related pathology mimicking as a TMJ problem or vice versa. Document the muscle and capsulitis levels (0–4) in the chart! Note the palpation of the temporalis muscle insertion on the coronoid procession intraorally and note if tender.

After the examination, we will now have a very good idea of any abnormal variations noting the following: preauricular pain, mandibular range of motion and noise with mandibular movements, muscle pain, increased muscle mass, oral and pharyngeal problems, and many others. We should note these abnormalities in the chart as we move forward in the evaluation process and toward the correct "clinical diagnosis."

2.3 Radiographic Evaluation

Initial panorex radiograph can serve as a guide to any bony pathology (third molars, tumors, cysts, infections, etc.), asymmetry, bony ankylosis, condylar shape, etc. This initial panorex radiograph will help determine in some cases if the TMJ is a real causal entity. This initial panorex radiograph should be a regular protocol at the visit for the consultation. The radiograph below shows a multilocular cyst involving the ascending right ramus and condyle and coronoid process of the mandible. Good views of the TM joints can show degenerative joint disease and asymmetry of mandible, cysts, and other odontogenic problems. If condylar hyper- or hypoplasia is present, one should consider a bone scan to rule out continued growth of the condyle. If there is fusion of the condyle to the temporal bone (bony ankylosis) and decreased range of motion (ROM), we can proceed to additional radiographs such as CAT scan and perhaps a surgical intervention without a need for conservative treatment.

Radiographic and imaging for evaluation of TMJ disorders include panorex and open and closed TMJ radiographs, open and closed MRIs with T1 and T2 of the sagittal views and T1 of the coronal views, edge to edge T1 sagittal views, CAT scans, cone beam CAT scans, and bone scans for active growth using T-99 and other modalities.



T1-weighted MRI with maximum vertical opening showing anterior dislocation without disc reduction, left TMJ

The need for additional radiographs, MRIs, CAT scans, and bone scans can also be determined at this time and ordered. Evaluate the condyle shape and form. Look for irregularities in the smooth rounded normal contour. When in doubt order a CAT scan or cone beam CT to evaluate the condyles.

2.4 The Etiology for TMJ Disorders

"Problems" can be described according to many authors as falling into groups or types (I–V) similar to our circles of problems, diagnosis, and treatment sequences. These will help us to discover additional information to the chief complaint and the history of present illness and are as follows:

- Type I: Myofascial pain and dysfunction (bruxism, clenching, other muscle disorders, etc.)
- Type II: Malocclusion, genetic, syndromes, orthognathic surgery, and concomitant TMJ disorders
- Type III: Hard tissue trauma, micro or macro, and direct or indirect
- Type IV: Soft tissue trauma, micro or macro, and direct or indirect
- Type V: Systemic diseases, infections, and others

The etiology or the cause that the patient presents with these signs and symptoms is an important aspect of finding the problem, the "clinical diagnosis," and thus a correct course of treatment. Identifying the cause of the patient's CC will hopefully prevent a reoccurrence in the future. As an example, the patient with severe bruxism (abnormal attrition of the dentition) and neuromuscular pain (type I) but no MRI evidence of internal derangements should be treated conservatively with night guards and medications (such as low-dose Elavil). Type II patients present with genetic, syndrome, or other malocclusion disorders and may have concomitant TMJ disorders (internal derangements, condylar resorption from juvenile arthritis, etc.) which can be treated as a separate entity or together with repair of the genetic disorders combining orthognathic surgery and TMJ surgery. Type III patients may have a history of direct or indirect hard tissue trauma, such as facial fractures, and type IV patients may have a history of indirect or direct soft tissue trauma, such as whiplash injuries, MVA, accidental facial trauma, general anesthesia with intubation, etc. When these patients in type III and IV show additional positive findings with MRI effusion, pain, jaw deviation, decreased vertical opening in the TMJ, etc., they can then be placed into the proper Wilkes classification as we shall see. Other patients with systemic disorders, collagen vascular disorders, juvenile rheumatoid arthritis, etc. (type V) will need initial and future medical intervention to prevent resorption of condyles or antibiotic intervention for the infections. If these initial treatments are unsuccessful, then future interventions, such as arthroscopic lysis and lavage, debridement, potential orthognathic surgery in the future, and possible bone grafting or total TMJ reconstruction, will need to be considered and presented to the patient, parents, and guardians.

The first involves muscular and myofascial issues. These can be multiple as in bruxism, grinding, or clenching habits. However, other potential muscular diseases and pathologies exist and so are on the lookout for problems like myositis ossificans, multiple sclerosis, and others. These long-term habits in some presentations can cause hyperplasia of the muscles of mastication especially the masseter and temporalis and show clinically as a "bulge" or increased size of those muscles. Eliminating these habits can correct the pain and dysfunction as long as there is not an internal problem with the TMJ itself. So any pathology of the TMJ proper must be looked into as well. If correcting the muscular problems (Botox for hypertrophy, physical therapy, orthotic devices, etc.) eliminates the TMJ problems, then we are finished. If not then the search goes on for the internal pathology noted above. There can be tendonitis of the temporalis tendon as well as a presenting pain in the TMJ area, so palpation of that tendon in the coronoid area, intraoral, is a must. We must distinguish between muscular pain and joint pain. Some of the muscles may also exhibit painful areas in the muscle, called "trigger points." Injecting these areas with local anesthesia or acupuncture needle can eliminate the pain in those muscles. This procedure is helpful in making the diagnosis by elimination.

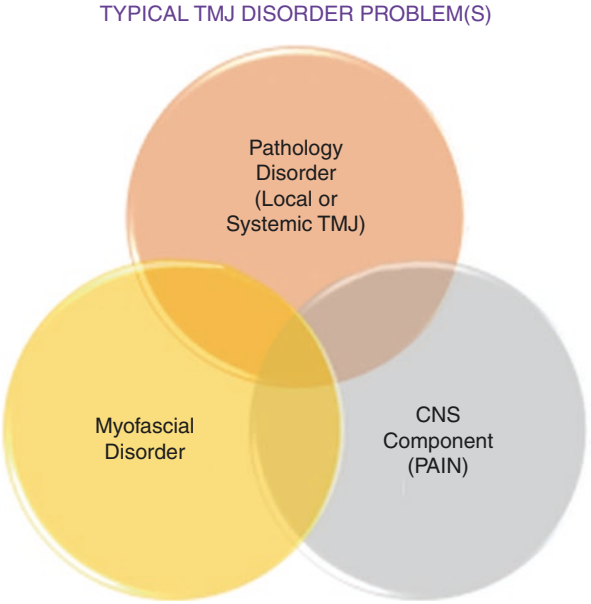
The second area involves any malocclusion or genetic bony/soft tissue problems that need to also be ruled out as we advance in our process. Orthodontia with traction and other devices can produce pain in the TMJ area. Some of the severe cases of malocclusion and bony/soft tissue abnormalities can be corrected by orthognathic surgery. There may also be concomitant TMJ problems which will need to be addressed either separately or together, so evaluation of any internal pathology with these cases is imperative.

A third area is hard tissue injury via trauma to the head and neck which can produce a macro- and/or micro-injury to the internal TMJ with resultant pain and dysfunction. Some causes of this are motor vehicular accidents, whiplash injuries, sports-related injuries, direct altercations, difficult dental alveolar surgery including removal of difficult third molar teeth (wisdom teeth), general anesthesia with intubation, condylar fractures and the treatment of those fractures, and others.

A fourth area involves trauma to soft tissue and can occur in relation to all the reasons noted in number three above as well as direct laryngoscopy, esophagoscopy, intubation for anesthesia or other surgeries, and others.

A fifth area of concern involves some systemic diseases such as arthritis, rheumatoid arthritis, and collagen vascular diseases; infections in the TMJ area (acne), systemic or internal; and local dental or medical pathology which involves the TMJ by local invasion such as parotid tumors, mandibular cysts, etc.

Thus the history of the etiology gives us additional information and yet another method for determining (and perhaps in the future preventing) the "problem." The specific and correct "clinical diagnosis" can then be addressed by using one or several parameters in combination such as the etiology, the Wilkes Classification, the Quinn's classification, the synovial disorder list, or other specific straightforward problems like hypermobility or bony ankylosis. These will give us a good start to finding the appropriate treatment modality, nonsurgical or surgical. Remember that most TMJ disorders involve the triad of pain, myofascial disorders, and local TMJ pathology.



The overlapping circles above represent the typical problems and hence diagnosis issues that are presented in most cases of TMJ disorders. This primarily involves pain in or around the TMJ area as the initial presenting problem. This also usually involves some element of dysfunction of mandibular motion (difficulty chewing, limited opening, jaw deviation, etc.). This also usually involves the muscles of mastication, and pain can be associated with these muscles per se and not involve any TMJ issues at all. Thus the overlap and need to address each of these problems. Do we do so together or separately? Well it depends.

Remember that the correct "clinical diagnosis" can involve many overlapping facets including:

1. Neurological (CNS) and muscular disorders of pain (headaches or TMJ specific) and myofascial disorders
2. Internal disorders of the TMJ proper with local or systemic pathology to include hard (arthritis) and soft tissue (disc and synovial pathology) pathology
3. Genetic and syndromes of the head and neck involving hard and soft tissue disorders
4. Psychological disorders
5. Combinations of the above

2.5 "Clinical Diagnosis" or Bust?

So now what do we do with all this information? We have a review of systems, a past medical history, the chief complaint, a history of present illness, overlapping areas that are "problems," radiographs and MRI images, and now an etiology of how things

happened. So to putting altogether, we will proceed to the "clinical diagnosis" in several ways by using PCP, PT, DDS, etc. to eliminate these overlaps. If the overlapping areas were the real "problem," then dealing with any local or systemic pathology of the TMJ may not be needed. Some overlapping areas are the following:

- If psychogenic then referral to the PCP, psychologist, or psychologist for treatment would be appropriate.
- If CNS pain, headache or migraines, then referral to the PCP or neurologist for treatment would be appropriate.
- If bony fractures then immediate treatment by OMS or other source would be appropriate.
- If there are craniofacial disorders, genetic bone/soft tissue disorders, and/or malocclusions (especially class II cases), then referral to an orthodontics and/or OMS would be appropriate.
- If primary arthritis of synovial nature, referral to a PCP and rheumatologist would be appropriate.

Eliminating the overlapping "problems," we then arrive at a smaller subset of "problems" that we can now address as the "clinical diagnosis of TMJ disorders leading to a surgical correction" and that we initially set out to find. So to find this very specific and correct "clinical diagnosis," we will take a look at synovial joint disorders, the Wilkes classification of internal derangements, chondromalacia, fibrous ankylosis, and bony ankylosis.

2.6 The Synovial Joint Disorders

Next, we will look at other causes of joint disorders, and these can involve the synovium of the TMJ in some very different ways. The synovium is the source of nutrients to the disc (meniscus) and lubrication of the internal normal function of the TMJ complex. It is also a potential source of pathology in any joint and specifically the TMJ and can be affected by many of the etiologies noted above. Synovial TMJ disorders can be classified as inflammatory or noninflammatory. Examples of inflammatory synovial disorders include pathologies of primary arthritis, secondary arthritis, and non-arthritis diseases. Primary arthritis is composed of several entities that include rheumatoid arthritis, juvenile arthritis, and HLA-B27-associated arthritis (including Reiter's syndrome, psoriatic arthritis, others) and Behcet's syndrome. Secondary arthritis is composed of traumatic arthritis, infective arthritis (many offending agents are possible and culture of the TMJ is necessary), crystal-induced arthritis (gout, uric acid crystals, others), and degenerative arthritis (degenerative joint disease or osteoarthritis as seen in Wilkes IV and V cases). The non-arthritis group is composed of internal derangements as seen in Wilkes I, II, and III cases and in synovial chondromatosis (calcified, loose bodies from inflamed synovium). Examples of noninflammatory synovial TMJ disorders are composed of aseptic necrosis, primary and secondary osteoarthrosis (normal wear of the joint bones with age), and hypermobility of the mandible cases.

The diagnosis of these synovial diseases may be evident from the age of the patient, MRI findings, clinical findings, lab data, etc. A generalized synovitis and pain in the preauricular area with a noted effusion (fluid) on MRI evaluation, and without apparent cause, can later be confirmed to a specific pathology only with a biopsy via arthroscopic intervention. Synovitis of the TMJ comes in many forms and levels of severity. Hence, the presenting "clinical diagnosis" can only take us so far.

2.7 The Wilkes Classification of Internal Derangements of the TMJ

In 1989, Dr. Clyde Wilkes of Minneapolis published his seminal work on classifying internal TMJ disorders involving the inside structures of the TMJ proper which included clinical, radiographic, and surgical descriptions of his findings. His classification of internal derangements of the TMJ is the gold standard. These findings included disc position and appearance, pain and noises, synovitis and adhesion, and degenerative joint bone changes and disease. We now use this classification for stratification and consistency in the grading of these diseases. In his studies he related the clinical findings, the radiographic findings, and the surgical findings to complete his five stages of the classification.

2.7.1 The Wilkes Classification of TMJ Internal Derangements

2.7.1.1 Stage I (Early)

- Clinical: No pain, reciprocal clicking early and late on opening with soft intensity, no restriction of motion or vertical opening, and no mechanical symptoms
- Radiographic/MRI: ± effusions, no degenerative joint disease (DJD), slight anterior displacement of the disc
- Surgical: Normal anatomy with slight anterior displacement of the disc, ± synovitis

2.7.1.2 Stage II (Early-Intermediate)

- Clinical: First few episodes of pain, occasional joint tenderness, and related temporal headaches. Beginning of mechanical problems with increasing joint sounds and late in opening and the beginning of transient joint subluxations with occasional catching or locking
- Radiographic/MRI: Slight forward displacement of the disc, slight thickening of the posterior edge, and the beginning of anatomical deformities via MRI, no degenerative joint disease noted. ± Effusions
- Surgical: Anterior disc displacement and mild deformity, ± synovitis

2.7.1.3 Stage III (Intermediate)

- Clinical: Multiple episodes of pain, joint tenderness, temporal headaches, major mechanical symptoms to include transient catching, locking (closed locks), restriction of motion, and difficulty with function. Noises ±
- Radiographic/MRI: Anterior displacement with or without reduction and with significant anatomical deformity or prolapse of the disc. ± Effusions. Normal tomograms and CAT scans and no degenerative joint disease
- Surgical: Anterior displacement of the disc with or without reduction, variable adhesions (lateral anterior and posterior), ± synovitis, and no hard tissue changes

2.7.1.4 Stage IV (Intermediate/Late)

- Clinical: Characterized by chronicity with variable and episodic pain, headaches, variable restriction of motion and undulating course, noises ±
- Radiographic: Increase in severity over stage III, abnormal tomogram, and CAT scan with early to moderate degenerative remodeling of hard tissues: + DJD
- Surgical: Increase in severity over stage III, hard tissue degenerative remodeling changes on both bearing surfaces, osteophyte projections, ± synovitis, multiple adhesions (lateral, anterior, and posterior recess), and *no* perforation of the disc or attachment

2.7.1.5 Stage V (Late)

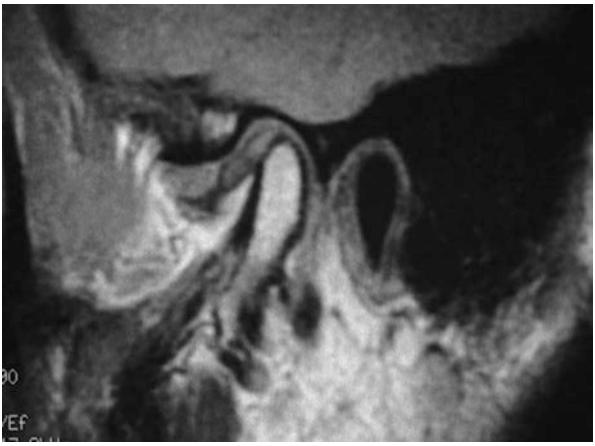
- Clinical: Characterized by noises of crepitus, scraping, grating, and grinding. Variable and episodic pain and chronic restriction of motion and difficulty with function
- Radiographic: Anterior disc displacement, perforation, gross anatomical deformity of the disc and hard tissue, abnormal tomograms and CAT scans
- Surgical: Gross degenerative changes of the disc and hard tissues. Perforation of the posterior attachments, erosions of the bearing surfaces and multiple adhesions equivalent to degenerative arthritis (sclerosis, flattening, anvil-shaped condyle, osteophyte projections), and subcortical cystic formation

With the progression of this disease, the articular disc becomes more and more displaced anteromedially, and finally the disc can become perforated, revealing the underlying bone of the condyle. Also with progression of this disease, the articular surfaces of the temporal bone undergo changes as well as the condylar bone which becomes degenerated with loss of normal rounded, healthy architecture and forms an anvil-like shape with spurs and bony spikes. This condition can on bone-on-bone contact produce the grinding and grating sounds noted clinically and on auscultation.

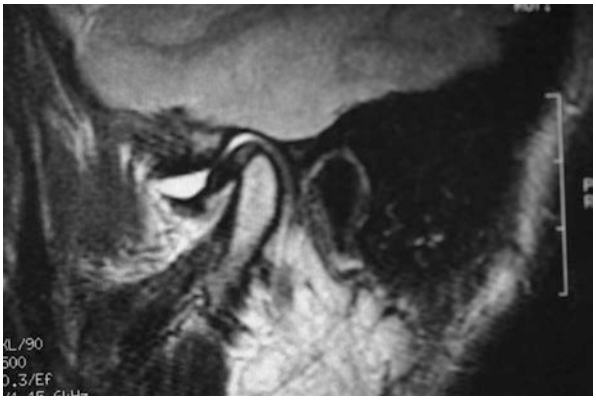
The Wilkes classification according to Dr. Kurt Schellhas (1989) showed consistent material for each stage and has helped define the MRI presentation within the Wilkes classification:

- Stage I: Disc displacement (minimal), normal disc, − degenerative joint disease (DJD) morphology, normal MRI signal, ± effusion
- Stage II: Disc displacement and deformity (increased over stage I) ± effusion, − DJD morphology
- Stage III: Same as II + ROM ± reduction of disc on opening, ± adhesions, ± effusion, − DJD morphology
- Stage IV: Severe changes from stage III + osseous changes and + DJD morphology, ± effusion
- Stage V: Perforation + osseous changes and + DJD morphology and increased over stage IV

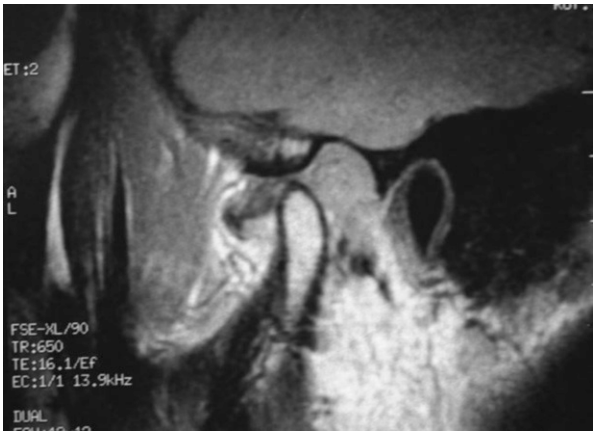
Kurt Schellhas: Internal derangements of the Temporomandibular Joint: Radiologic Stages with Clinical, surgical and pathological correlation. Magnetic Resonance Imaging. 7: 495–515, 1989.



T1-weighted MRI, closed mouth position: anterior disc displacement, mucoid degeneration, left TMJ



T2-weighted MRI with effusions (fluid), closed mouth position, left TMJ



T1-weighted MRI with maximum vertical opening showing anterior dislocation without disc reduction, left TMJ

Disc dislocation can also occur medically or laterally, and we will need coronal views of MRIs to see this malposition of the TMJ meniscus (picture). As noted the Wilkes classification of internal derangements is the gold standard for internal pathologies of the TMJ. There are other pathologies that this classification does not consider and those include chondromalacia, lateral impingement syndrome, primary and secondary osteoarthrosis, hypermobility and multiple mandibular dislocations, fibrous ankylosis, and bony ankylosis. These conditions will be considered next.

2.8 Chondromalacia and the Lateral Impingement Phenomena

In addition to the synovial disorders, in the progression of the pathology noted in the TMJ, there are varying degrees of cartilage damage to the articular surfaces in the TM joint. The pathology or damage to these surfaces is described as chondromalacia. Dr. James H. Quinn defined these stages or grades in 1989. He noted that the mechanism of cartilage degeneration followed from stress/bruxism to chronic micro-trauma to compression and sheering to chondrocyte damage with release of collagenases to splitting of proteoglycans chains and water loss to loss of cartilage resilience and water reabsorption to frank chondromalacia. His stages or grades are as follows (note these stages of chondromalacia can only be confirmed via arthroscopic evaluation): grade I, on probing there is a softening of the otherwise firm cartilage; grade II, rupture of underlying fibrils producing an undulating surface with furrows; grade III, loss of base of the cartilage and production of fingerlike projections or fibrils; and grade IV, advanced stage of cartilage fibrillar degeneration with full thickness of cartilage and bone exposure.

Chondromalacia relates to the internal cartilage on the bony surface and the reaction to stress and inflammation as a resultant pathology and the progression of disease. These next several slides (if not shown in another area) show an arthroscopic view of the pathology of chondromalacia and how to determine the degree of

pathology and disease. It is necessary to have looked at these joints via an arthroscope or with an OnPoint (small diameter arthroscope) to make this diagnosis. Grades II and III show an increased in cartilage breakdown and progression of the pathology. Grade IV is the highest form and usually shows fibrous adhesions to the articular disc as noted on the right.

The lateral impingement phenomenon from Dr. Jeff Moses relates to fibrous or scar tissue developing between the lateral ligament and the temporal bone in the anterior lateral synovial pouch. This problem will decrease the ability to enter into the anterior synovial space via arthroscopy. By releasing these adhesions, this will allow for increased volume in the anterior synovial space and will allow for easier arthroscopic access to this space and for visualization of this space. Clinically, this will also allow for increased vertical opening.

2.9 Primary and Secondary Osteoarthrosis, Condylar Hypoplasia, and Condylar Hyperplasia

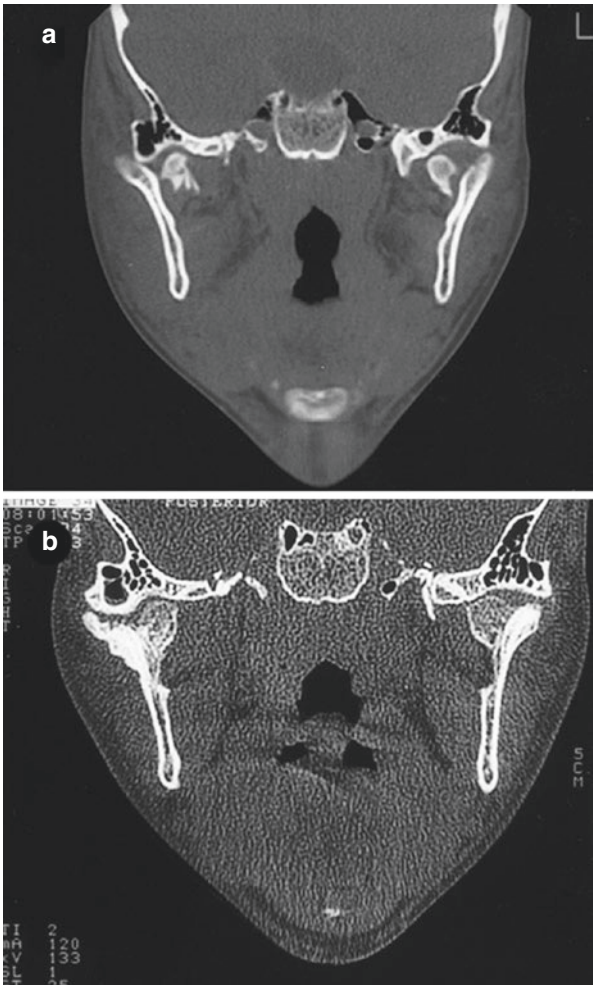
Some patients present with no clinical symptoms but have degeneration of the condyles from age and normal wear. If symptoms of pain and dysfunction are not present and normal function is uninterrupted, then no treatment is recommended. As noted with time and wear, the condyles can show radiographic resorption. When this resorption occurs at a young age, then this is termed idiopathic condylar resorption and shows loss of condyle or condyles. This typically occurs in young women, and hence the term "cheerleader condition" describes those cases. The opposite occurs when condylar growth occurs either unilateral or bilateral (as in growth producing a class III genetic bony protrusion or prognathism). In unilateral condylar hyperplasia, this can result from an osteochondroma (rare in the TMJ) or unabated growth with normal bone formation. A biopsy would need to identify the difference.

2.10 Hypermobility and Mandibular Dislocation and Hypomobility: Coronoid Elongation, Ankylosis of the TMJ—Fibrotic and Bony

Patients with hypermobility of the mandible and with multiple dislocations of the condyle out of the fossa can have a central nervous system causality. These problems include epilepsy, Parkinson's disease, and other neural activity. If medications cannot prevent the hypermobility and dislocations, then a surgical treatment of the hypermobility and multiple dislocations can be an option and will be covered in the surgical chapter on correction of persistent dislocation and hypermobility.

However, patients with the inability to open because of an increased restriction of motion and pain can be due to several etiologies: to coronoid hyperplasia, to a

fibrous ankylosis of the TMJ (severe chondromalacia late grade IV, very late Wilkes V, trauma, fractures of the condyle without treatment, joint infections with resultant scaring and fibrosis, etc.), or to a frank total bone or partial bone to bone ankylosis of the condyle to the temporal bone which has a debilitating condition. Clinical evaluation along with appropriate radiographic imaging will provide the correct "clinical diagnosis" and set the path for the surgery algorithm and correct treatment.



(a) Shows bilateral medical displaced condylar fractures. (b) Shows resultant ankylosis without treatment

2.11 Conclusion

The correct "clinical diagnosis" of any disease shows us the pathway to treatment whether medical, dental, or surgical. Making the "correct clinical diagnosis" can be a real challenge no matter what the malady, but this is especially complicated in assessing disorders of the TMJ (the most complicated joint in the body). Thus, the above gathering of information for diagnosis is imperative for any future treatment and any hope of improving the patient's quality of life. From the comprehensive consultation, we should then be able to make a medical decision on what to do next, but as noted this is very complicated. We need to identify the overlapping problems, to recognize medical problems and refer to medical colleagues for appropriate treatment, to recognize dental problems and refer to other practitioners for potential treatments, to decide whether we should take on the problems and diagnoses together or separately, to decide where to start (pain and function should come first), to eliminate the peripheral problems, and to end up with a "correct clinical diagnosis."

There can be stages of nonsurgical intervention or specific surgical treatments to be performed, and that is for another chapter. Incorporating all the above information will help on the way to identify the "problem or problems" and make the "correct clinical diagnosis" to present to your patient as the correct path to surgery and surgical correction. Remember that there is a great potential for overlap in the problems presented and in the diagnosis that follows. For the specific treatment, we must concentrate on the problems presented, eliminate the non-problems, and follow the real problems. This will lead to the correct "clinical diagnosis" and then to an appropriate surgical algorithm and a surgical treatment proposal.

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Surgical Pathways to the Temporomandibular Joint

3

A. Abdullakutty and A. J. Sidebottom

Abstract

Evidence-based management of TMJ problems is limited with few randomized control trials. Although TMJ diseases were managed surgically, this is changing, and the vast majority is medical/non-surgical or minimally invasive. The management of temporomandibular joint conditions is an established area of subspecialization as they are common, and they contribute to a substantial workload in oral and maxillofacial units. Initial management with non-surgical or medical treatment is successful in most cases, as a result of advances in analgesia and the introduction of botulinum toxin injections. Since the pioneering work by Ohnishi, initial surgical management has largely changed from open operations on the joint to the use of arthroscopy for therapeutic and diagnostic benefit. Increasingly multidisciplinary approaches to TMJ treatment have more structure and science to their planning. Open surgical approaches to TMJ diseases have specific indications and should be done at specialist centres. To that end, this chapter details anatomic pathways that are used for open surgical access to the joint and related structures.

3.1 Introduction

Evidence-based management of TMJ problems is limited with few randomized control trials. Although TMJ diseases were often managed surgically, this is changing, and the vast majority is medical/non-surgical or minimally invasive [1]. The management of temporomandibular joint conditions is an established area of

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sub-specialization as they are common, and they contribute to a substantial workload in oral and maxillofacial units. Initial management with non-surgical or medical treatment is successful in most cases, as a result of advances in analgesia and the introduction of botulinum toxin injections [2]. Since the pioneering work by Ohnishi [3], initial surgical management has largely changed from open operations on the joint to the use of arthroscopy for therapeutic and diagnostic benefit. Increasingly multidisciplinary approaches to TMJ treatment have more structure and science to their planning [4]. Open surgical approaches to TMJ diseases have specific indications and should ideally be done under specialist guidance.

This chapter will provide an overview of the workup and approaches to surgery of the TMJ which will be covered in more detail elsewhere in this book.

3.2 Surgical Anatomy of TMJ

The temporomandibular joint (TMJ) is formed of the craniomandibular articulation [5].

The TMJ is a ginglymoarthrodial joint that is made of superior and inferior joint spaces separated by the meniscus. The articulatory system also consists of capsule, ligaments, masticatory and accessory muscles and teeth. Most sensory and motor branches are supplied by trigeminal nerve and partly by facial nerve.

3.3 Bony Boundaries

3.3.1 Glenoid Fossa

Anterior—articular eminence
Posterior—post glenoid tubercle
Medially—spine of sphenoid
Laterally—root of the zygomatic process
Superiorly—temporal bone
Presence of air cells in the arch and eminence (Fig. 3.1)

3.3.2 Mandible

The condylar process articulates with the glenoid fossa. It is broad laterally and narrower medially. The articular part of the condyle is covered by fibrocartilage.

3.3.3 Capsule

The capsule is made of thin sleeve of fibrous tissue investing the joint completely. It forms the anatomic and functional boundary of the TMJ, which originates from the periosteum of the mandibular neck, then envelops the articular disc and attaches to eminence and glenoid fossa.

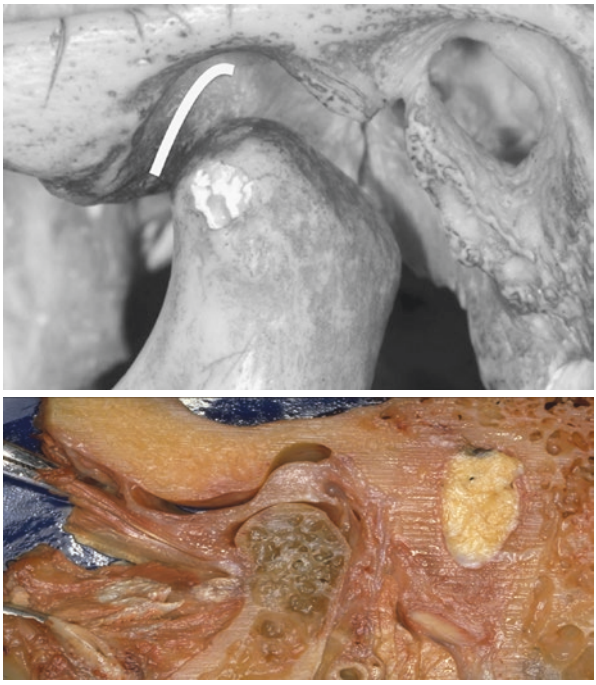


Fig. 3.1 Anatomical location of the Upper Joint Space below the articular eminence

3.4 Articular Disc

This is an oval-shaped fibrous biconcave tissue, which divides articular space into two compartments. The inferior compartment lies between the condyle and the disc. This space is rarely accessed in arthrocentesis or with an arthroscope, most often by accident or perforation (iatrogenic or disease related).

The superior disc is mostly accessed for therapeutic and diagnostic reasons, which is between the disc and the glenoid fossa. The disc is formed of three zones, posterior, intermediate and anterior. The intermediate zone being thinner is prone to perforation. The disc blends medially and laterally with the capsule, which in turn is attached to the medial and lateral poles of the condyle [6].

The posterior attachment of the disc (retrodiscal tissue) is vascular and can stretch leading to pain and clicking and also bleeding during discectomy. It may also thicken in response to repetitive trauma again leading to clicking. The vascularity of the retrodiscal tissue also permits suturing and repositioning of the disc. This area can be injected with HIGH concentration dextrose IN THE MANAGEMENT OF disc displacement or recurrent dislocation.

Volumes

Superior space, 1.2 mL

Lower space, 0.9 mL

The synovial fluid maintains the integrity of the disc (Fig. 3.2).

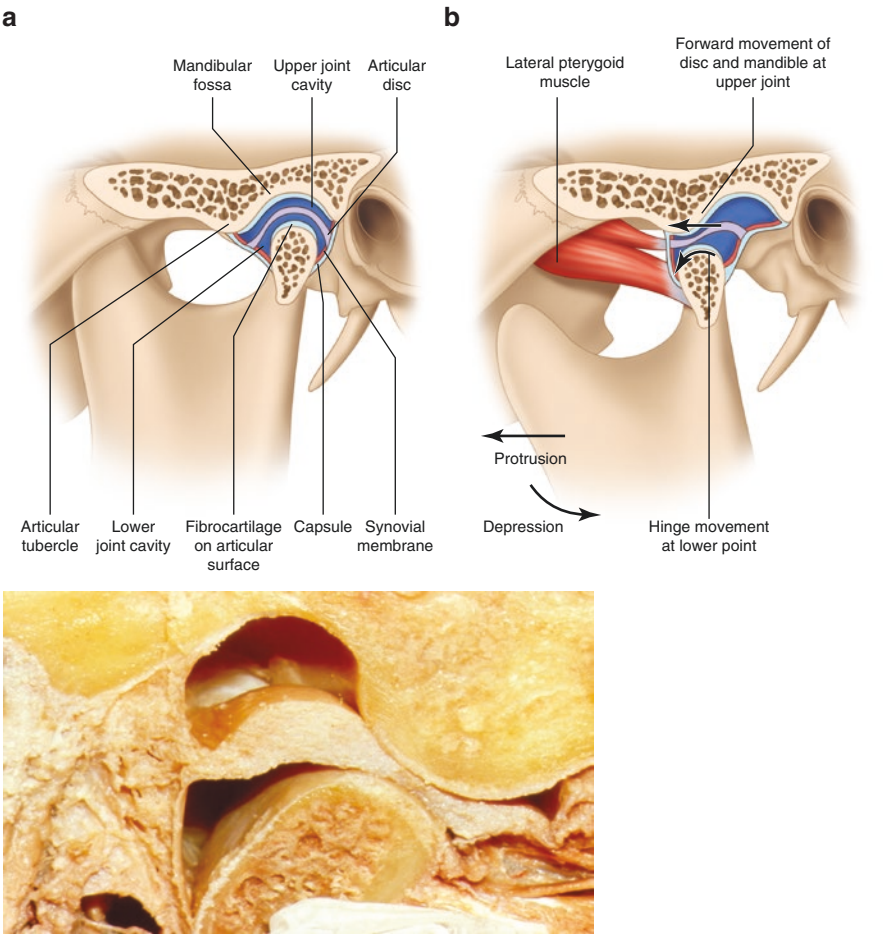


Fig. 3.2 This diagram illustrates the stylised anatomy of the TMJ and the Rotational movement which occurs in the lower joint space and the gliding movement which occurs in the upper joint space

3.5 Ligaments

3.5.1 Sphenomandibular Ligament

The sphenomandibular ligament arises from the sphenoid spine running downwards and medially to attach to the medial aspect of the ramus.

Surgical importance: maxillary artery and auriculotemporal nerve lie between the ligament and condylar neck. It has also been reported to have calcified and caused limitation of mandibular motion, which improved on its release [7].

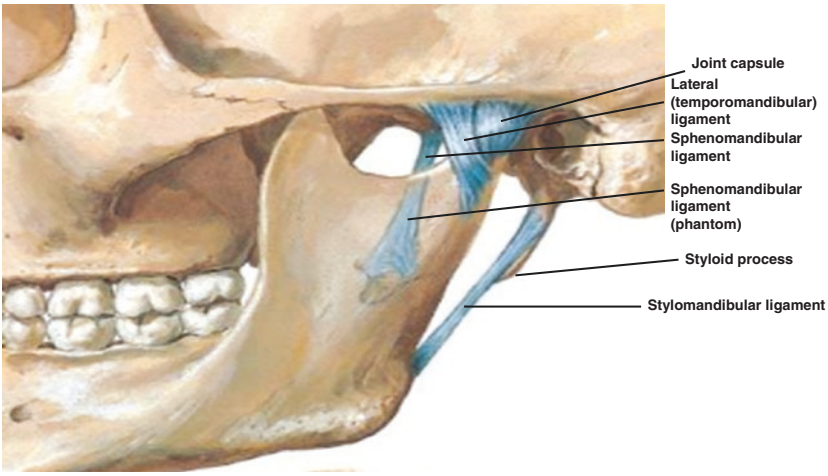


Fig. 3.3 Ligaments surrounding the TMJ

3.5.2 Stylomandibular Ligament

This is a condensation of deep cervical fascia extending from the styloid process to the mandibular angle. It may help to maintain stability of the joint but is of little surgical relevance.

3.5.3 TMJ or Lateral Ligaments

These reinforce the TMJ capsule. They extend from the articular eminence posterolaterally to the condylar neck, also called "the check ligament" as they help to prevent anterior and posterior dislocation (Fig. 3.3).

3.6 Blood Supply to TMJ

The superficial temporal artery and internal maxillary artery supply the TMJ via the deep auricular, posterior auricular and masseteric branches (Figs. 3.4 and 3.5).

3.7 Nerve Supply to TMJ

The TMJ is mainly innervated by THE auriculotemporal nerve supplying the posterior, medial and lateral aspect of the joint. Masseteric and deep temporal nerve SUPPLY the anterior part of the joint. The large bulk of the auriculotemporal nerve lies deep to the joint; hence the use of cryoanalgesia to the lateral capsule will not affect this part of the nerve [8] (Figs. 3.6 and 3.7).

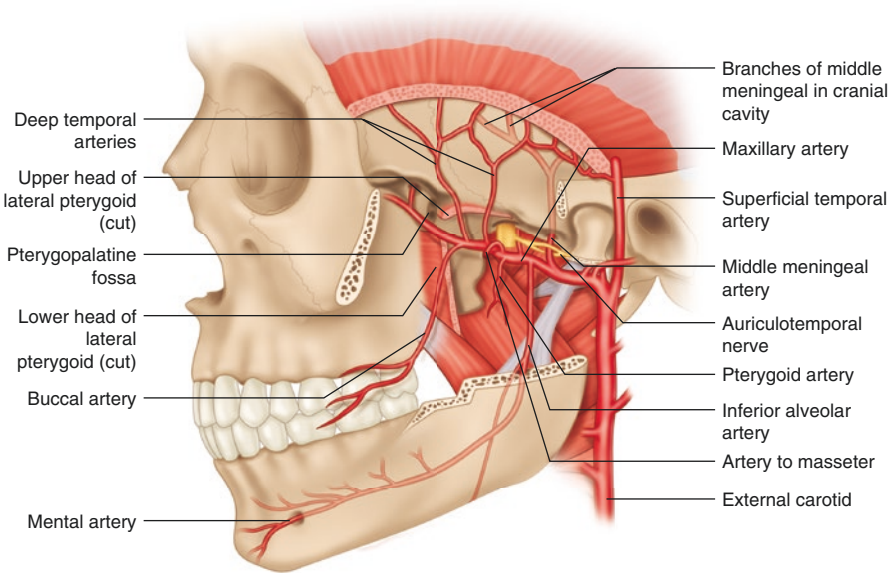


Fig. 3.4 Anatomical schematic showing the blood supply surrounding the TMJ. This is mainly via the terminal branches of the external carotid artery - superficaial temporal and maxillary arteries

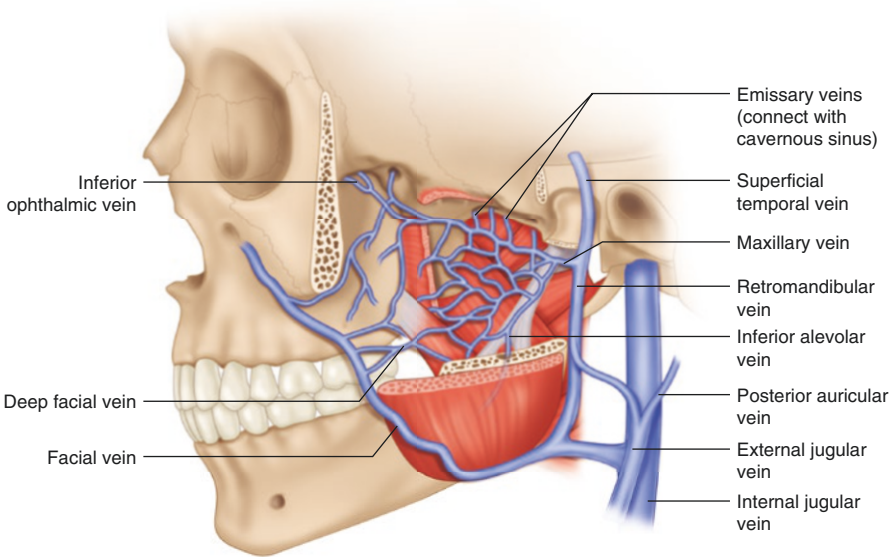


Fig. 3.5 Schematic diagram showing the venous structures surrounding the TMJ

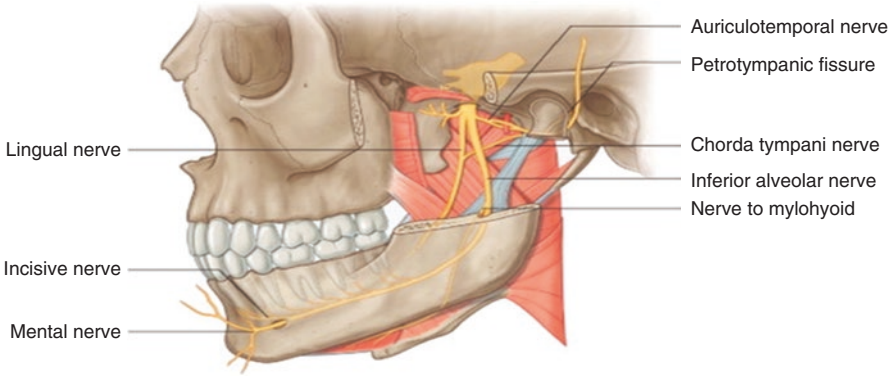


Fig. 3.6 Nerve relations to the TMJ

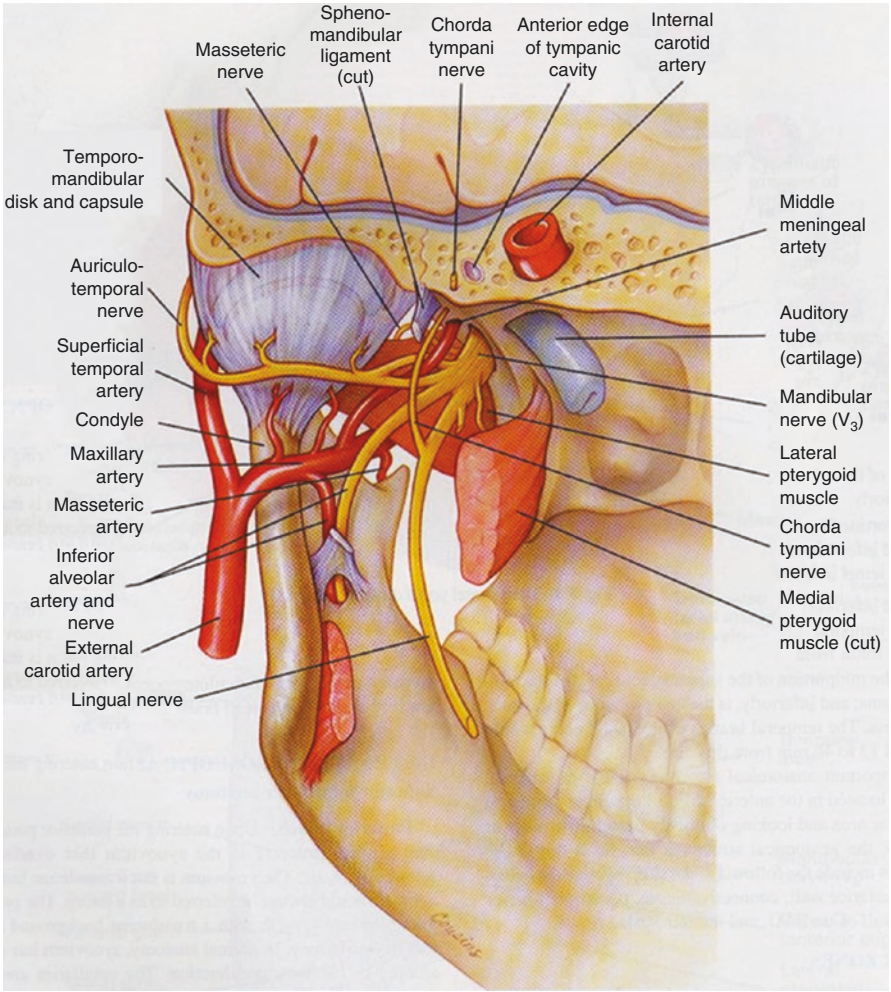


Fig. 3.7 Schematic view of the deep structures around the TMJ viewed from behind

3.8 Facial and Nerve and Its Surgical Importance in TMJ Surgery

The facial nerve lies deep to the condylar neck after emerging from the petrotympanic fissure. It divides into its five terminal branches, and the two most at risk during surgery to the TMJ are the frontal (temporal) and marginal mandibular branches, although injudicious retraction or too deep dissection may occasionally compromise the full nerve.

The frontal branch crosses the condylar neck within the SMAS layer and comes to lie superficial to the SMAS crossing the zygomatic arch between 8 and 28 mm anterior to the tragus[c]. Subperiosteal dissection from the root at the zygomatic arch carries this in the superficial tissues and helps to prevent traumatic neurotmesis.

The marginal mandibular branch passes through the parotid gland dividing it into superficial and deep lobes with the zygomatic, buccal and cervical branches [5, 6]. Transparotid dissection usually encounters this nerve lying on or near to the masseteric epimysium, and it can be retracted either superiorly or inferiorly to carry it out of the surgical wound.

3.9 Maxillary Artery and Its Surgical Importance

The course of the maxillary artery is relevant to surgical approaches which involve dissection deep to the head of the condyle as in joint replacement and discectomy. In particular the artery may be encountered passing through an ankylotic mass, the middle meningeal vessels lies just deep to the medial discal attachment and the masseteric vessels traverse the sigmoid notch.

3.10 Common TMJ Problems

3.10.1 Conservative Management

The temporomandibular joint is a load-bearing joint associated with teeth/dentures. The use of orthopaedic principles used in the management of other injured joints is therefore similarly applicable.

The mainstay of conservative management is rest, occlusal splints (offload the joint) and systemic or topical NSAIDS. Ice can help with pain, but compression and elevation are not possible (RICE). These statements are supported by Cochrane and other meta-analysis of the existing data.

Meta-analysis: Topical vs. systemic NSAIDs [8, 9]

- Splints [10]
- Occlusal modification [11]and later studies of Axelsson [12].

Seventy percent of secondary care patients in the UK can be effectively managed conservatively. Differentiating myofascial pain from joint problems is important, and local anaesthetic injections into trigger points can aid in diagnosing myofascial pain. This can subsequently be managed using either muscle relaxant medication or botulinum injections [13].

Subsequent management of joint-related pain (the diagnosis of which can be confirmed with intra-articular local analgesic injection) initially in the uncomplicated joint can be considered with either arthrocentesis or arthroscopy. This should be omitted in patients with ankylosis (the joint cannot be accessed) or joint collapse with occlusal derangement (condylar resorption) unless the primary aim is purely pain relief. These cases should be considered for joint reconstruction with alloplastic joint replacement.

1. Arthrocentesis [13, 14]
   (a) Indications [23, 24]
   - Acute closed lock (acute severe restriction of opening or "anchored disc phenomenon")
   - Inflammatory and degenerative conditions giving rise to joint pain

   (b) Technique
   - The authors advocate a two-needle technique with step-down from the zygomatic arch to avoid penetration of the floor of the fossa [14].

2. Arthroscopy
   (a) Indications
   - Clinical and/or radiological evidence of degenerative disease.
   - To rule out disc pathology.
   - Therapeutic management of joint pain, restriction and locking.
   - Arthroscopy gives a better diagnostic accuracy than MRI and arthrocentesis with the added benefit of therapeutic improvement over MRI alone.

   (b) Technique
   - Scope diameter varies from 1.2 to 2.1 mm.
   - Zero-degree need for direct access further anteriorly than 30-degree and hence failure to access the anterior recess is common.
   - Similarly a step-down technique is favoured to reduce the risk of penetration of the fossa floor into the middle cranial fossa.
   - A second portal is required either as a needle outlet for the fluid or for arthroscopic surgery where this is indicated. This requires significant arthroscopic skills to master.

3.11 Acute Severe Restricted Opening (Acute Closed Lock): Diagnosis/Management

Acute severe restriction of opening more commonly occurs in adolescents and young adults with an equal sex predilection, which should be treated early [15]. This condition presents as painful and limited mouth opening less than 26 mm. This is a result of reversible restriction of gliding motion of the joint due to disc adherence to the fossa in the upper joint space. Conservative measures and arthrocentesis with or without manual unlocking is effective in managing over two third of the cases. The remaining one third may progress to chronic features with partial improvement [10, 15]. The "stuck disc" is released as a result of lavage in arthrocentesis is effective in releasing 90% of anchored disc phenomenon cases in the studies of Nitzan and others. 2/3 is a VERY conservative estimate [16–18]. The use of intracapsular medications such as steroids and hyaluronic acid has not been found to be effective in a randomized study [19] although some case series with repeated injections and anecdotal evidence have occasionally shown benefit. Above 70% success rate has been reported in large studies after arthrocentesis [11] with similar outcomes following arthroscopy [14, 20] (Figs. 3.8, 3.9, 3.10, 3.11, 3.12, and 3.13).

Open approach

- Expose joint
- Capsule divided
  - Disc
  - Joint space(s)
- Repair at end
- capsule
- temporalis fascia

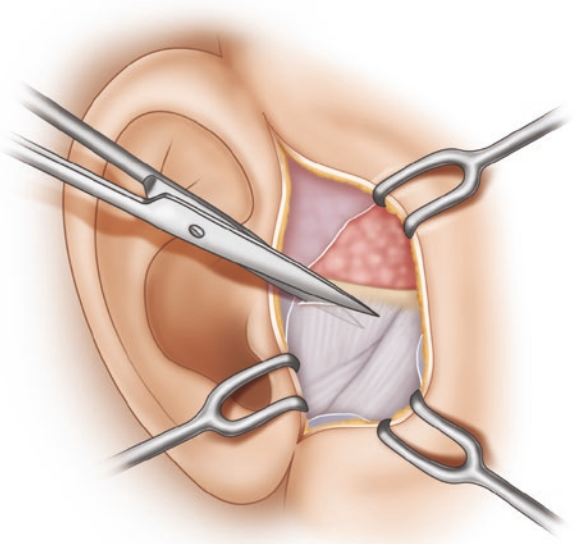


Fig. 3.8 Summary of technique for open TMJ surgery showing division of the superficial temporal fascia with exposure of the arch and eminence and subsequent opening of the capsule. These layers should be repaired on closure

RELATIONS

Laterally –

Skin and fascia
Parotid gland
Temporal branches of facial nerve

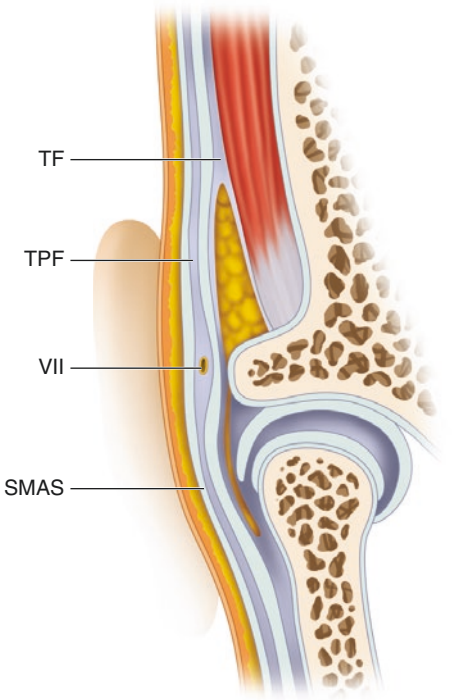


Fig. 3.9 Superficial relations of the TMJ. *TF* temporalis fascia; *TPF* superficial layer of temporalis fascia; *VII* temporal branch of facial nerve; *SMAS* superficial musculoaponeurotic system

Open approach

- Critical anatomy
  - "Splitting of outer layer of superficial temporalis fascia"
  - Incise fascia
  - Raise ABOVE thin fat layer
  - Turn forward and down
  - VII Temporal protected

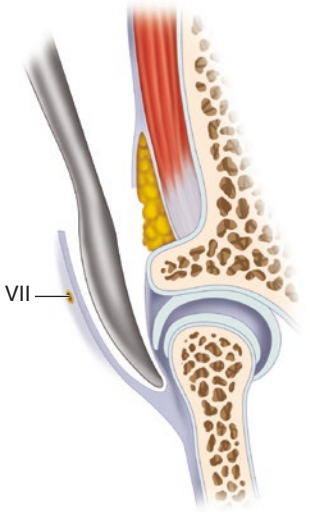


Fig. 3.10 Preservation of the temporal branch of facial nerve is acheived by dividing the temporalis fascia from the base of the zygomatic arch and extending this incision 45 degree superoanteriorly then carrying out subperiosteal exposure of the arch

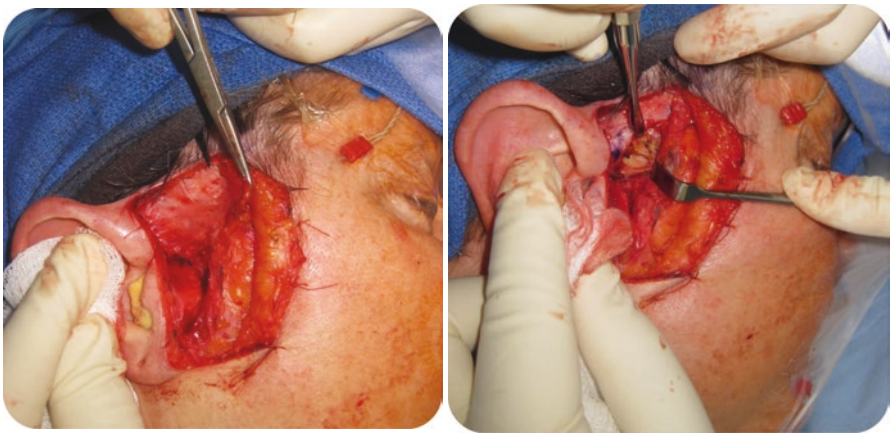


Fig. 3.11 Division of the temporalis fascia from the base of the arch as above with subperiosteal exposure of the zygomatic arch

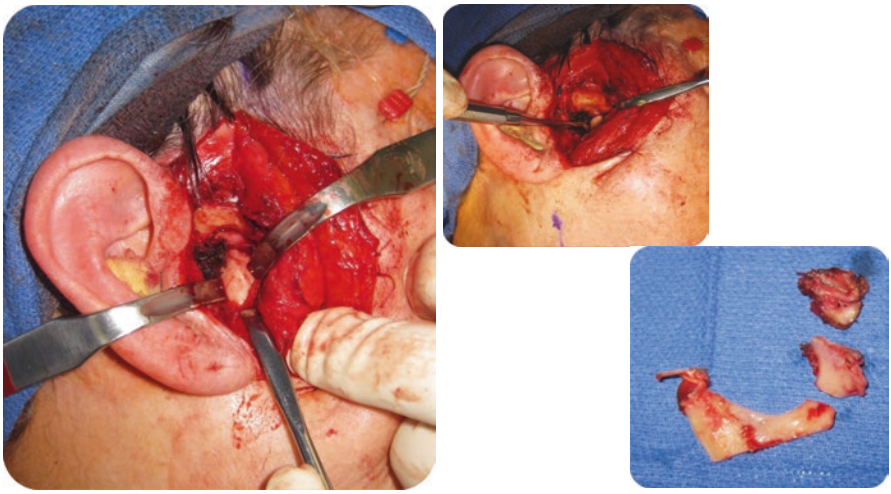


Fig. 3.12 Capsule opened and exposure of the condylar neck

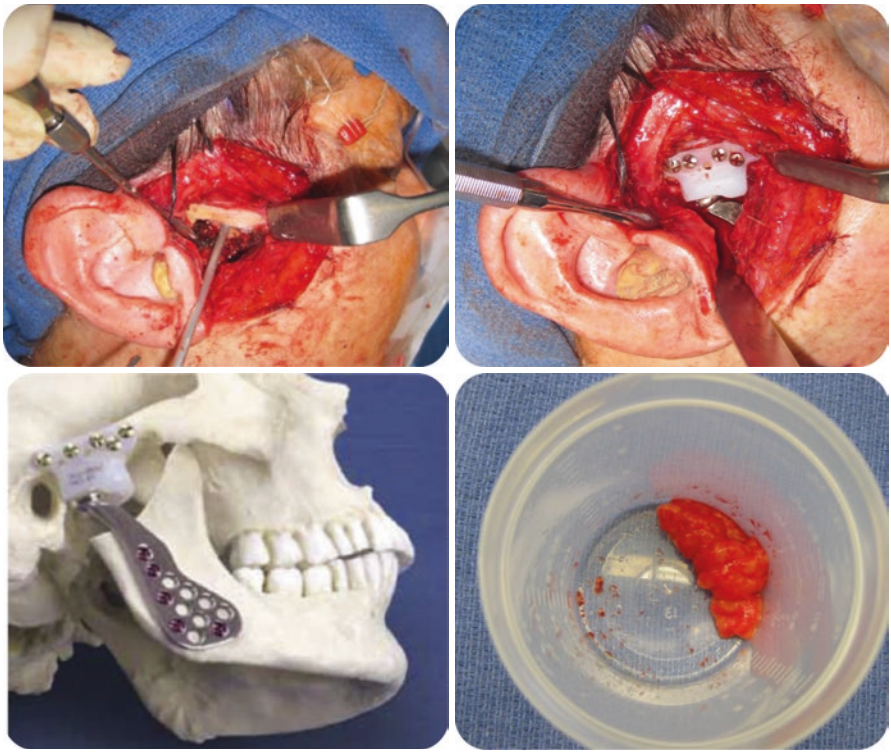
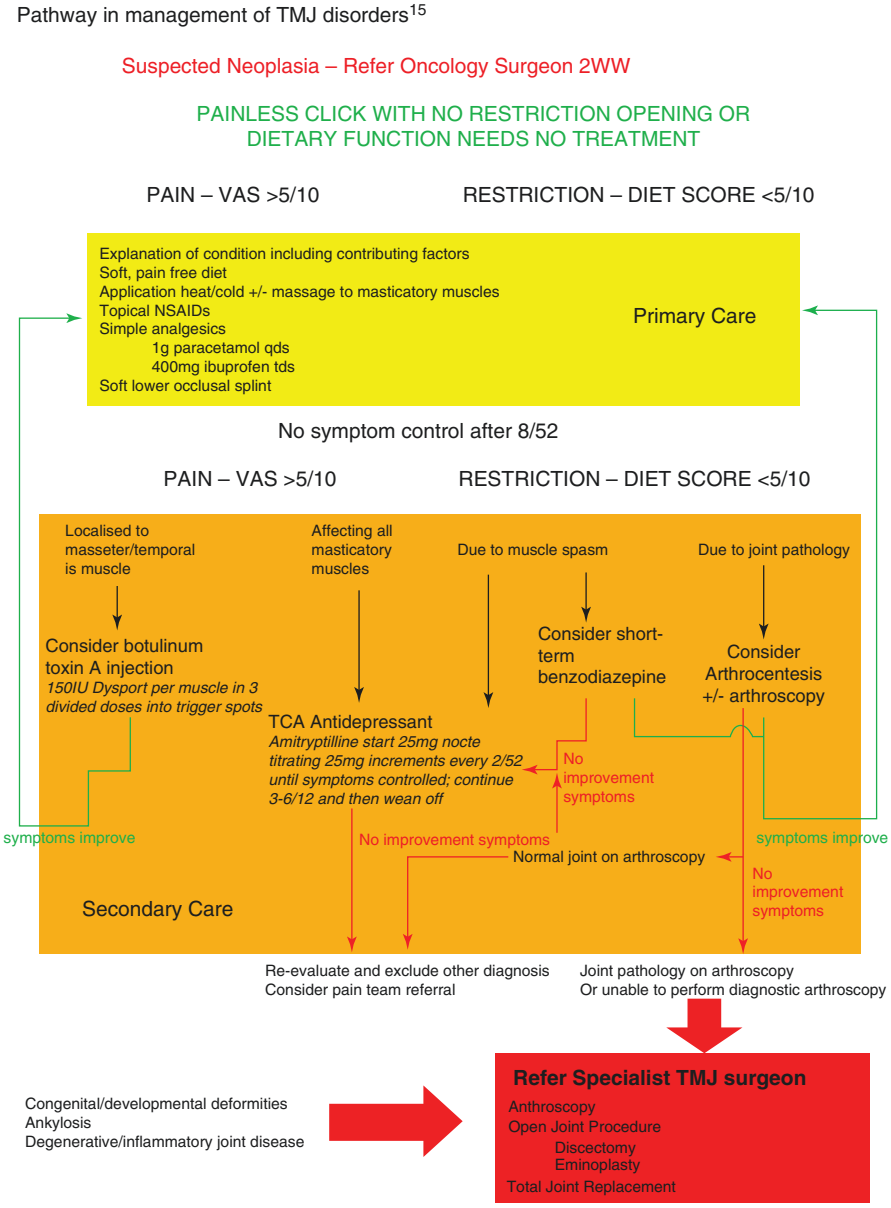


Fig. 3.13 Fossa and eminence are trimmed to accommodate stock Biomet polyethylene fossa which is then fixed with at least 3 screws. A fat graft may be packed around the articulation, particularly in cases where ankylosis is the indication for alloplastic replacement

3.12 Pathway in Management of TMJ Disorders [21, 25]

Pathway in management of TMJ disorders[15]



3.13 Surgical Management

Open surgery of the joint should only be considered where arthroscopy has failed and there was clinical evidence of pathology at arthroscopy.

Open joint procedures (for discectomy/repair or repositioning, condylar shave, condylectomy and eminoplasty) (see clinical photographs of this approach)

The authors do not believe that eminectomy can truly be performed as the eminence extends significantly medially along the skull base, and therefore the term eminoplasty is more appropriate.

- Preauricular approach to joint is common although endaural and postauricular incision has been described in the literature.
- Preauricular region is prepared with appropriate antiseptic cleaning agents and draped with provisions to manipulate the mandible (urology drape). The ear canal should also be prepared, and if the mouth is to be accessed at any stage, then a preoperative chlorhexidine mouth rinse should be employed.
- Incision is marked with or without temporal extension (Al-Kayat/Bramley [22]).
- Local anaesthetic infiltration.
- The temporalis fascia is identified higher up along the incision and then the plane of the fascia is defined. The skin incision is then deepened in the relatively avascular plane immediately adjacent to the tragal cartilage until the base of the zygomatic arch is located.
- The temporalis fascia is incised carefully at the base of the arch keeping in mind the anatomy of the temporal branch of the facial nerve, and this incision is then continued through the temporalis fascia in a line 45° anterosuperiorly (see diagrams above).
- The root of the zygomatic arch is identified, and periosteum is swept anteriorly along the arch till adequate exposure of the capsule anteriorly (to the front of the eminence) and inferiorly to develop the plane superficial to the capsule (this can usually be achieved in previously unoperated joints by blunt dissection but may need sharp dissection in previously operated cases). Using this plane sweeps the temporal branch above the plane of dissection and prevents incision. The capsule is then defined by blunt and sharp dissection in the same plane just below the arch.
- The capsule is incised vertically, and superior and inferior joint spaces are approached carefully not to cause any iatrogenic disc perforation by horizontal incision. The upper and lower joint spaces and disc are inspected.
- The disc is now mobile and can be inspected for any lateral perforation that can be trimmed and moved off the articulating surface. The disc can be repositioned laterally or posteriorly if the diagnosis reveals anterior displacement.
- If the disc is irreparably damaged, discectomy is performed. Starting posteriorly the disc is mobilized carefully diathermying the retro discal tissues to avoid bleeding and dissection carried out anteriorly (again using diathermy to remove the lateral pterygoid attachment) and medially.
- It is important not to leave any disc remnants, and good inspection is possible after downward displacement of the mandible.

- Consideration for autogenous interposition at this stage although the evidence suggests this is not necessary and causes an additional site for morbidity
- If the condylar surface is eroded or osteophytic, then smoothing of the surface can easily be performed through the lower end of the capsular incision.
- The Dunn-Dautrey's retractor is useful to insert posterior and anterior to the condylar neck to isolate the condyle.
- If the eminence is eroded, osteophytic, overlarge or overhanging laterally (lateral impingement), then it can be smoothed (eminoplasty).
- Combining the above steps, discectomy, high condylar shave and condylectomy and eminoplasty can be carried out to re-establish the joint equilibrium and permit functional healing. The joint is then copiously irrigated with isotonic saline.
- Closure with PDS to the capsule and temporalis fascia and superficial fascia with resorbable Vicryl, and then the skin is closed with monofilament. Drainage is not usually necessary if adequate haemostasis has been maintained throughout.

3.14 TMJ Replacement

Total TMJ replacement has evolved considerably in the recent past and there is a choice of stock and custom-made prosthesis.

Indications for TMJ prosthesis [18, 26] are:

Prerequisite: Failed conservative management (including arthroscopy if possible)

Diagnosis: Computed tomogram or MRI as a minimum (not just plain radiograph)

Diseases involving condylar bone loss:

- Degenerative joint disease (OA)
- Inflammatory joint disease (e.g. rheumatoid arthritis, ankylosing spondylitis, psoriatic)
- Ankylosis
- Post-traumatic condylar loss or damage
- Postoperative condylar loss (including neoplastic ablation)
- Previous prosthetic reconstruction
- Previous costochondral graft
- Serious congenital deformity
- Multiple previous procedures

Indications (usually a combination of the following):

- Dietary score of <5/10 (liquid scores, 0; full diet scores, 10)
- Restricted mouth opening (<35 mm)
- Occlusal collapse (anterior open bite or retrusion of mandible)
- Excessive condylar resorption and loss of height of vertical ramus
- Pain score >5 out of 10 on VAS (combined with any of the others)
- Other QOL issues

Contraindications:

- Local infective process
- Severe immunocompromise
- Severe coexistent diseases (ASA III)

Surgical indications for hemiarthroplasty (fossa-eminence prosthesis):

This procedure has been abandoned in the UK as many patients subsequently develop degenerative disease of the condylar head.

Indications:

- Painful or dysfunctional internal derangement after failed conservative and surgical treatment and a healthy condyle on computed tomogram or MRI
- Associated QOL issues as with TPR

Contraindications:

- Disruption of the condylar surface
- AVN
- Presence of osteophytes

Surgical technique:

- Preparation of the site includes pre-operative oral rinsing with chlorhexidine, ear canal preparation and adequate hair removal with surgical clippers to avoid hair in the wounds.
- The oral and skin sites should be strictly separated to reduce the risk of cross-contamination and infection.
- Placement of arch bars or IMF screws to aid intraoperative occlusion.
- Preauricular with temporal extension and retromandibular approach.
- Antibiotic prophylaxis and antiseptic preparation of the incision areas.
- Joint exposure similar to open approach as described above.
- Fossa is cleared of disc, debris and periosteum.
- Condylectomy is carried out via a preauricular approach to start with to aid in fossa component try-in. The remaining part of condylar neck and ramus is resected as per the surgical plan executed via the retromandibular approach or by pushing the condylar neck into the wound and carrying out second-stage resection.
- Retromandibular incision (see clinical photographs of the approach) through to the platysma, and blunt dissection to the lower border/angle of the mandible is done.
- The marginal mandibular nerve is often found lying on the masseteric epimysium and should be mobilized gently and retracted out of the wound superiorly or inferiorly.
- Release of the pterygo-masseteric sling along the lower border and lower ascending ramus facilitates superior dissection.

- Masseter muscle is then gently stripped subperiosteally, and the ramus is exposed on the lateral part to aid in further resection and condylar prosthesis try-in.
- The sigmoid notch can be the site of placement of the Dunn-Dautrey retractor which facilitates the view of the condylar neck for second-stage ostectomy, and a similar retractor can be placed over the anterior portion of the coronoid to facilitate coronoidectomy if required.
- The prosthetic components are soaked in antibiotic-containing and the wound sites are irrigated with antibiotic containing solution.
- The fossa prosthesis is fixed as per the surgical plan using at least three screws.
- Ensure adequate freedom of movement of the mandible below the fossa prosthesis.
- The ramus prosthesis is then tried in (or the trial prosthesis if this is used).
- Once try-in is satisfactory, the patient is placed in an intermaxillary fixation ensuring no cross-contamination from the mouth to the skin wounds. This will achieve the desired occlusion that may be different to the pre-operative occlusion. If both side joints are being replaced, then the second side resection should be completed prior to achieving the final occlusal position.
- It is important to re-scrub at this point to keep the surgical field aseptic.
- The condylar component is now fixed via the retromandibular approach with the screws supplied ensuring adequate positioning in the fossa. The most important screws are the most proximal screws to maintain biomechanical stability. At least six screws should be used paying attention to avoid the position of the inferior alveolar canal in stock cases.
- IMF is released and occlusion checked by the assistant keeping the surgical field aseptic.
- Check for dislocation of the prosthesis, and if this occurs, 1 week of LIGHT elastic intermaxillary fixation will prevent this in the post-operative period.
- The authors suggest placing only 3 screw initially prior to releasing the IMF to check the occlusion and articulation of the prosthesis. If this needs to be repositioned then there are less screw holes causing issues.
- Antibiotic containing solution is washed over the surfaces of the prosthesis. Placement of an abdominal fat graft is optional but is considered desirable in ankylosis and revision surgery cases.
- A drain is inserted through the superior wound into the inferior wound and should be removed at 24 h to reduce the risk of infection.
- Closure is in layers after drain is inserted.
- Mouth-opening exercises should be started following surgery.

3.15 Conclusion

The temporomandibular joint is a complex joint which should be managed using a team-based approach aimed at determining whether the main issues relate to the joint or muscles. Operative intervention should be reserved for specific indications and preferably following a stepwise approach involving conservative management

followed by minimally invasive arthrocentesis or arthroscopy. Long-term prospective clinical trials with appropriate study designs will help determine the best treatment options for a specific pathology.

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Part II

Surgical Procedures Other than Total Joint Replacement

Surgery of the Temporomandibular Joint: Surgical Arthroscopy

4

C. Seebauer, W. Kaduk, J. Fernandez Sanroman, and Rebeka G. Silva

Abstract

Arthroscopic surgery is one of the most popular and effective methods of diagnosing and treating TMJ disorders since TMJ disorders have become an increasingly widespread problem in our society. Arthroscopic evaluation enables the surgeon to visualize the joint and, therefore, contributes to the diagnosis of the internal pathologic condition of the joint. It has advantages over open joint surgery as it allows inspection of a surgically undisturbed joint both at rest and in function. However, TMJ arthroscopy only allows access to the upper joint space and is limited in the procedures and pathology it can be applied to. Surgical treatment is indicated in only about 5% of patients with TMJ disorders. Thus, a stringent patient selection is the key and an essential foundation for successful surgical treatment.

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4.1 History

The first report of an arthroscope for diagnostic purposes in the TMJ was given by Ohnishi in 1975 [1]. He adapted the orthopedic arthroscopy for use in small dimensions and developed a puncture method, in which a puncture needle and a sheath needle were utilized to examine the TMJ cavity [2]. In 1980, Murakami performed cadaver studies, described normal anatomy and a safe and effective method of joint puncture, followed by topographic terminology and histologic studies, and then clinically applied it to patients with internal derangement and arthrosis [3–5]. In the 1980s Holmlund and Hellsing performed independent research in cadaver studies, identified puncture sites that correlated with the tragal-lateral canthus line, and described puncture techniques and anatomic key points to make the technique of TMJ arthroscopy secure and standardized [6, 7]. Since that time, TMJ research and arthroscopy have led to a better understanding of the normal and abnormal intra-articular anatomy and associated diseases, which has led to an improved understanding of TMJ pain as well as dysfunctions. Therefore several studies concerning the benefit of arthroscopy for treating TMJ diseases have been published over the following decades. By the 1980s, arthroscopy of the TMJ had first developed as a diagnostic tool and further on as a surgical intervention for patients with TMJ diseases. In 1982, Murakami and Hoshino developed the nomenclature of TMJ arthroscopic anatomy [8]. McCain published his research and development of a puncture technique, an irrigation system, and diagnostic observations, as well as complications during arthroscopic surgery in 1985 [9, 10]. Shortly thereafter, in 1986, Sanders described and published his research about therapeutic benefits of arthroscopy in patients with acute painful hypomobility of the joint and acute and chronic closed lock of the TMJ and introduced the terms lysis as a distension of the joint with a blunt trocar to eliminate the suction effect of the disc to the fossa and by that lysing or breaking the adherences [11]. In the same year, arthroscopic suture for the treatment of anterior disc displacement or recurrent mandibular dislocation has been described by Murakami and Ono [12]. In 1987, arthrocentesis as a form of repositioning of the anteriorly displaced disc by mandibular manipulation after pumping hydraulic pressure to the upper joint of the TMJ has been introduced by Murakami [13, 15]. In the subsequent years, several techniques for arthroscopic suture were described by McCain in 1992 [14] and Tarro in 1994 [15]. In 1991, Nitzan presented a modified method, which was based on the insertion of two needles in the upper joint space for lavage without direct visualization of the joint [16]. The role of molecular pathological sequences in synovial fluid of diseased TMJ has been examined closer by Milam and Schmitz in 1995 [17]. Many ensuring regarding the TMJ synovial fluid demonstrated that various cytokines, pain mediators, and substances detected were higher in diseased TMJ compared with the control and closely linked to the pain and/or osteoarthritic changes [18–30]. Since the late 1980s and 1990s, a large number of articles and publications regarding TMJ arthroscopy were published.

4.2 Indications and Contraindications for TMJ Arthroscopy

Arthroscopic surgery is one of the most popular and effective methods of diagnosing and treating TMJ disorders since TMJ disorders have become an increasingly widespread problem in our society. Arthroscopic evaluation enables the surgeon to visualize the joint and, therefore, contributes to the diagnosis of the internal pathologic condition of the joint. It has advantages over open joint surgery as it allows inspection of a surgically undisturbed joint both at rest and in function. However, TMJ arthroscopy only allows access to the upper joint space and is limited in the procedures and pathology it can be applied to. Surgical treatment is indicated in only about 5% of patients with TMJ disorders. Thus, a stringent patient selection is the key and an essential foundation for successful surgical treatment [31]. Because TMJ surgeries are such specialized procedures, it often takes years to acquire adequate clinical experience. The surgeon's task is to accurately interpret the symptoms reported by the patient, taking into account the success of nonsurgical treatment, the disability from which patients suffer from and the pathology underlying the condition.

4.2.1 Indications

TMJ arthroscopy is indicated for particularly severe cases that have not been adequately managed by conservative therapy. The principal indications for TMJ arthroscopy are forms of craniomandibular dysfunction originating in the articular disc and the retrodiscal tissue also known as the posterior attachment, posterior ligaments, or retrodiscal pad. The most common disorders indicated for TMJ arthroscopy are degenerative joint diseases and kinds of internal derangements, e.g., disc hypomobility as a result of fibrosis or adhesions and disc hypermobility as a result of elongation of the retrodiscal ligaments combined with anterior disc displacement. The American Association of Oral and Maxillofacial Surgeons (AAOMS) established five main indications for TMJ arthroscopy: (1) internal derangement of the TMJ, mainly Wilkes stages 2–4 (Table 4.1) [32, 33], (2) degenerative joint disease, (3) synovitis, (4) painful hypermobility or recurrent luxation of the disc, and (5) hypomobility caused by intra-articular adherences [34, 35].

4.2.2 Contraindications

Common contraindications for arthroscopic treatment are acute cutaneous, otic, or articular infections, severe fibrous or osseous ankylosis, risk of tumor dissemination, general medical contraindications, and anatomical contraindications.

Table 4.1 Classification for TMJ internal derangement (ID), clinical and radiologic findings according to Wilkes [32], and arthroscopic findings according to Bronstein and Merrill [33]

	Clinical and radiologic findings according to Wilkes			Arthroscopic findings according to Bronstein and Merrill	
Stage	Clinical	Imaging	Surgical	Arthroscopic	Roofing (%)
I. Early	Painless clicking	Slightly forward disc, reducing[a]	Normal disc form	Elongation of bilaminar zone, normal synovia, and disc, no cartilage involvement	80–100
	No restricted motion	Normal osseous contours	Slight anterior displacement		
			Passive incoordination (clicking)		
II. Early/ intermediate	Occasional painful clicking	Slightly forward disc, reducing	Anterior disc displacement	Elongation of bilaminar zone, synovitis with adherences in initial phase, anterolateral prolapse of the capsule	50–100
	Intermittent locking	Early disc deformity	Thickened disc		
	Headaches	Normal osseous contours			
III. Intermediate	Frequent pain	Anterior disc displacement,	Disc deformed and displaced	Elongation of bilaminar zone, important synovitis, decrease of lateral recess, adherences, chondromalacia I–II	25–50
	Joint tenderness, headaches	Reducing early progressing	Variable adhesions		
	Locking	To nonreducing[a] late	No bone changes		
	Restricted motion	Moderate to marked disc			
	Painful chewing	Thickening			
		Normal osseous contours			
IV. Intermediate/ late	Chronic pain, headache	Anterior disc displacement,	Degenerative remodeling of	Hyalinization of posterior ligament, synovitis, adherences, chondromalacia III–IV	0–25
	Restricted motion	Nonreducing	Bony surfaces		
		Marked disc thickening	Osteophytes		
		Abnormal bone contours	Adhesions, deformed disc		
			Without perforation		

Table 4.1 (continued)

Stage	Clinical and radiologic findings according to Wilkes			Arthroscopic findings according to Bronstein and Merrill	
	Clinical	Imaging	Surgical	Arthroscopic	Roofing (%)
V. Late	Variable pain	Anterior disc displacement,	Gross degenerative changes of disc	Retrodiscal hyalinization, disc perforation, fibrillation of articular surfaces, advanced synovitis, gross adhesions, chondromalacia IV	0
	Joint crepitus	Nonreducing with perforation	And hard tissues		
	Painful function	And gross disc deformity	Perforation		
		Degenerative osseous	Multiple adhesions		
		Changes			

[a]Refers to disc position in relation to the condyle when the mouth is open

4.3 Arthroscopic Instrumentation and Equipment

There are many different components to an arthroscopy equipment system that is described in more detail below.

4.3.1 Arthroscopy Equipment

Arthroscopes are optical instruments allowing the surgeon to examine the articular environment in a minimally invasive manner. The arthroscopes themselves are rigid endoscopes that generally range from 1.9 to 2.7 mm in diameter. Crudely, an arthroscope consists of a series of lenses and a fiber-optic light wire housed in a metal tube. Three basic optical systems have been described in rigid arthroscopes: the classic thin lens system, the rod-lens system, and the graded index lens system (Fig. 4.1a). Fiber-optic technology, the use of magnifying lenses, and digital monitors have allowed advancements in arthroscope design. Newer arthroscopes offer an increased field of view with smaller scope diameters, better depth of field with improved optics, and better flow through the cannula. Certain features determine the optical characteristics of an arthroscope. Most important are the diameter, angle of inclination, and field of view. The angle of inclination is defined as angle between the axis of the arthroscope and a line perpendicular to the surface of the lens and

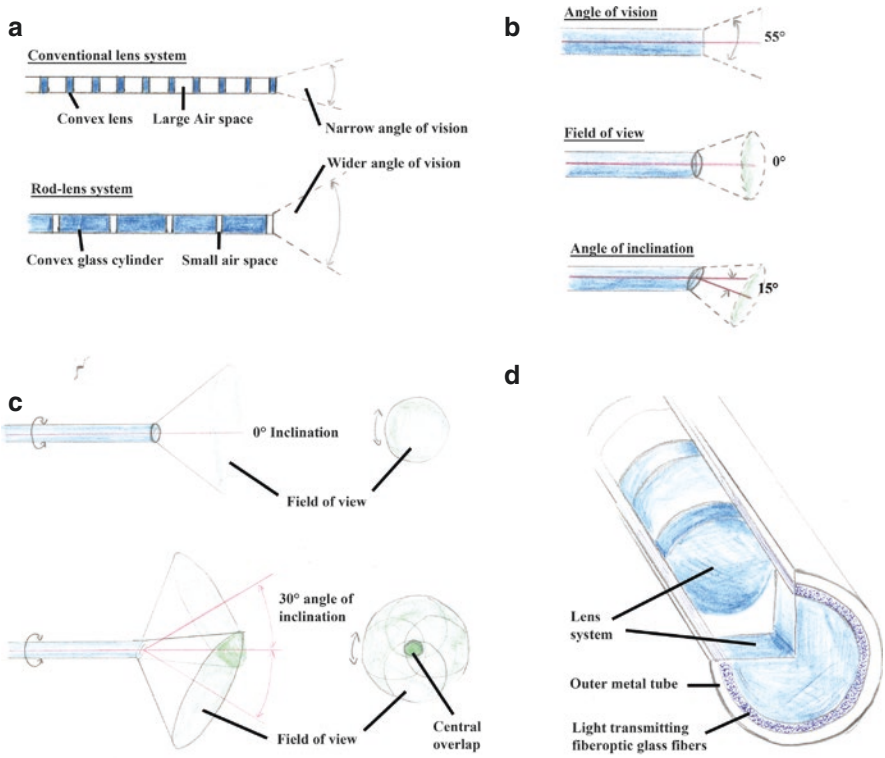

Fig. 4.1 (**a**) Comparison of the structure of the conventional endoscopic lens system showing a narrow angle of vision and the Rod-lens system showing a wider angle of vision. (**b**) The drawing illustrates the terms of ankle of vision, field of view, and angle of inclination. The 0° angle of inclination gives a straight-ahead view. (**c**) The drawing illustrates the effect of arthroscope rotation. With a 0° arthroscope, the field of view is unchanged with rotation. Rotating of an oblique angle of inclination around its axis (25° and 30° arthroscopes) increases the field of view and creates overlapping circular images at the center. (**d**) Cross-sectional representation of an arthroscope showing the interior light transmitting fiber-optic glass fibers surrounding the lens system

defines the direction of view (Fig. 4.1b). The usual angles of inclination are 0°, 25°, and 30° (Fig. 4.2a). Rotation of an arthroscope with a 30° angle of inclination enables scanning effect and increases field of view (Fig. 4.1c) [36]. Nevertheless, the 25° and 30° arthroscopes are not used frequently, because their handling is more difficult and the overview is not necessarily more in a small joint space, e.g., the TMJ. Field of view refers to the viewing angle encompassed by the lens and varies according to the type of arthroscope. As the diameter of the scope decreases, the apparent field of view and brightness of the image decrease. To overcome this fact, either an integrated video arthroscopic system with zoom camera couplers is used or the light source is enhanced. The light transmission through the arthroscope is accomplished by the light fibers surrounding the lens system and is connected at the side of the arthroscope to a fiber light-cord coupler which attaches it to the light source (Fig. 4.1d). The light source is usually fitted with an automatic light level

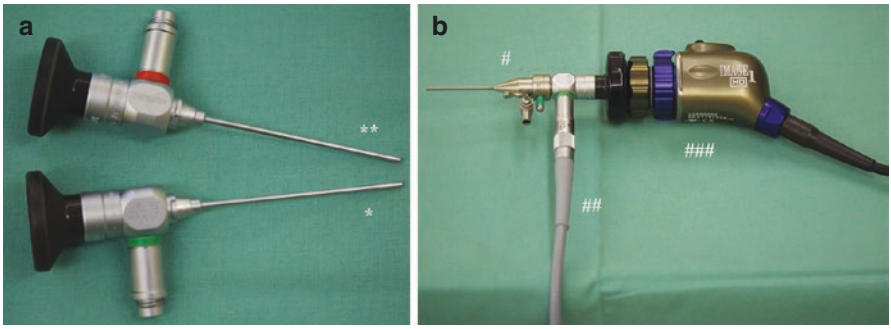

Fig. 4.2 (**a**) Comparison of the most frequently used straightforward 0° (asterisk) arthroscope and the 30°-angled arthroscope (doubel asterisk) (HOPKINS™, Storz, Tuttlingen, Germany) with a diameter of 1.9 mm and a length of 6.5 cm. (**b**) For clinical use, the arthroscope is connected with the working sheath (hash) with a lateral Luer Lock adapter, the light transmission cable (double hash), and the camera head with the CCD sensing chip (triple hash)

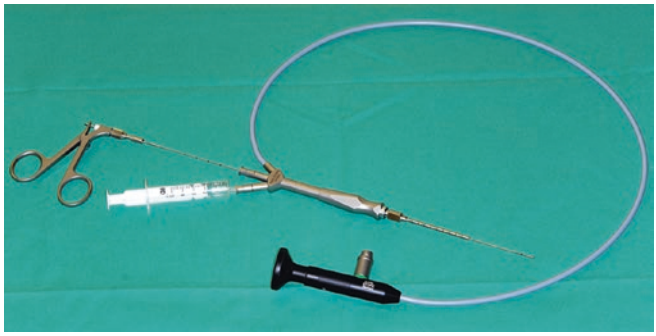

Fig. 4.3 The all-in-one arthroscope has an outer diameter of 2.2 mm and an integrated 1.4 mm working channel. It combines the telescope, the irrigation channel, and the working channel and thereby allows arthroscopic lavage as well as arthroscopic microsurgery. The palpation hook, scissors, and biopsy forceps can be directly inserted into the joint through the endoscope's integrated working channel

adjustment system connected to the camera's console for a feedback loop. The arthroscope is connected to a camera head and light source which allows the magnified image of the inside of the joint to be displayed on a monitor (Fig. 4.2b). During the past 10 years, analogous endoscopic technology has been almost replaced by digital systems. But in general, the spatial resolution of the digital image is limited by the pixel size. Therefore, image resolution is limited by ever-decreasing sizes of endoscopic optics and optical fibers by now. All arthroscopes are passed into the joint via a trocar. The trocar is a tube that the arthroscope slides down and locks into when it is seated properly. It provides protection against bending and provides a conduit for fluids to irrigate the joint. An all-in-one arthroscope by Storz (Tuttlingen, Germany) combines the telescope, the irrigation channel, as well as the working channel (Fig. 4.3). It has an outer diameter of 2.2 mm and enables the direct

insertion of instruments through the endoscope's integrated 1.4 mm working channel. Users can simultaneously view the joint through the arthroscope and use the instruments through the working channel under the very same arthroscopic view. Thereby the difficult and time-consuming triangulation step, which involves finding the working channel with the endoscope, is eliminated (Fig. 4.3) [37].

4.3.2 Light Sources

All endoscopes utilize a light source to illuminate the inside of the joint during the procedure. The light source consists of a box that houses the bulb (usually xenon or LED) which is connected to the arthroscope via a fiber-optic light cable. This cable carries the light to the arthroscope and can be set at various light intensity levels (Fig. 4.4).

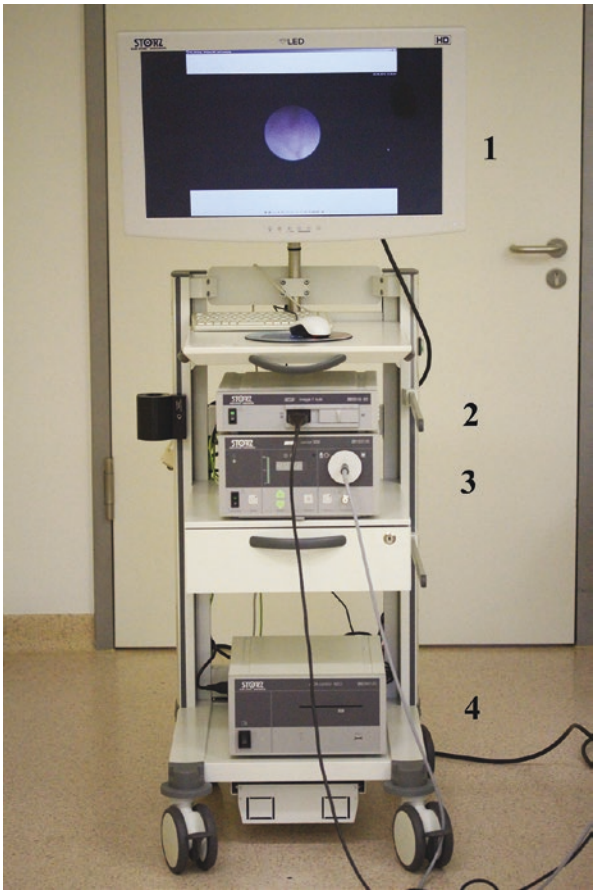

Fig. 4.4 The basic mobile video cart contains the monitor (1); the camera control unit, which converts optical images to digital (2); the cold light fountain with the light transmission cable (3); and the recording unit (4) (Storz, Tuttlingen, Germany)

4.3.3 Video Equipment

The arthroscope is attached to the camera head that is responsible for producing the image on a video monitoring system. Inside the camera head, there are small computer chips that capture the actual image into a digital image. Usually cameras provide high-definition (HD) technology. Digital imaging and visualization of the joint allow to document surgical procedures and pathologies. A complete video monitoring cart contains the monitor, light source, camera unit, and documentation equipment (Fig. 4.4).

4.3.4 Image Capturing

Medical image storage has become standard and mandatory in clinical routine for documentation, educational purposes, and legal safeguarding. Image capture devices are commonly found on every arthroscopy towers today that save pictures or movies during the arthroscopic procedure onto internal or external hard drives.

4.3.5 Fluid Management

A constant flow of irrigation fluid is essential for providing a clear view of the joint surfaces through the distention of the joint space and compartments and for flushing out of blood and debris and cooling during, e.g., laser interventions. Additional benefits of the irrigation are comparable with the therapeutic effects of lavage and arthrocentesis. The fluid can either be introduced using gravity and a simple intravenous fluid bag or via a specialized pump that forces fluid into the joint at a specific rate and pressure. For joint distention during arthroscopy, lactated Ringer has proven to be better than isotonic sodium chloride solution. Ringer solution is physiological and has proven to maintain meniscal cell integrity. The inflow may pass directly through the arthroscopic cannula or through a separate portal by means of a cannula. The diameter of the outflow portal should be of smaller size than the inflow portal, which allows a slight pressure difference in order to maintain sufficient joint distention. Collecting the irrigation fluid allows visible evidence in determining whether the amount of fluid pressured into the joint is equal to the amount coming back out of it, or not, preventing extravasation into the periarticular tissues.

4.3.6 Arthroscopic Hardware

There are various handheld instruments that are used during the arthroscopic procedures, e.g., instruments used for grasping, cutting, and extracting tissue. The most commonly used are the hooked probe, grasping and biopsy or cutting forceps. Through a trocar, the arthroscope can be passed into the joint space. In addition to the arthroscopic trocar, there are also instrument cannulas and outflow cannulas in

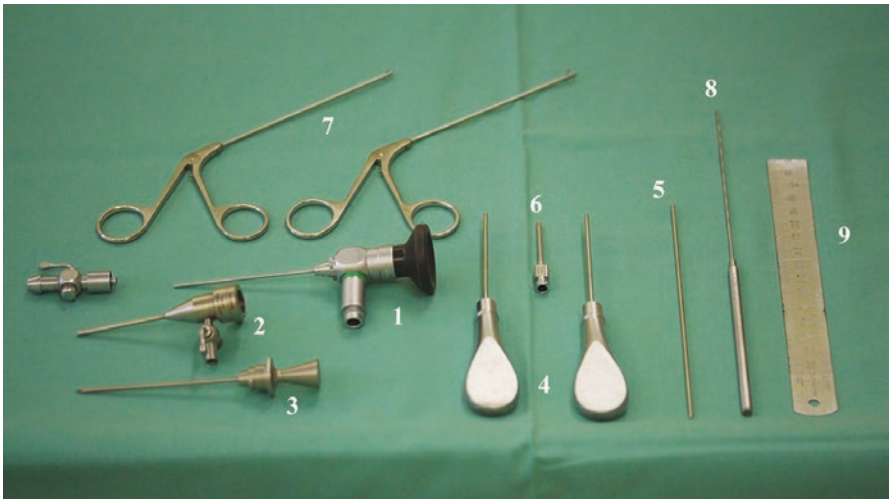

Fig. 4.5 The basic armamentarium for TMJ arthroscopy contains the (1) straightforward telescope 0°, diameter 1.9 mm, length 6.5 cm; (2) high-flow arthroscope sheath, diameter 2.5 mm, working length 4 cm, for use with the telescope 0°; (3) trocar, diameter 2.5 mm, length 3.5 cm; (4) sharp and a blunt obturator; (5) changing rods for the sheath and (6) cannula, length, 15 cm; (7) biopsy forceps, diameter 1.3 mm, single-action jaws, length 6 cm; (8) hooked probe; and (9) ruler

use. These tubes allow access into the joint for instrumentation or let the irrigation fluid out of the joint. All cannulas have an associated obturator, which is a metal rod that fits down the middle of the tube. The end of the obturator is pointed and either sharp or blunt ended. After the punction, the obturator will be removed (Fig. 4.5).

4.3.7 Shaver Systems

Arthroscopic shavers are tools that provide aggressive tissue resection and rapid bone debridement during arthroscopic surgery. Shavers usually consist of a power box and the handheld unit. That is the driver for various attachments, e.g., burrs, shavers, and biters, that can be placed into the joint via the instrument portal.

4.3.8 High-Frequency Surgery

High-frequency ablation instruments may also be part of the arthroscopic equipment. These instruments use high-frequency sound waves to generate heat at the tip of the instrument. This heat is used to ablate unwanted or damaged tissues within the joint.

4.3.9 Laser

The holmium:YAG laser has been shown to be effective for the TMJ arthroscopy in reduction of synovial and vascular hyperplasias and debridement of fibrous tissues and therefore can be used for the release of the anterior capsule and reduction of chondromalacia. Due to gas insufflation and excessive depth of tissue damage, the carbon dioxide and Nd:YAG laser have proven to be ineffective for TMJ arthroscopy.

4.3.10 Sterilization of Instruments

Arthroscopy equipment that is heat stable may be autoclaved for sterility. Heat- or moisture-sensitive equipment may be sterilized with a low-temperature hydrogen peroxide gas plasma. A low-temperature sterilization process, gas sterilization, and activated glutaraldehyde have been shown to be less effective and have more potential side effects.

4.4 Joint Entry Techniques

TMJ arthroscopy is much more demanding than arthroscopy in larger joints, e.g., knee joint and efforts precise instruction and training. Various arthroscopic approaches to the TMJ and maneuvers have been described and become important for sufficient arthroscopic diagnosing and treatment since many soft tissue disorders may occur and cannot be accurately visualized before, e.g., lateral capsular synovial proliferation or capsular herniation. Current surgical techniques usually involve the placement of at least two cannulas into the superior joint space. One cannula is used for visualization of the procedure with the arthroscope, whereas instruments are placed through the other cannula to allow instrumentation in the joint and the flow of the rinsing fluid. For arthroscopic approach to the TMJ, it is mandatory to localize important landmarks. After the TMJ region has been palpated and the position of the condylar head has been determined by passive movement of the TMJ, the trocar insertion points are marked on a line between the center of the tragus and the lateral canthus of the eye (Holmlund–Hellsing Line). The insertion point of the first trocar is to be marked 1 cm from the center of the tragus and 2 mm below the abovementioned line. This is the approximate area of the maximum concavity of the glenoid fossa. The insertion point for the second trocar is located 2 cm from the center of the tragus and 1 cm below the out marked line (Fig. 4.6). In cases in which the superior compartment is collapsed because of fibrosis or advanced arthrosis, the entrance point at the skin must be placed at approximately 1 cm ahead of and 1 cm below the entrance point of the first cannula. Attention has to be given to the patient's

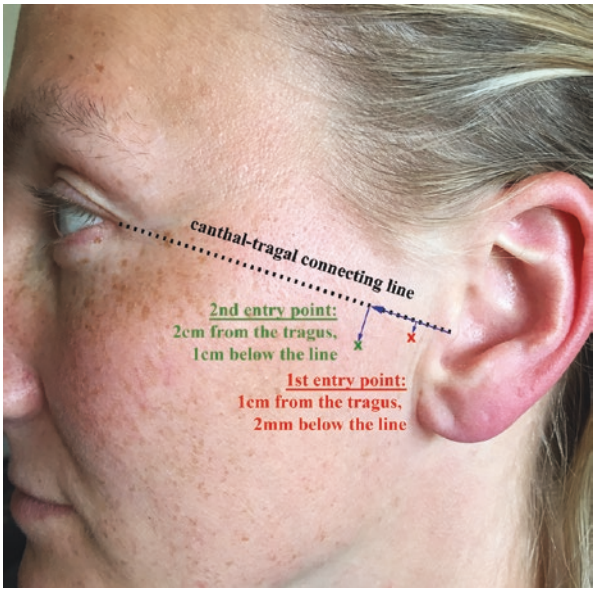

Fig. 4.6 For orientation during approaching the TMJ, localization of important landmarks is mandatory. On a line between the center of the tragus and the lateral canthus, the insertion point for the first trocar is placed 1 cm from the tragus and 2 mm below the line. The insertion point for the second trocar is placed 2 cm from the tragus and 1 cm below the line

constitution where size, weight, and age can lead to variations of the puncture, too. For experienced surgeons, the palpation and mandibular mobilization are just as important as the measurements. Before insertion of the trocars, the correct place should be verified by palpating the TMJ and moving the joint confirming that the points have been marked correctly, since some distortion may occur due to skin shifting. Initial needle puncture into the posterior aspect of the superior joint and irrigation with solution leads to a fully distention of the joint compartments allowing testing the depth and direction for easier trocar puncture and minimization of risks of iatrogenic intracapsular damaging. Mandibular distraction downward and forward simplifies this puncture procedure. The first cannula is inserted through a skin puncture with a sharp trocar inside it at the first landmark (Fig. 4.7). By pushing it upward, inward, and forward to the temporal bone, keeping the cannula tip in contact with the bone by advancing the tip approximately 2.5 cm the TMJ will be reached into the upper joint space. Reaching and entry into the joint are far easier if the capsule is taut after it has been distended with saline before or by traction into an anterior caudal direction [38–40]. Once the joint has been reached, the sharp trocar can be removed and replaced with the blunt obturator. The fluid for irrigating the joint space (Ringer's solution) is removed from the outflow tubing and connected to the irrigation cannula which is attached to the arthroscope with a stopcock. The arthroscope is placed in the sheath and attached to the fiber-optic light source and saline for irrigation. Because there tends to be some bleeding into the

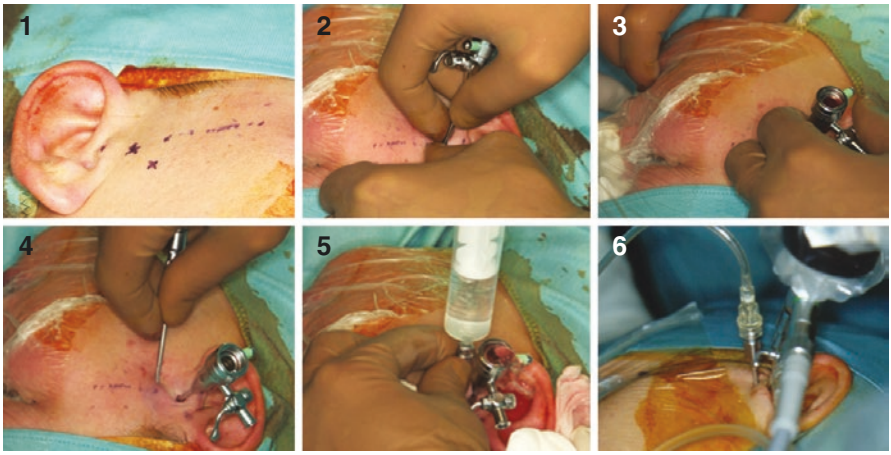

Fig. 4.7 The steps of the approaching procedure are shown: (1) The entry points are marked as described in Fig. 4.5. (2) After verification of correct place by palpating and moving the TMJ, the first sharp trocar is inserted into TMJ at the first landmark. (3) The trocar is replaced by the cannula. Moving the mandible allows to check the correct placement in the TMJ. (4) The second trocar is inserted at the second landmark and replaced by the second cannula. (5) The correct placement of both cannulas can be checked by irrigation of one cannula. (6) The diagnostic TMJ arthroscopy can be started

joint at the point of entry, vision would rapidly deteriorate if the joint were not rinsed, but at this stage, there is only one portal for both entry and exit. Thus, a correct placement cannot be verified optically by the arthroscope. Moving the mandible allows to check the correct placement of the arthroscope. If the fluid level in the cannula moves synchronously with the mandible movement, the correct placement in the joint space is confirmed. The second cannula is inserted at the second landmark according to the aforementioned procedure. The TMJ will be reached with an upward angulation under bony contact to the temporal bone of the glenoid fossa and an advance of approximately 2.5 cm. Then, the inflow stopcock on the arthroscope cannula, which is connected to an infusion system, can be opened. If continuous irrigation is obtained with an inflow pressure of approximately 1000 mm H_2O and there is a good reflux of irrigation liquid through the cannula, an infusion extension tubing can be connected to the arthroscope cannula. The irrigation liquid is drained through the second trocar, which also provides access for passing instruments to the operative site. The triangulation process which involves finding the working channel and instruments with the arthroscope in the narrow joint space is often challenging and time-consuming and needs some practice.

4.4.1 Superior Posterolateral Approach

By directing the trocar anterosuperiorly toward the posterior slope of the eminentia while distracting the mandible forward and downward, a triangular depression

bordered superiorly by the glenoid fossa, anteroinferiorly by the dorsal aspect of the condylar head, and posteriorly by the external auditory canal is achieved, which enables a visualization of the posterosuperior joint space is allowed. The superoanterior synovial pouch and medial paradiscal synovial groove are difficult to visualize [41, 42].

4.4.2 Superior Anterolateral Approach

By directing the trocar superiorly, posteriorly, and medially along the inferior slope of the articular eminence while distracting the mandible inferiorly and posteriorly, access to the anterior recess of the upper compartment is provided. Visualization of the anterosuperior joint compartment is allowed [41, 42].

4.4.3 Inferior Lateral and Inferior Posterolateral Approach

By directing the trocar against the lateral posterior surface of the mandibular head, the inferior posterolateral approach is achieved as a variation of the inferolateral approach where the posterior part of the upper compartment, the inferoposterior synovial pouch, and posterior condylar surface can be examined. Access to the anterior recess is limited [41, 42].

4.4.4 Inferior Anterolateral Approach

By inserting the trocar anteriorly to the lateral pole of the condylar head and below the articular tubercle, the lower anterior synovial pouch can be examined [41, 42].

4.4.5 Endaural Approach

Certain limitations have become evident using the traditional posterolateral and anterolateral arthroscopic approaches. The endaural approach provides access and visualization of the posterior superior joint space as well as to the medial and lateral paradiscal troughs. This approach also provides better access for the retrieval of loose bodies and broken instruments and permits access to other portals for instrumentation. This access is initiated by a trocar entering the posterosuperior joint space from a point 1 to 1.5 cm medial to the lateral edge of the tragus through the anterior wall of the external auditory meatus. The trocar is directed in an anterosuperior and slightly medial direction toward the slope of the eminentia. If a surgeon is inexperienced in this technique, it is best to initially penetrate the superior joint space from the standard superior posterolateral approach. Then the arthroscope is rotated so that the light shines through the anterior wall of the external auditory canal. While the mandible is distracted downward and forward, the anterior wall of the external auditory canal is perforated with the sharp trocar [41, 42].

4.5 Diagnostic Technique

During diagnostic TMJ arthroscopy, seven anatomic areas are to be examined: (1) the medial synovial drape, (2) the pterygoid shadow, (3) the retrodiscal synovium and the posterior ligament (Zone 1, oblique protuberance; Zone 2, retrodiscal synovial tissue attached to posterior glenoid process; Zone 3, lateral recess of retrodiscal synovial tissue) (4) the posterior slope of the articular eminence and glenoid fossa, (5) the articular disc, (6) the intermediate zone, and (7) the anterior recess (Zone 1, disc synovial crease; Zone 2, midportion; Zone 3, medial-anterior corner; Zone 4, lateral-anterior corner) (Fig. 4.8) [43, 44]. We start diagnostic arthroscopy in the posterior recess, looking at the position of the disc, the condition of the posterior attachment tissues, and the synovium on the medial aspect of the joint. The scope is then swept anteriorly over the top of the disc to look at the anterior parts of the joint.

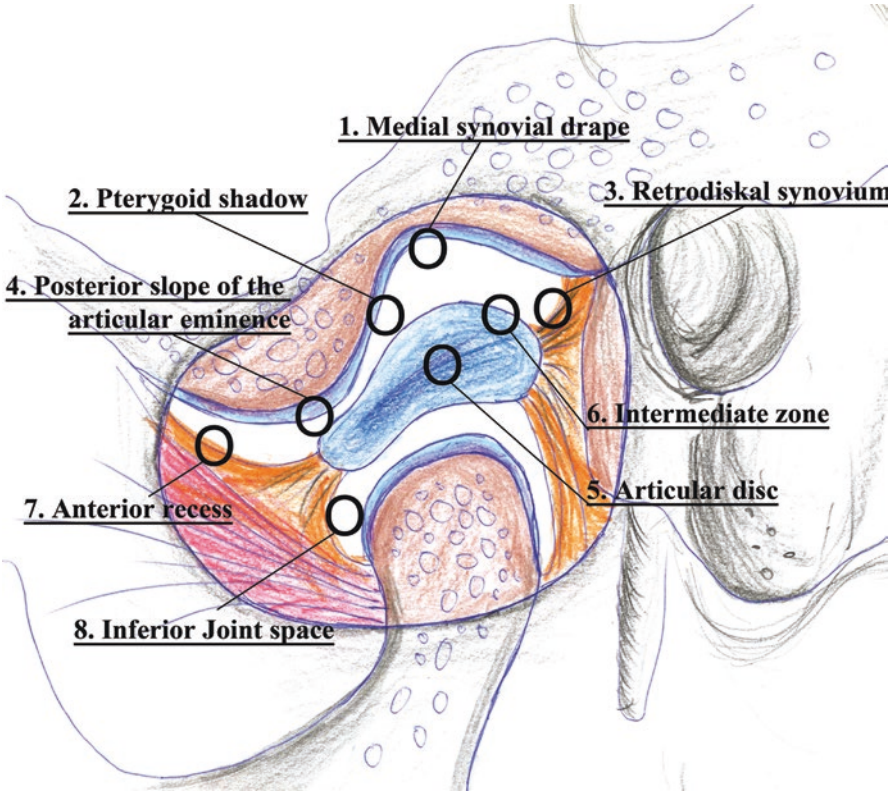

Fig. 4.8 During diagnostic TMJ arthroscopy, seven anatomic areas are to be examined: (1) the medial synovial drape, (2) the pterygoid shadow, (3) the retrodiscal synovium and the posterior ligament, (4) the posterior slope of the articular eminence and glenoid fossa, (5) the articular disc, (6) the intermediate zone, and (7) the anterior recess. (8) The inferior joint space is not routinely explored. In cases of disc perforation, the inferior joint space can be examined by introducing the scope through the perforation

By inspection alone, it is possible to detect disc displacement, adhesions, degenerative changes in the disc and cartilage over the glenoid fossa and articular eminence, and synovial inflammation. If two excess ports are used, it is possible to perform arthroscopy under direct vision.

4.5.1 Medial Synovial Drape

In a healthy condition, the medial synovial drape appears with a gray-white translucent lining and a tense appearance with distinct superior-to-inferior striae.

In acute inflammatory states, capillary proliferation with hyperemia of the synovia is increased. In addition, the entire drape may appear erythematous or may prolapse or bulge into the joint space. In chronic inflammatory states, the drape may appear fibrotic or whitish (Fig. 4.8) [43, 44].

4.5.2 Pterygoid Shadow

The pterygoid shadow is located anterior to the medial synovial drape. In normal situations, the pterygoid shadow has a purple appearance, because of the pterygoid muscle under the synovial lining. In pathologic states, the pterygoid shadow appears erythematous and hypervascularized. The synovial lining can thin out allowing herniation of the pterygoid muscle directly into the anteromedial aspect of the superior joint space (Fig. 4.8) [43, 44].

4.5.3 Retrodiscal Synovium and Posterior Ligament

The synovial membrane with the posterior ligament located in the posterior side of the posterior synovial recess has a soft appearance in healthy condition. From the lateral side, several folds on the surface of the synovial membrane appear, and they disappear as long as the disc is displaced anteriorly. The posterior insertion of the disc is covered by synovial membrane and is reflected superiorly to the temporal fossa. During mouth opening, the posterior insertion covered by the synovial lining appears as crest or crease, which is named oblique protuberance. The location of the oblique protuberance is in the middle third of the retrodiscal synovium. In inflammatory pathologic states, the synovial tissue appears hypervascularized and erythematous (Figs. 4.8 and 4.9) [43, 44].

4.5.4 Posterior Slope of the Articular Eminence and Glenoid Fossa

In the back slope of the eminence, the fibrocartilage appears thick, white, and highly reflective with anteroposterior striae. Toward the glenoid fossa, the fibrocartilage

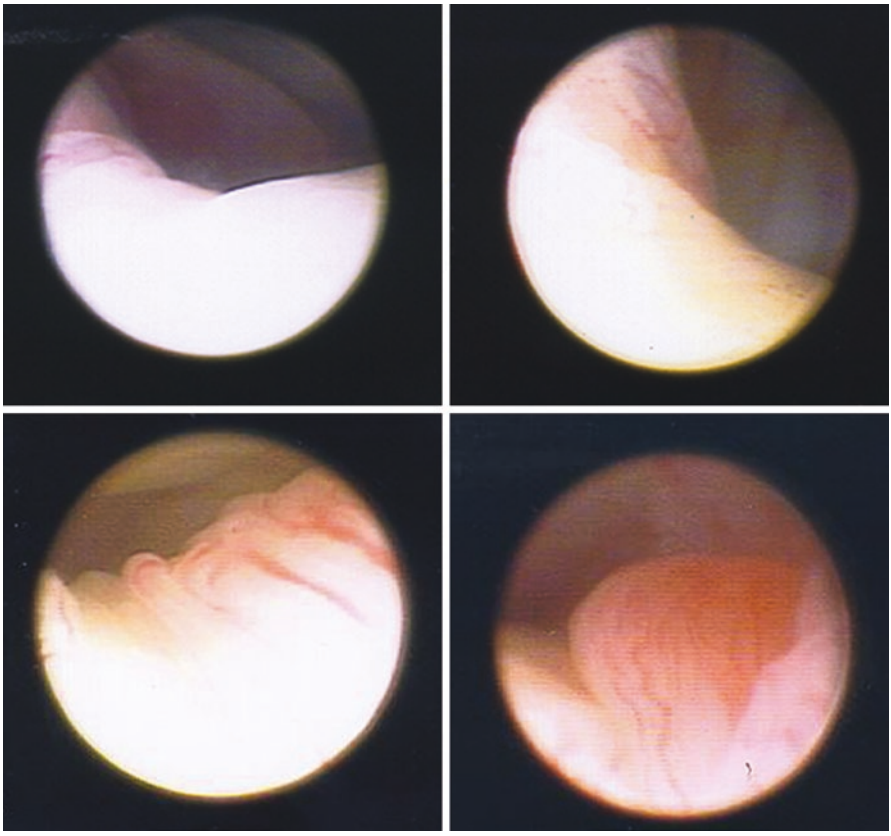

Fig. 4.9 Above: normal arthroscopic findings. View on the healthy dorsal ligament and the cross over the disc. Pathologic arthroscopic findings. View on the hyperplastic and elongated dorsal ligament

has a darker and thinner appearance and becomes thin without striae over the glenoid fossa. The pathologic changes in this region appear as various stages of chondromalacia. When destruction of the fibrocartilage is advanced, the underlying bone appears slightly yellow or brownish. In inflammatory states, creeping of the synovial tissue can be observed in the glenoid fossa (Fig. 4.8) [43, 44].

4.5.5 Articular Disc

In healthy condition, the articular disc appears milky white, highly reflective, and without striae. Its surface is smooth and without fibrillations. The union between the posterior band of the disc and the synovium is marked as red-white line. In normal arthroscopic anatomy, the posterior band of the disc lies adjacent to the back slope of the fibrocartilage of the articular eminence and the glenoid fossa

when the condyle is in the forward and seated positions, respectively. In pathologic states, the synovium creeps onto the surface of the disc. The disc mobility is examined by smooth movements of the condyle forward and backward. Normally, the disc glides smoothly and fluently along the articular eminence without any erratic movements. If an erratic movement is noted in the anteroposterior direction with a simultaneous audible or palpable clicking, a reducing disc is the most likely situation. Fragmentation of the disc surface usually indicates that disc perforation is either imminent or present. The arthroscopic evaluation and grading of the covering of the articular disc over the condyle is designated as roofing. The concept of roofing describes the position of the posterior band of the articular disc relative to the articular eminence. The disc is in a normal position and has a roofing of 100% if the posterior band of the disc is lying adjacent to the posterior slope of the articular eminence and abuts at approximately the midportion of the glenoid fossa. The disc has a roofing of 50% if the posterior band of the disc is lying in the midportion of the articular eminence. The posterior band of the disc is lying adjacent to the anterior slope of the articular eminence at a roofing of 0% (Figs. 4.8, 4.9, 4.10, and 4.11) [43, 44].

4.5.6 Intermediate Zone

In healthy condition this area has a white-on-white appearance with the fibrocartilage cranially and the disc caudally. The concavity of the disc can be observed clearly. The degree of roofing can be assessed by comparing the white fibrocartilage, cranially, and the red retrodiscal synovium, caudally (Fig. 4.8) [43, 44].

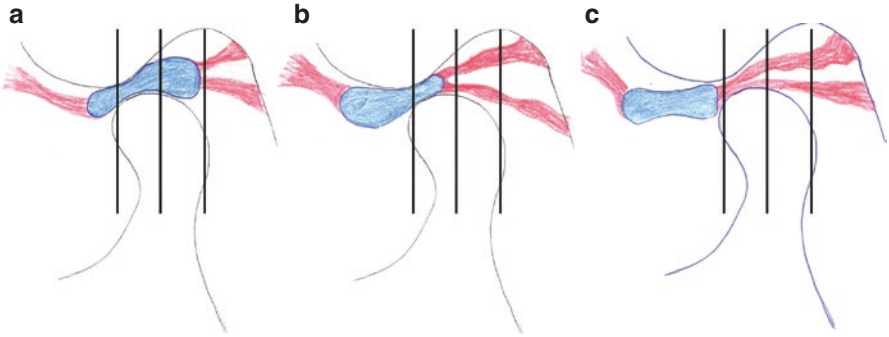

Fig. 4.10 Roofing describes the position of the posterior band of the articular disc relative to the articular eminence. (**a**) The disc is in a normal position and has a roofing of 100% if the posterior band of the disc is lying adjacent to the posterior slope of the articular eminence and abuts at approximately the midportion of the glenoid fossa. (**b**) The disc has a roofing of 50% if the posterior band of the disc is lying in the midportion of the articular eminence. (**c**) The posterior band of the disc is lying adjacent to the anterior slope of the articular eminence at a roofing of 0%

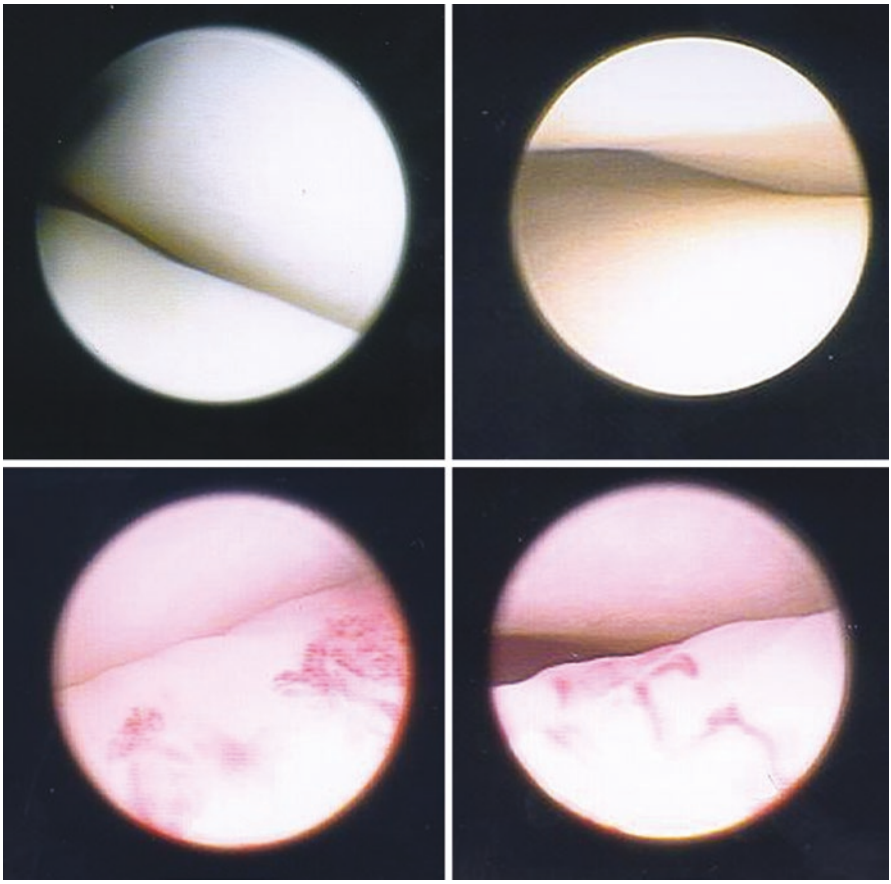

Fig. 4.11 Above: normal arthroscopic findings. View on the tuberculum articulare with regular positioned disc. Below: pathologic arthroscopic findings. View on the tuberculum articulare with the dorsal ligament underneath and anterior disc displacement

4.5.7 Anterior Recess

In this area, the anterior disc synovial crease is identified. At the anterolateral site, the union between the lateral synovial capsule and the anterior disc synovial crease can be observed. This is the best place for insertion of the second or working cannula. In pathosis, the vascularity of the anterior synovial pouch increases, and all characteristics of inflammation of synovium are present (Fig. 4.8) [43, 44].

4.5.8 Inferior Joint Space

The inferior joint space is narrow compared with the superior joint space and is not routinely explored. In cases of disc perforation, the inferior joint space can be

examined by introducing the scope through the perforation. The posteroinferior and anteroinferior recesses are separated by the intermediate zone formed by the condyle and the disc (Fig. 4.8).

4.6 Therapeutic Techniques and Contemporary Procedures

4.6.1 Arthroscopic Lavage and Lysis (ALL)

Lavage and lysis is the simplest and minimal invasive form of surgery in the TMJ with the aim to release the articular disc and to remove adhesions between the disc surface and the mandibular fossa, to eliminate restrictions on the disc and lateral capsule, to wash out micro debris resulting from the breakdown of the articular surfaces, to irrigate the joint by enzymes and prostaglandins, and to stimulate the normal lubricating action of the synovial membrane by means of hydraulic pressure from irrigation of the upper chamber of the TMJ. The presence of fibrous adhesions in the superior joint space limits normal translatory function of the disc condyle complex. If the disc has become adhered to the fossa surface or locked for a short period of time, this procedure may remobilize the disc [45–48]. The main pathogenesis of reduced disc mobility is the myopathy. It is also speculated that the restricted gliding movement of the mandibular condyle over the articular eminence may be due to a reversible adhesion of the disc to the glenoid fossa caused by a vacuum effect or alteration in synovial fluid consistency. Furthermore, it is suspected that a macro- or microtrauma induces hemorrhage. In the presence of limited joint mobility, the blood clot that forms will organize into a fibrous adhesion.

The advantages of TMJ arthrocentesis and lavage are that it is a simple, inexpensive, and minimally invasive procedure with little morbidity that can be easily undertaken in an outpatient setting. ALL can be performed by a single-puncture or a double-puncture technique. Eight different methods have been published: (1) the single-needle arthrocentesis, (2) the single-puncture arthrocentesis, (3) the use of a single Shepard cannula with two ports and two lumens, (4) the two-needle arthrocentesis, (5) the two-needle arthrocentesis using an irrigation pump, (6) a modified two-needle arthrocentesis, (7) the double-needle cannula method, and (8) the two-needle arthrocentesis with modified anatomical landmarks [49–56]. The technique can be complemented with the injection of substances such as corticoids. After the removal of the needles, the patient's mandible is gently manipulated to help further free up the disc. Being the least invasive and simplest form of surgical interventions into TMJ, this procedure carries a very low risk and is relatively easy to proceed under local anesthesia alone or in combination with conscious sedation. If the pain does not subside, more invasive procedures are probably necessary [45, 48–87]. The therapeutic success, however, depends on numerous factors involving chronicity of the disease and its characteristics, on adequate diagnosis, on patients' cooperation, on the technique used, and on professional experience. In a Cochrane review, the effectiveness of arthrocentesis and lavage for the treatment of TMJ disorders compared with controlled arthroscopy interventions have been assessed. No statistically

significant difference was found between the interventions in terms of pain, but a statistically significant difference in favor of arthroscopy was found in maximum interincisal opening (MIO). Mild and transient adverse reactions such as discomfort or pain at the injection site were reported. There is insufficient, consistent evidence to either support or refute the use of arthrocentesis and lavage for treating patients with temporomandibular joint disorders [57].

4.6.2 Therapeutic TMJ Arthroscopy

TMJ arthroscopy is more involved and invasive than ALL. This procedure is almost always done under general anesthesia in the outpatient facilities (or day surgery) at the hospital. Procedures including removing scar tissue and thickened cartilage, reshaping parts of the jawbone, disrupting adhesions, biopsy, and smoothing roughened areas may be relatively straightforward for the expert arthroscopist, but attempts are also being made to shorten the posterior attachment tissues and reposition the disc by laser, high-frequency, and waterjet applications. Especially suture techniques, e.g., to fix the disc, are difficult and need some training. It is possible, if adhesions are detected, to replace the blunt-ended trocar and sweep around within the joint to break them down. The joint must be thoroughly irrigated at the end of the procedure, and in case of chronical inflammation of the synovia, it is possible to instill a steroid before leaving the joint. Various therapeutic aspects are described below. In a Cochrane review, the effectiveness of arthroscopy for the management of TMJ disorders has been assessed by Rigon et al. Both arthroscopy and nonsurgical treatments reduced pain after 6 months. When compared with arthroscopy, open surgery was more effective at reducing pain after 12 months. There were no differences in mandibular functionality or in other outcomes in clinical evaluations. Arthroscopy led to greater improvement in maximum interincisal opening after 12 months than arthrocentesis; there was no difference in pain [58]. In a systematic review, the clinical outcomes of arthroscopic lysis and lavage, arthroscopic surgery, and open surgery have been assessed. The results showed that open surgery is superior to arthroscopy in pain reduction, with comparable MIO, jaw function, and clinical findings (clicking, joint tenderness, and crepitation). In addition, the results showed that lysis and lavage provides greater improvement in MIO and comparable pain reduction when compared to arthroscopy. There was a significant improvement in joint movement for patients managed with arthroscopy. The results of the meta-analysis showed a trend toward better outcomes with open surgery for pain reduction and improvement of jaw function; arthroscopy is a safe technique associated with only mild and transient complications, with a more rapid patient recovery [59].

4.6.3 Injection of Intra-Articular Substances

Various studies have demonstrated the use of drugs like opioids, corticosteroids, or sodium hyaluronate as source of management for TMJ disorders.

4.6.3.1 Corticosteroids

Injection of intra-articular steroids has been used in different joints with good clinical outcomes [60]. Nowadays we advise dexamethasone palmitate as a water-soluble drug. 1 mL could be used at the end of lysis and lavage of the superior compartment of the TMJ. Corticosteroids have a potent anti-inflammatory action on synovial tissue well known to reduce effusion, decrease pain, and bring about an increase in range of motion. However, diverse secondary effects (including degenerative joint disorders) have also been reported. Injection of corticoids into the inflamed tissues (subsynovial infiltration) under arthroscopic view can be advised in selected cases (TMJ arthritis, psoriasis, RA, SLE).

4.6.3.2 Sodium Hyaluronate

Sodium hyaluronate (SH) is a naturally occurring substance that is produced by synovial cells and continuously released into the synovial fluid, which serves as a lubricant, anti-inflammatory, and pain reliever and also acts as adjunct. It has been proposed as an alternative therapeutic agent which is high viscous, high molecular substance and plays an important role in joint lubrication and protection of the cartilage. It is abundant in joint cartilage and synovial fluid. Different studies have shown the efficacy of intra-articular injection with SH in treating disc displacement and degenerative joints [61–63].

The use of SH after arthroscopic lysis and lavage or after surgical arthroscopic oblation technologies has also shown good clinical outcomes [62]. Infiltration of 1 mL of SH into the superior joint space or even also into the inferior joint space under arthroscopic view could be used in cases with degenerative joint diseases at the end of the arthroscopic procedure [63].

4.6.3.3 Plasma Rich in Growing Factors

The use of plasma rich in growth factors (PRGF) is an autologous biological therapy that is based on the use of the patient's own plasma, platelet-derived growth factors, and endogenous fibrin scaffolds for regenerative purposes. Some randomized clinical studies have concluded that PRGF exhibits superior clinical results compared to hyaluronic acid (HA) in alleviating the symptoms of mild to moderate osteoarthritis of the knee. It has been published that infiltration of PGRF into TMJ joints with anterior disc displacements is a more effective method than arthrocentesis alone. Also the use of PRGF after arthroscopy seems to be more effective when compared with the use of HA or saline solution [64–66]. Infiltration of 1–2 mL of PRGF in both the superior and inferior joint compartments at the end of the surgical procedure can be indicated in cases with anterior disc displacements with or without osteoarthritis [64] (Video 4.1).

4.6.3.4 Opioids

Synovial receptors of opioids can participate in the clinical perception of pain. So the use of opioids can be indicated to decrease postoperative joint pain. Some authors have published better clinical outcomes when comparing the usage of opioids to placebos [67].

4.6.4 Arthroplasty

Can be used as an adjuvant procedure when severe chondromalacia or osteophytes are present. In these cases the elimination of the altered cartilage can improve joint function after surgery. Arthroplasty can be performed using forceps, rotary motorized instruments, oblation probes, or laser systems [68] (Video 4.2).

4.6.5 Disc Repositioning Techniques

4.6.5.1 Oblation

Oblation is a low-temperature technique that can avoid deleterious effects into the surrounding tissues. The technique of oblation has proved to be an effective and minimally invasive option for the treatment of TMJ internal derangement, with advantages such as offering a high degree of precision, causing little or no thermal damage to surrounding tissue, leaving smooth anatomic surfaces, and achieving hemostasis of smaller blood vessels [64, 69–71].

The use of oblation probes to perform anterior disc release and posterior coagulation of the retrodiscal tissues is the preferred surgical technique used in surgical arthroscopy of the TMJ. Oblation can also be used to resect adherences or to treat altered cartilage surfaces in the joint. Laser can be a surgical alternative to perform all these techniques; however it is a more dangerous and expensive technique (Videos 4.3a, 4.3b, and 4.4).

4.6.5.2 Sutures

Although posterior repositioning of the anteriorly displaced disc can be accomplished with the oblation techniques already described, stabilization of the disc in the long term is not possible when this technique is used. Posterior fixation of the disc with the use of sutures or pins could be used to stabilize the disc. Few studies have been published about the arthroscopic suture techniques, e.g., Joe Mc Cain. Also Zang [72] and Goizueta [73] offer the possibility to stabilize the disc using two or three traction points fixated to the articular capsule. Clinical results using these techniques are promising. All these techniques need a third trocar portal entry to be performed, so they can be considered as difficult techniques for the beginner in arthroscopy.

4.6.5.3 Pins

Fixation and stabilization of the articular disc can also be achieved using the surgical technique described by McCain [74]. In this case the disc is stabilized to the posterolateral condylar side with resolvable pins. Recent publications offer good clinical outcomes with reduction of postoperative pain and normalization of the mandibular function, when this technique is used [75, 76]. Occlusal changes after the surgical procedure are not uncommon. A posterior open bite in the ipsilateral side of the surgical procedure is the most frequent sign described. It resulted from the presence of joint effusion and inflammation of the posterior disc attachment. In

most cases, it lasts only some days and does not need any additional treatment. When aggressive disc repositioning techniques (sutures or pins) are performed, these occlusal disturbances can last more time or even become permanent. In this case the use of postoperative elastic traction can be necessary. Long-term clinical results are still lacking (Video 4.5 and 4.6).

4.6.6 Other Arthroscopic Procedures

4.6.6.1 Synovial Chondromatosis

Synovial chondromatosis (SC) is a benign disease characterized by the formation of metaplastic cartilaginous nodules within subsynovial connective tissue that may detach inside the joint space, forming loose bodies. Arthrotomy of the affected temporomandibular joint, with removal of the loose bodies and synovectomy, is the standard treatment. Otherwise, arthroscopy, a less invasive surgical procedure, could be effective in some patients with SC to remove the loose bodies, with coagulation of the affected synovium using conventional bipolar electrocautery or radiofrequency devices [77]. Loose bodies can be removed using a wider third cannula but is restricted by diameter. In selected cases, fragmentation of the largest loose bodies with forceps may be helpful (Video 4.7).

4.6.6.2 Stuck/Fixed Disc, "Anchored Disc Phenomenon"

Anchored disc phenomenon—ADP—is one of the possible etiologies of TMJ closed lock [78, 79]. ADP is characterized by a sudden, severe, limited mouth opening associated with pain on forced mouth opening. MRI studies with the presence of a disc fixed to the glenoid fossa facilitate a final diagnosis. Arthroscopic findings include adherences and synovitis (hypervascularity, hyperemia, and redundancy of the posterior ligament) both in the anterior and posterior compartments of the superior joint space [80]. Arthrocentesis, a least invasive technique with predictable outcomes, could be the best indicated treatment for patients with ADP. The alternative would be arthroscopy which permits direct visualization of pathological tissues and allows removal of adhesions with injection of anti-inflammatory drugs or coagulation into inflamed synovial tissue [80].

4.6.6.3 Recurrent Mandibular Dislocation

Arthroscopy can be used to treat recurrent mandibular dislocation. Different surgical techniques have been used to create scarification and contracture in the retrodiscal synovial tissue and the oblique protuberance. Oblation lasers have been reported with good clinical results [81–83] (Video 4.8).

4.7 Complications

TMJ arthroscopy is a safe and minimally invasive surgical intervention usually performed under general anesthesia as an outpatient procedure. However, like in any surgical procedure, different complications have been reported [45, 84, 85]. There

have been several studies on a relatively large number of arthroscopy cases, but prospective studies on a large number of cases performed using the same surgical technique are few; in fact most of the complications that have been reported are isolated cases [86]. Complications can occur both during and after the surgical intervention.

4.7.1 Intraoperative Complications

4.7.1.1 Intra-Articular Damage

Damage to the articular surfaces or to the articular disc during insertion of trocar-obturator units has been described [87, 88]. This complication is more common when two or three portals are used and in joints with an abnormal cartilage (osteoarthritic joints). Cartilage rupture can interfere with the normal arthroscopic view; in this case the cartilage fragments have to be removed by forceps in combination with high-frequency probes or motorized instruments. To prevent this complication, extreme care is advised when introducing the surgical instruments. Up to date, it has not been properly studied the possible relation of these cartilage lesions with the development of secondary degenerative changes into the joint.

Perforation of the glenoid fossa with intracranial injury has been reported but is extremely rare. A softly introduction of the blunt trocar prevents this severe complication [89].

4.7.1.2 Instrument Breakage

With the use of more sophisticated and complex arthroscopic procedures involving the use of different and delicate instruments, the complication potential of a broken instrument exists [90–92]. It is of paramount importance to use instruments only indicated to perform TMJ arthroscopy and to examine carefully the integrity of the instruments before surgery. To prevent fractures of the equipment, the surgeon should avoid the use of excessive forces during the surgical procedure. If an instrument breaks, the surgeon should be prepared to either retrieve it through the arthroscope or perform an open procedure at that time.

4.7.1.3 Joint Irrigation Fluid Extravasation

Swelling from excessive extravasation of the irrigation solution into tissues around the joint is also possible during surgery [84, 86, 93]. A careful check for continuous outflow of the irrigation fluid is mandatory to avoid this complication. It is more common when fluid pumps systems are used. Extravasation of fluids can be responsible of neurologic or otological complications and also can collapse the joint space limiting the surgical procedure. Perforation of the medial wall can lead to extravasation of the irrigation fluid into the parapharyngeal space compromising the airway [86, 87]. If this complication occurs, arthroscopy should be stopped, and the patient may not be extubated until a free air passage is achieved.

4.7.1.4 Vascular Complications

Bleeding is one of the most frequent complications found during arthroscopic procedures [84–86]. Extra-articular bleeding secondary to injury of the superficial

temporal vessels is not uncommon, but it is easily controlled with pressure in most cases, and when this is not the case, then a suture is needed to stop the bleeding. Intra-articular bleeding is not uncommon [85, 86, 92]. When this happens, visibility into the superior joint is reduced. It can be the result of capsular bleeding secondary to the insertion of the trocar or in the other hand during the anterior release procedure. Irrigation at a higher flow can stop intra-articular bleeding. When this maneuver does not work, direct vaporization of the injured vessels is advised. Some authors have described the use of Fogarty catheters to treat bleeding. Blood clots should be always removed from the joint to avoid possible postoperative intra-articular fibrous adhesions.

4.7.1.5 Neurological Complications

Neurological injuries can occur to cranial nerves V and VII [45, 86, 88, 94]. Fluid extravasation is the most common cause of transient nerve injury. Inadequate trocar insertion or perforation of the medial joint wall can injure the facial or even the trigeminal nerves. Temporary paralysis of the zygomatic branch of the facial nerve has also been described. Surgical procedures involving the use of a third portal entry have potentially higher risk of VII nerve injury, so a careful surgical technique is recommended. Temporary hypesthesia in the region of the auriculotemporal nerve, caused by injury of the trigeminal nerve (third division) with numbness to the teeth and skin, has been reported. It seems that extravasation of fluid and improper or repeated insertion of trocars during the surgical procedures are the main causes of neurologic lesions. Damage of the masseteric nerve resulting from a direct injury to the nerve during the anterior release procedures can occur [92]. Therefore, weakness of the masseteric muscle or even muscle atrophy can develop. A careful surgical technique when entering the lateral pterygoid muscle is of paramount importance to avoid such complication. Lesions of the sympathetic plexus within the parapharyngeal space also have been reported [95].

4.7.1.6 Otological Complications

From small lacerations or blood clots in the external auditory canal to severe tympanic membrane and middle ear and inner ear, injuries have been described [86, 96–99]. Blood clots in the external auditory canal are the most frequent complaints of patients [4]. To prevent blood clots, the external auditory canal should be protected using a cotton pellet or other types of barrier. The external auditory canal should be irrigated with saline after the arthroscopic procedure. With this simple method, our complication rate has decreased significantly. Lacerations of the external auditory canal were recognized in some cases. A careful palpation of the roof of the glenoid fossa and anterosuperior direction during the insertion of the obturator are very helpful techniques to avoid entering the canalis acusticus externus [87]. Postoperative partial hearing loss and vertigo are also described in literature [86]. May be the persistence of the foramen of Huschke or the course of ligaments within Hughie's canal might be a pathway for the inner ear injuries [100]. Fistulae between TMJ joint and the inner ear have been also described.

4.7.1.7 Other Complications

Parotid gland injuries, cardiac arrhythmias, or pulmonary edema has been reported in association with TMJ arthroscopy as isolated cases [96, 101].

4.7.2 Postoperative Complications

4.7.2.1 Infection

Arthritis is an extremely uncommon complication, although joint infection, infratemporal infection, and otitis media have been reported [102, 103].

4.7.2.2 Malocclusion

Occlusal changes postoperatively are not uncommon. A posterior open bite in the ipsilateral side is one of the most frequent signs described [73, 104–106]. It results from the presence of joint effusion and inflammation of the posterior disc attachment. In most cases malocclusion lasted only some days and do not need any additional treatment. When aggressive disc repositioning techniques (sutures or pins) are performed, these occlusal disturbances can last longer or even became permanent. In this case the use of postoperative elastic traction can be necessary [104, 105].

4.7.2.3 Other Infrequent Complications

Severe swelling after surgery is not a common complication and is easily treated with steroids. Reaction to foreign bodies used during the surgical technique as sutures has been described [92]. When this occurs, removal of the suture is indicated. Arteriovenous fistula [107, 108], condylar resorption [109], pseudoaneurysm, hematoma, synovial fistula, skin atrophy [110], and thermal skin injury [111] also have been described in some isolated cases. The use of high-frequency probes is contraindicated in patients with pacemakers [70].

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The Intraoral Vertical Ramus Osteotomy

5

Rebeka G. Silva

Abstract

The intraoral vertical ramus osteotomy (IVRO) has a distinct advantage over other TMJ surgeries; the joint capsule and intracapsular structures are preserved, and the surgery has a low complication rate. For selected patients with symptomatic anterior disc dislocation, the IVRO is a classic operation that can unload the joint as well as reposition it more favorably under the disc. The new condylar position can be characterized as an increase in the superior joint space dimension and a slightly more anterior angulation of the joint head. Patient selection is important, due to the need to maintain control over the occlusion through the use of maxillomandibular fixation for several weeks.

5.1 Introduction

The concept of joint preservation, including preservation of the (displaced) disc and synovium, is attractive to many surgeons who wish to take a more conservative surgical approach with selected TMD patients. One is tempted to be more conservative, perhaps, for the younger patient, with the idea that the condylotomy, also known as the intraoral vertical ramus osteotomy (IVRO), will keep the joint mechanism "virgin" and that the surgery will not close the door for later successful intracapsular surgery should the need arise. Similarly, older patients who may not be outstanding candidates for longer surgeries with higher bleeding risk may do well and get relief from painful opening with a condylotomy.

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Physiologic changes in disc position can produce changes in joint movement, joint noise, and pain if the patient is not able to adapt. A displaced disc that causes pain or limitation in maximum opening seems like a perfect candidate for repositioning and stabilization to the joint head, but why not bring the joint to the displaced disc instead? The net result is that the new joint position, guided by the surrounding muscular envelope, is similar to what is achieved through the use of an anterior repositioning splint. H. David Hall described the IVRO in 1975 as an alternative to the sagittal split osteotomy and the *extraoral* vertical ramus osteotomy for surgical treatment of mandibular prognathism [1]. In 1987 Hall reported on his series of patients who underwent IVRO for malocclusion after he modified his technique in 1977, and the modifications, which included a longer period of maxillomandibular fixation (MMF) and a less aggressive approach to stripping of the medial pterygoid muscle from the proximal segment, resolved some of the problems associated with the technique such as open bite and excessive condylar sag [2].

The idea that a fractured condylar neck could relieve TMD symptomatology is attributed by Hall to one of a few English surgeons in the late 1940s [3], although other sources point to a surgeon using the technique for correction of malocclusion as early as 1925 [4]. Early proponents created an osteotomy that was short and subcondylar, to mimic a subcondylar fracture. To decrease the incidence of inadvertent medial displacement or anterior displacement of the condylar head with respect to the eminence, the osteotomy orientation was changed to be more vertical, thus the change in name from "subcondylar osteotomy" to "intraoral vertical ramus osteotomy," also known as the *modified condylotomy*. For the purposes of this chapter, we shall use the terms interchangeably as long as it is understood that the original condylotomy was a very different surgery from the present-day IVRO. Initially, a softly curved osteotomy was advocated, giving it a slight C-shape to avoid the lingula (Fig. 5.1a). Later, to reduce the incidence of inferior alveolar nerve injury, Hall proposed eliminating the curved cut in favor of a much straighter and easier cut through the ramus to create a butt joint between the proximal and distal segments, with or without lateral overlap of the proximal segment (Fig. 5.1b) [3, 5]. He recognized the value of the IVRO to increase the superior joint space through a controlled sag of the condylar head and through normalization of the joint-disc relationship. Today, we must credit Hall and his contemporaries for modernizing the IVRO technique for the selected TMD patients and for carefully quantifying the results of the surgery.

5.2 Indications and Patient Selection

The contemporary "modified" *modified condylotomy* technique has several clinical goals related to the reestablishment of a normal joint head-disc relationship: (1) to reduce joint pain, (2) to improve function, and (3) to possibly decrease risk of TMD progression from simple anteriorly displaced disc with reduction to anteriorly displaced disc without reduction to more serious degenerative joint

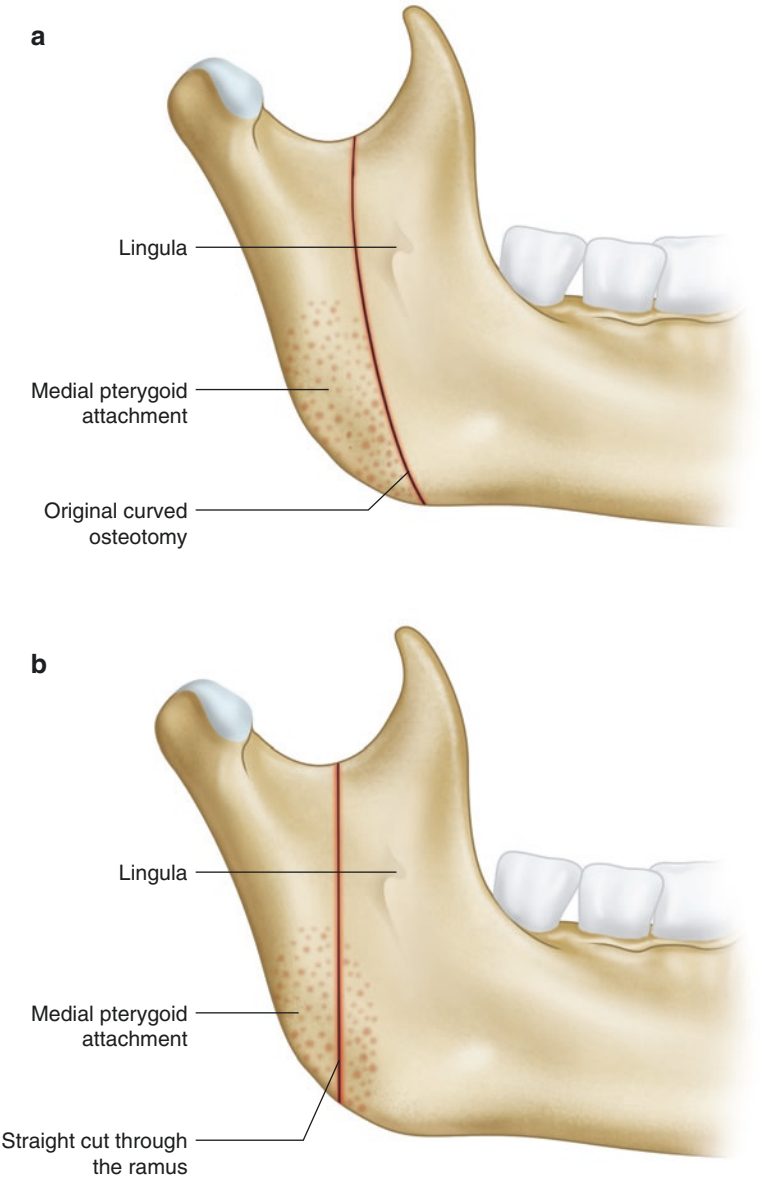

Fig. 5.1 The original osteotomy design featured a slight curve to avoid the lingula (**a**). The modified condylotomy is a straight cut to create a butt joint between the proximal and distal segments (**b**)

disease, should such disease progression be in the cards. The patients most likely to benefit from the IVRO surgery are those with a painful anteriorly displaced disc with reduction on opening and those who have acutely progressed to a non-reducing disc.

The occlusion must be controlled with MMF, or else an open bite will result. Thus, the IVRO candidate must have solid occlusion bilaterally, with teeth that have enough anatomy for good intercuspation. If the teeth are flattened due to bruxism, the surgeon will lose control of the occlusion and is advised to either create a splint to lock in the bite or select a different operation. Patients who have previously undergone a sagittal split osteotomy may be more difficult to osteotomize properly with an IVRO due to altered bone anatomy. The patient must be able to tolerate the MMF appliance for many weeks, whether a traditional arch bar is employed or an MMF device is stabilized to the bone with screws. The recommended period of MMF varies in the literature, but experience dictates that 3–4 weeks will be needed depending on the patient and perhaps his/her age, with many surgeons electing to maintain light guiding elastics for several weeks longer. Hall, in his 1996 paper, reported on his experience with reduction of postoperative MMF to 8–10 days but followed this up with guiding elastics for traction for 4½ weeks [5]. This modification, suggested by Bell et al. [6], along with the additional modifications of creating a butt joint and less stripping of the medial pterygoid muscle as previously described, resulted in 85% reduction of symptoms for patients with Wilkes stage II and early-stage III joints [5]. Prior to this technique modification, Hall reported a 72% reduction of symptoms with the older technique [7]. Based on his experience with hundreds of joints, Hall concluded that the IVRO could be offered to patients with early- and late-stage osteoarthrosis as well as those with internal derangements, spanning the entire Wilkes classification.

5.3 The Counterargument

It has been argued that the ideal method of treating internal derangement should focus on the reduction of inflammation through various techniques, including decreased loading, gentle physiotherapy, anti-inflammatory medication, and restoration of normal synovial fluid through lavage. Instead, the IVRO focuses on the alteration of anatomy within the joint apparatus. The fact that a large number of adults have occult or relatively asymptomatic disc displacement speaks to the temporomandibular joint's marvelous ability to adapt to changes in the joint-disc anatomic relationship. It can also not be denied that arthrocentesis and nonsurgical arthroscopy have shown very good outcomes in comfort and maximum incisal opening, often without altering the disc position at all [8, 9]. In his commentary on the utility of the IVRO to treat TMJ conditions, Israel points out that surgeons should ask themselves which is the real problem to be corrected. Is the problem a mal-relationship of the condyle to the disc, or is it the pathologic molecular and microscopic changes that arise from overloading, parafunctional habits or trauma, which caused the mal-relationship in the first place [10]? The surgeon who focuses on modifying the physical condyle-disc relationship without understanding or addressing the true reasons for the pathology risks poor outcomes, relapse, and/or the need for additional surgery.

5.4 Basic Technique

Anesthesia preparations:
- General, nasotracheal intubation, stabilize tube.
- Neuromuscular blockade for ease of jaw opening.
- IV prophylactic antibiotic and steroids.

Soft tissue:
- Place throat pack and prep mouth with chlorhexidine rinse.
- Apply MMF system of choice, with the understanding that maintenance of fixation followed by guiding elastics will be needed for many weeks.
- Bite block to the contralateral side.
- Infiltration of local anesthesia with epinephrine to the buccal vestibule.
- Identify external oblique ridge and ascending ramus.
- Incision through mucosa with blade or Bovie, lateral to the external oblique ridge, as for sagittal split osteotomy, leaving a good 2–3 mm cuff of unattached gingiva lateral to the attached gingiva so that closure of the incision is facilitated. A more laterally-based incision than described may heal with a scar band that creates a food trap. Carry incision through submucosa, muscle, and periosteum, and laterally retract the flap to expose the ramus of the mandible, taking care to develop an atraumatic soft tissue envelope.
- Smoothly dissect all periosteum off the lateral ramus, so that the sigmoid notch, posterior ramus, and inferior border can be visualized.

Osteotomy:
- Helpful instruments include a set of lighted Bauer retractors (Fig. 5.2) to visualize the sigmoid notch and the antegonial notch; the Levasseur-Merrill retractor (Fig. 5.3) to retract the masseteric sling, stabilize the ramus during the osteotomy, and allow for proper A-P positioning of the oscillating saw blade; and a curved freer or other ramus measuring instrument to check the trajectory/position of the osteotomy and determine if the cut is full thickness.
- Place a lighted Bauer retractor in the sigmoid notch. Using an IVRO oscillating saw with a fan-shaped blade big enough to fully penetrate the ramus, create the superior half of the osteotomy from the mid-ramus to the sigmoid notch, taking care to be posterior to the antilingula. The cut should be approximately 7–10 mm from the posterior border of the ramus. IVRO blades come in two sizes, 12 mm cutting edge × 7.0 mm cutting depth and the longer 11.5 mm cutting edge × 12.0 mm cutting depth (Fig. 5.4). The longer blade should be used with care as it may cause injury to medial soft tissues as it penetrates through the bone.
- The Levasseur-Merrill retractor is very helpful to position the oscillating saw blade, because it wraps around the posterior border of the mandible. When cutting with the oscillating saw, support the retractor with the nondominant hand to pull the mandible forward, and rest the oscillating saw against the retractor's "shelf" (Fig. 5.5). This maneuver will position the saw blade cut, 7–10 mm

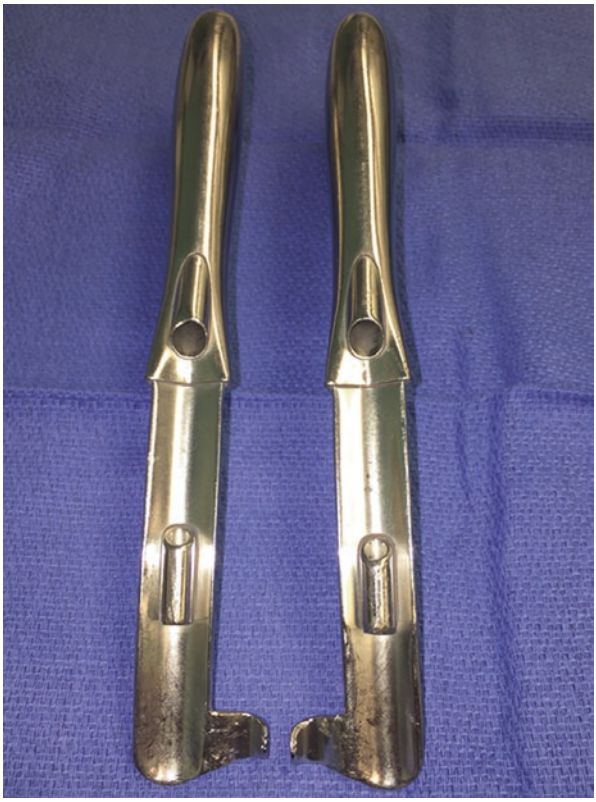

Fig. 5.2 Set of Bauer retractors capable of accepting a fiber-optic light cord. Within the surgical wound, one Bauer engages the sigmoid notch, and the opposite one engages the antegonial notch, giving excellent visibility. Each Bauer has a slightly curved blade and is approximately 19–20 cm in overall length

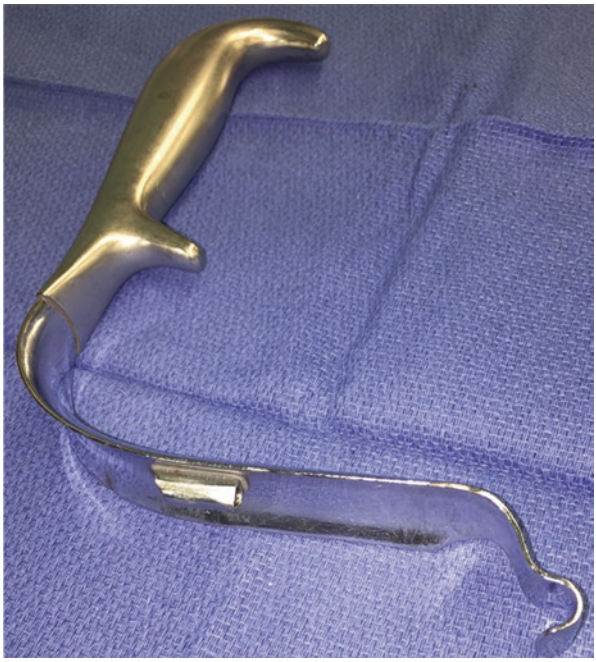

Fig. 5.3 The Levasseur-Merrill retractor can accept a fiber-optic light cord, and the handle has a finger rest allowing the surgeon to pull up on the retractor to stabilize the mandible. The hooked end engages the posterior border of the mandible, providing visibility during surgery

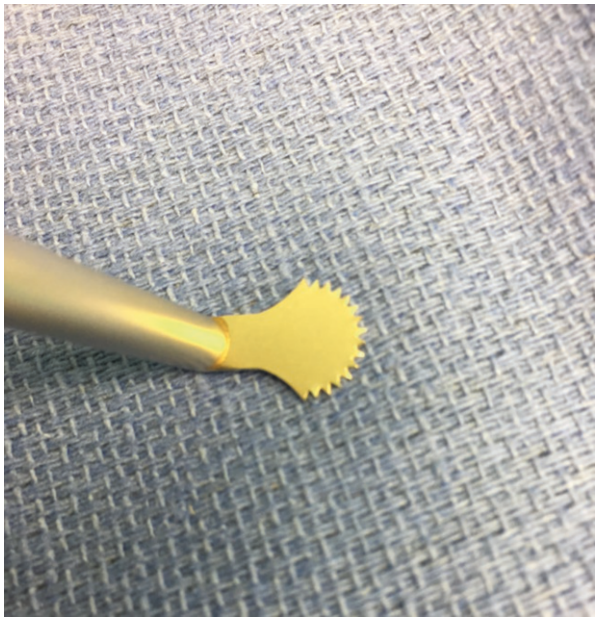

Fig. 5.4 Close-up view of a long sharp, fan-shaped oscillating saw blade for IVRO. The blade has a 12 mm long cutting edge and a 12 mm cutting depth

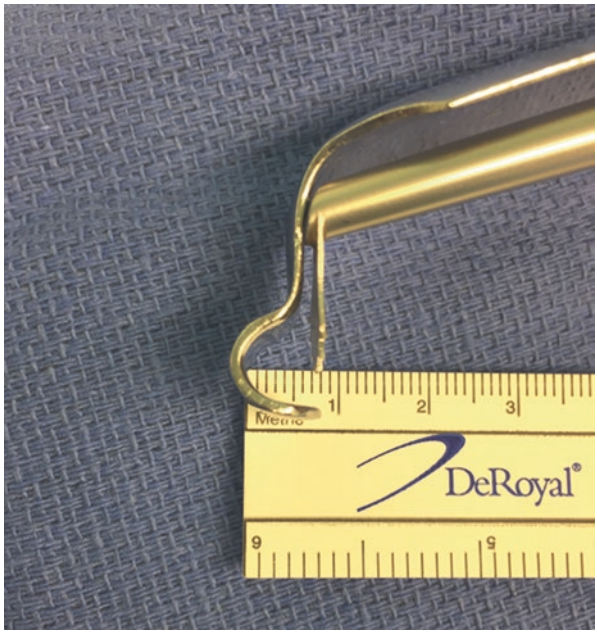

Fig. 5.5 The Levasseur-Merrill retractor provides a platform to position the oscillating saw blade at an A-P position, approximately 7–8 mm from the posterior border of the mandible

from the true posterior border of the ramus. Use the oscillating saw blade in a continuous sawing manner; the blade cuts best when one moves and rotates the blade against the bone, using the fan-shaped blade at an angle to start and continue the cut. Once the bony cut is well defined from the mid-ramus to the sigmoid notch, proceed straight down to the inferior half of the osteotomy, finishing at or near the angle of the mandible. For best visibility, remove the Bauer from the sigmoid notch, and place the opposite Bauer in the antegonial notch. Many surgeons aim to bring the inferior half of the cut slightly anterior to the angle of the mandible. The reasons for this are twofold: by curving the osteotomy anteriorly as one approaches the inferior border of the mandible, the free (proximal) segment is less likely to end in a sharp pointy bony tip. In addition, the proximal segment remains attached to a portion of the medial pterygoid muscle on the medial side. Refine the saw cut to ensure that the osteotomy is full thickness from top to bottom. In patients with a small mandible, there may not be enough room for both a Levasseur-Merrill retractor and a Bauer retractor at the sigmoid notch. In that case, a modified curved freer or a ramus-measuring instrument that is marked at 7–10 mm can be used to engage the posterior mandible, and the IVRO saw can be positioned with the aid of a dental or laryngeal mirror. Some surgeons prefer not to use the Levasseur-Merrill retractor as its placement requires the stripping of a portion of the periosteum from the posterior border of the mandible. Lighted retractors or a lighted suction tip is essential as visibility is notoriously poor.

- If there is a pointy tip of bone at the angle of the mandible after the osteotomy is completed, trim it with a round bur or rongeur.
- Grasp the loose proximal segment with a bone clamp, and tug to verify that the condyle is free to move, rotate, and sag slightly.
- Many surgeons advocate a “butt-end” relationship between the proximal and distal halves of the ramus osteotomy so that the principal component of proximal bone movement is inferior. Others, fearing that the proximal segment may slip onto the medial side of the ramus, try to create a “lap joint,” where the proximal bone laterally overlaps the distal segment by a small amount (Fig. 5.6a, b). If this is desired, one should gently strip a small portion of the medial pterygoid muscle off the proximal segment to allow for this overlap. The medial pterygoid detachment should be the minimum required to permit a passive, lateral position of the proximal segment (Fig. 5.7). In some cases, to prevent torquing of the ipsilateral condyle, it is necessary to bur away a thin strip of the bone from the proximal segment, along the medial aspect of the entire length of the cut edge. This morticing will allow the proximal segment to lie nicely against the lateral aspect of the distal segment, minimizing twisting of the bone. The proximal bone segment that will not stay lateral or butt end with respect to the distal segment may need to be stabilized with a suture through a small hole drilled through the inferior end of the proximal osteotomy and sutured to the lateral periosteal envelope (Fig. 5.8).

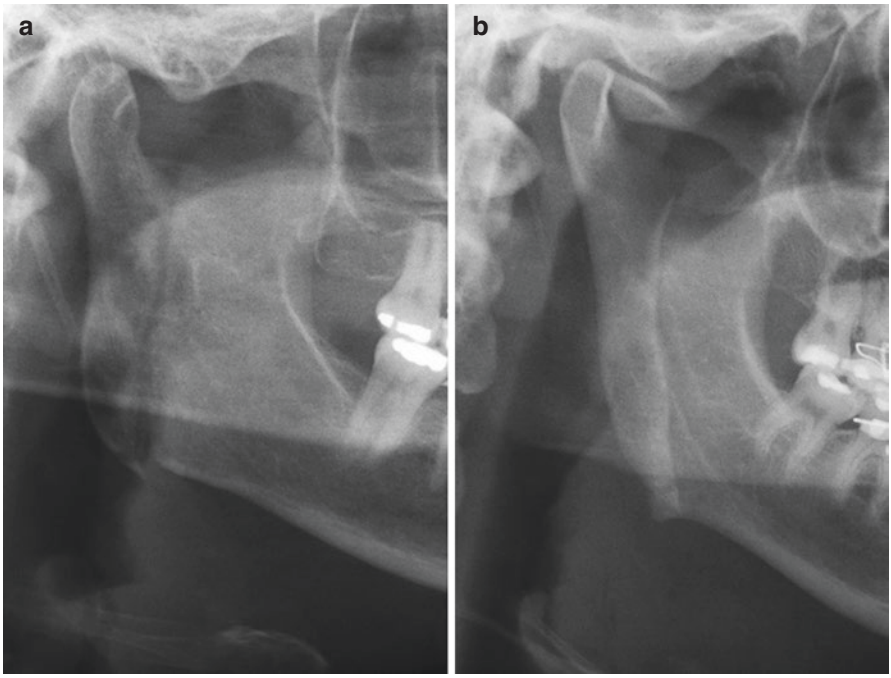

Fig. 5.6 A passive butt-end relationship is created between the proximal and distal portions of the IVRO osteotomy (**a**). The proximal portion of the osteotomy is lateral to the distal segments and overlapping it (**b**)

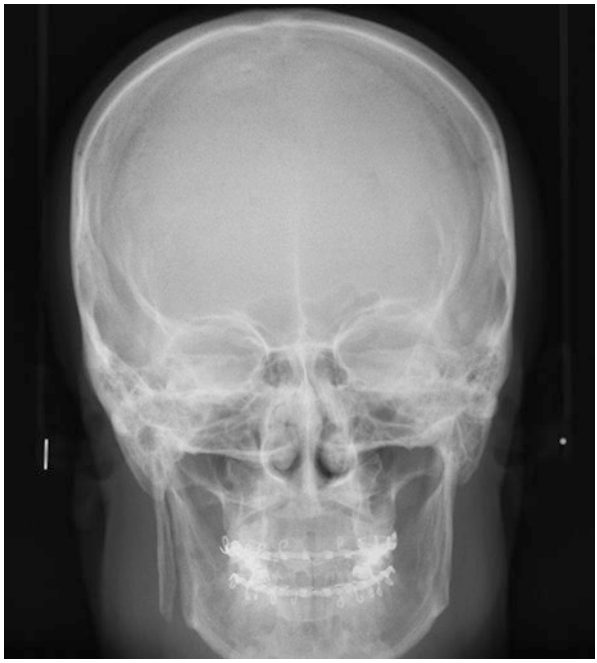

Fig. 5.7 The proximal portion of the right IVRO osteotomy lies lateral to the distal portion of the osteotomy in this PA cephalometric image

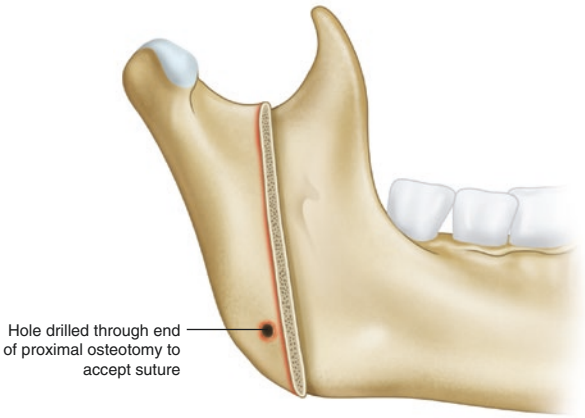

Fig. 5.8 A suture placed through the drilled hole can be sutured to the lateral periosteal envelope to stabilize the proximal portion of the osteotomy if it does not remain butt end or lateral to the distal portion of the osteotomy

Finish:

- Irrigation of wound
- Tight wound closure with polyglactin suture
- Removal of the throat pack
- Application of strong maxillomandibular fixation (MMF) using wires or elastics
- Head wrap and ice pack for swelling

Postoperative course:

- Tight MMF is needed for the first 3–4 weeks, with the longer period advised for bilateral cases. This is followed by up to 4 weeks of progressively lighter-guiding elastics to assist the patient with finding his/her occlusion and to discourage chewing. Toward the end of the guiding elastic period, the patient may briefly remove elastics and initiate gentle range of motion exercises. Food with slightly firmer texture may also be started.
- After release of fixation and removal of the arch bar devices, physical therapy is strongly encouraged to restore normal range of motion and jaw strength. Physical therapy may be supplemented by at-home jaw exercises consisting of jaw opening repetitions and stretch-and-hold sequences.

5.5 Results

The separation of the proximal segment containing the condyle, from the distal segment containing the dentition, may serve as a stress breaker, permitting "unloading" of the synovial tissues. Many authors have shown excellent, long-lasting improvement in function and comfort following IVRO for internal derangement [11–16]. Indeed, our own informal review of patient satisfaction among patients with internal derangement who underwent a surgical procedure demonstrated that the patient

cohort with the highest level of satisfaction is the IVRO group within the first few years after surgery (unpublished data). The prospective study published in 2000 by Hall, Navarro, and Gibbs showed that at 1 year following IVRO, there was a statistically significant improvement in most measures of pain and that results at 3 years were essentially unchanged [11]. A progression from a displaced disc with reduction to displaced disc without reduction, even for those with Wilkes IV and V, was not observed. The IVRO has also been employed in cases of TMJ degenerative joint disease. Tasanen and Lamberg in 1974 and Tasanen and Jokinen in 1981 reported on patient cohorts with radiographically documented cases of osteoarthritis and found high patient satisfaction and functional status to be quite good [17, 18].

Park et al. found excellent resolution of TMD symptoms in patients who underwent IVRO instead of sagittal split osteotomy (SSO) with rigid fixation for "surgery-first" orthognathic surgery [19]. In the surgery-first approach, orthognathic surgery is carried out without the typical presurgical orthodontic preparation. While the opportunity for rigid fixation is afforded by the sagittal split osteotomy to stabilize the mandibular bony segments, the authors opine that the technique can torque the joints and lead to worsening of TMJ symptoms in those with preexisting TMD. Their finding that the IVRO allows for a natural and comfortable joint position is consistent with other investigators. Ueki reported that 88% of patients who underwent IVRO with or without Le Fort I osteotomy reported fewer or no TMJ symptoms as opposed to 66.7% of patients who underwent sagittal split osteotomy with or without a Le Fort I osteotomy [20]. The author's experience, consistent with above, is that unfavorable condylar seating or torquing during the application of fixation screws or plates in sagittal split osteotomy cases may occasionally cause new-onset TMJ internal derangement or worsening of preexisting TMJ dysfunction. These observations suggest that the surgeon should carefully consider the choice and method of fixation technique when planning sagittal split osteotomy, instead of IVRO, for the surgical correction of malocclusion. This is of particular importance in patients with preoperative intracapsular TMJ symptoms, because the relationship of the condylar head, the disc, and the fossa is hard to control.

5.6 Complications

Reoperation rates for IVRO have been reported to be low. Yamauchi and his group observed that out of 638 IVROs performed on 319 patients (all bilateral cases) for either mandibular prognathism or TMD, the condylar head was dislocated anterior to the articular eminence unilaterally in only 8 patients, or 1.25% [21]. One patient had the condyle repositioned in a closed manner under local anesthesia, and four patients underwent open reduction. Three patients did not have any intervention as they were symptom-free, and condylar head remodeling was noted over the 12-month follow-up period. Therefore, the reoperation rate for this large series of IVRO patients was less than 1%. Hall and Werther showed that in a group of 184 consecutive patients with 299 operated joints, less than 5% of joints underwent reoperation. All joints that were reoperated had an MRI-proven

displaced disc, and the majority of those had lost most or all of the increased joint space achieved by the initial surgery [22]. Other authors have also had similar observations and have shown that the maintenance of the increased superior joint space following IVRO is positively associated with improved long-term outcomes, including relief of pain [23–25]. Thus, the observation of loss of joint space is predictive of a poor outcome, probably due to the recurrence of heavy joint loading leading to intra-articular soft tissue injury and the elaboration of mediators of inflammation [22].

It has been shown that approximately 70–79% of joints with anteriorly displaced discs with reduction have that relationship corrected with IVRO [13, 16]. Among the IVRO cases that required reoperation, Hall found that a strong risk factor was the loss of the reduced disc relationship after it had been achieved with IVRO [22]. Some authors report a higher rate of poor outcomes following bilateral IVRO [24], and that has been this author's experience as well (unpublished data).

Infection rates are classically low and generally only occur if a hematoma within the wound is allowed to develop and persist. For this reason, a compressive wrap around the jaw is a good idea for the early postoperative period. The incidence of numbness of the inferior alveolar nerve distribution with IVRO is much less than with sagittal split osteotomy. Chen et al. reported a 9% rate in the early postoperative period with improvement down to 2% at 6 months or more [26]. Al-Bishri et al. found a 7.5% rate of neurosensory disturbance after IVRO using a questionnaire [27]. Takazakura et al., testing with a trigeminal somatosensory evoked potential, showed that none of his IVRO patients had hypoesthesia 3 months after surgery [28]. Through accurate positioning of the osteotomy at no more than 10 mm anterior to the posterior border of the ramus, and by carefully overlapping the segments versus creating a butt-end relationship between the proximal and distal segments, the rate of inferior alveolar nerve injury can be significantly minimized. If one uses the antilingula as a landmark during surgery, the osteotomy should be at least 5 mm posterior to it to reliably avoid the inferior alveolar nerve, per Aziz's anatomic study [29].

5.7 Conclusion

The literature appears to support the utilization of the IVRO for selected patients with anteriorly displaced discs with reduction and anteriorly displaced discs with acute nonreduction status. Some surgeons have achieved good results in patients with joints demonstrating the full gamut of osteoarthritic changes, but total joint replacement may be a better long-term option in this group of patients. However, patients with multiple medical comorbidities who have failed conservative measures and for whom a lower-risk, shorter operation is desired may benefit from IVRO. The surgeon is cautioned to control the occlusion during the healing period and to carefully select patients who can tolerate extended weeks of MMF.

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Surgery of the Temporomandibular Joint: Discectomy and Arthroplasty

6

Michael Han, Michael Markiewicz, Michael Miloro, Larry Wolford, and M. Anthony Pogrel

Abstract

Surgery of the temporomandibular joint apparatus is rarely the first line of treatment for articular disc disorders or internal derangements. However, persistent symptoms following nonsurgical treatment modalities, as well as failed prior less invasive joint procedures (e.g., arthrocentesis, arthroscopy), may warrant open-joint surgery.

This chapter will focus on open surgical management of internal derangement of the temporomandibular joint, including disc repositioning, discectomy with replacement, discectomy without replacement, and arthroplasty procedures.

6.1 Introduction

Surgery of the temporomandibular joint apparatus is rarely the first line of treatment for articular disc disorders or internal derangements. However, persistent symptoms following nonsurgical treatment modalities, as well as failed prior less invasive joint procedures (e.g., arthrocentesis, arthroscopy), may warrant open-joint surgery.

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Numerous procedures and techniques have been described based upon the best available evidence in the literature, as well as personal preference or experience, to surgically manage symptomatic internal derangement of the temporomandibular joint. Each of these procedures focuses on restoration of normal anatomy of the disc-condyle-fossa relationship and elimination of mechanical interferences that may contribute to the predominant symptoms. These disc procedures may be subtractive or additive in nature. The most commonly performed techniques include disc repositioning, discectomy with replacement (using various materials), discectomy without replacement, and osseous arthroplasty. These surgeries may be performed either as definitive treatments or as adjunctive procedures with other procedures. Many technical variations of each procedure have been described, with varying degrees of success. Regardless of the treatment modality, it is recommended that nonsurgical methods, when indicated, precede and follow open surgical management of internal derangements in order to ensure that the least invasive option can be explored which may ameliorate the symptoms adequately and that long-term success can be expected.

This chapter will focus on open surgical management of internal derangement of the temporomandibular joint, including disc repositioning, discectomy with replacement, discectomy without replacement, and arthroplasty procedures.

6.2 Indications

6.2.1 Discectomy

Discectomy, with or without replacement, is generally indicated for mechanical interferences and/or pain originating from a malpositioned disc. As with most other temporomandibular joint surgeries, this modality is considered when patient symptoms do not improve with initial nonsurgical management or following less invasive measures (e.g., arthrocentesis, arthroscopy).

The most commonly encountered mechanical interference is closed lock secondary to an anteriorly displaced disc without reduction. However, other rare situations such as posterior or lateral disc displacement causing malocclusion or restricted jaw mobility may warrant consideration for discectomy. Discectomy may be performed for intra-articular pain from a malpositioned disc and has been used for various progressive Wilkes stages of temporomandibular joint internal derangement.

The need for replacement of the removed disc is highly debated, and the importance of preservation of the disc has yet to be determined conclusively. However, various replacement options exist including autologous, allogeneic, and alloplastic disc replacement materials. These include autologous fat with or without dermis [1, 2], temporalis fascia with or without muscle (myofascial) flaps [3], cartilage (autologous [4] or allogeneic [5]), bovine pericardium, temporary silastic implants [6], as well as other materials. While most of these replacement materials are used to mimic the normal functions of the removed disc, some are also used to prevent joint ankylosis by protecting the cartilaginous articular surfaces.

Finally, discectomy without replacement has been shown to be an efficacious procedure in the long term for advanced Wilkes stage disease, but discectomy is also performed in cases of alloplastic or autogenous temporomandibular joint replacement/reconstruction, in order to remove the diseased joint tissues and allow for replacement with new articular surfaces (osseous or prosthetic).

6.2.2 Disc Repositioning

The indications for repositioning of a displaced disc are similar to those for discectomy; however, disc salvage is generally indicated for earlier stages of internal derangement. Proponents of disc repositioning advocate for early surgical intervention, noting a 4-year window from the onset of the disc dislocation in order for the discs to remain salvageable and amenable to repositioning with highly predictable long-term outcomes [7]. Two main repositioning techniques exist and include variations of the posterior disc attachment reconstruction as described by Wilkes [8] and the Mitek anchor technique as described by Wolford [9].

Proponents of the Mitek anchor technique recommend specific patient selection criteria be followed to maximize surgical outcomes including:

- Anterior and anteromedial disc displacement.
- Disc stabilization in conjunction with high or low condylectomy.
- Four years or less since onset of disc displacement.
- Orthognathic surgery can be done concomitantly.
- Salvageable disc and condyle.
- No significant intracapsular adhesions.
- No other joint involved (no polyarthritis).
- No reactive arthritis.
- No connective tissue/autoimmune diseases.

6.2.3 Arthroplasty

Arthroplasty is a term that encompasses procedures that alter the shape of the cartilaginous and osseous articular surfaces of the temporomandibular joint. It is occasionally performed in conjunction with discal procedures such as discectomy and disc repositioning. As the generic nature of the term suggests, “arthroplasty” has various indications, and various techniques have been described. When performed as an isolated surgical procedure, arthroplasty may involve an eminectomy procedure and/or reshaping of the condyle, glenoid fossa, and articular eminence in order to increase joint space and allow spontaneous or assisted disc repositioning.

Space-creating arthroplasties such as eminectomy may be used for mechanical interferences that affect joint function, similar to discectomy and disc-repositioning

procedures. In addition, when osseous irregularities such as osteophytes are identified, arthroplasty can be used to smooth the articular surfaces.

Recurrent joint dislocation or subluxation may be another indication for arthroplasty procedures. Eminectomy is a subtractive procedure that allows an unimpeded envelope of motion of the mandible and is commonly performed for hypermobility problems. Additive procedures have been described as the creation of an oblique osteotomy and downfracturing of the temporal extension of the zygomatic arch (LeClerc procedure [10]) that will serve to augment the height of the articular eminence and prevent condylar dislocation by physical obstruction. Also, alloplastic eminence implants are additive procedures that may prevent hypermobility. Both procedures indirectly address recurrent joint dislocation, which usually results from joint laxity with resultant jaw hypermobility.

6.3 Outcomes

6.3.1 Discectomy

6.3.1.1 Discectomy Without Replacement

Originally described in 1885 by Annandale [11], discectomy without replacement is one of the oldest forms of open-joint surgery of the temporomandibular joint. Despite its long history, the heterogeneity of success criteria and outcome measures, along with variable indications for this procedure, makes it difficult to accurately assess outcomes.

However, various long- and short-term studies show "success rates" of 87 [12] to 96.9% [8]. Most, if not all, studies show significant improvement in pain [12–22] and range of motion [12–14, 16–18, 20–24]. There does appear to be a tendency toward worse outcomes in later Wilkes stage disease, consistent with observations seen with other temporomandibular joint procedures.

Certain outcome measures do not improve with discectomy without replacement. It has been reported that joint noises (crepitus) tend to increase [14, 16] after this procedure, presumably due to loss of cushioning of the articulating surfaces and creation of cartilaginous irregularities (chondromalacia). Also, degenerative structural articular surface changes of the condyle and glenoid fossa tend to occur radiographically following discectomy [13, 14, 17, 24, 25]. In fact, one study showed more stable radiographic findings over time compared to an untreated control group [8]. However, degenerative radiographic changes of the articular structures after discectomy without replacement typically are not accompanied by significant symptoms or progressive changes that lead to condylar resorption of ankylosis and the need for total joint replacement. Therefore, degenerative radiographic changes following this procedure are of little clinical significance and are thought to represent adaptive changes to a newly created articular structure such as that seen in osteoarthrosis.

6.3.1.2 Discectomy with Replacement

Autogenous Materials

Although the sources of materials are limited and there are heterogeneous outcome measures examined in the literature, discectomy with autogenous replacement generally appears to have favorable outcomes, comparable to those with discectomy without replacement. The temporalis muscle, fascia, and myofascial flaps, dermis with or without fat, abdominal fat alone, and auricular cartilage have been used, with results showing improvement in pain and mandibular range of motion [22, 26–28]. For temporalis myofascial flaps and abdominal fat grafts, one study reported a mean decrease in pain of 78.3% and 52.8%, respectively, in the short term [26]. One study using disc replacement with auricular cartilage, however, noted persistent pain and no improvement in mandibular range of motion and with the development of more degenerative radiographic changes compared to discectomy without replacement [29]. Complications specifically related to the autogenous graft harvest site itself (e.g., donor-site morbidity, scar, paresthesia, cosmetic deformity) appear to be low.

Alloplastic Materials

Historically, the most used and studied alloplastic material for disc replacement has been silicone [6, 8, 30, 31]. This material has been used either as a temporary space maintainer or, less frequently now, as a definitive disc reconstruction. Most commonly, a silastic sheet was used as a temporary interpositional material following discectomy to allow for fibrous tissue encapsulation of the silastic sheet and the formation of a fibrous "pseudodisc" that would function to protect the articular surfaces. Outcomes for silicone disc replacement (temporary or permanent) have been less than encouraging, with failure rates up to 22.7% [30] and with no significant improvement in clinical joint dysfunction scores [31] and consistent findings of intensive inflammatory reaction to fragmented silicone/silastic material in removed implants [32–34]. Because of such poor outcomes, the clinical use of silicone as a definitive or temporary articular disc replacement has largely been abandoned.

Allogeneic Materials

Allogeneic cartilage has been used previously in animal studies which have shown progressive resorption of these materials with eventual replacement with a fibrous pseudodisc [5]. Other studies have demonstrated some protective effects on the articular surfaces despite perforation, displacement, or resorption of the graft [35]. No controlled human studies using cadaveric replacement materials are available.

6.3.1.3 Disc Repositioning

The success rates of traditional methods of disc repositioning are reported to be 80–94% [36, 37]. The specific disc-repositioning techniques can vary greatly and may include partial or full-thickness resection of a portion of the posterior band of

the disc and/or retrodiscal tissues with suture plication or may involve imbrication of the retrodiscal tissues without tissue resection. However short- and long-term results have demonstrated a lack of stability of the repositioned disc, with an 86% relapse in disc position [20]. Also, disc-repositioning procedures have been found to be less successful in later stages of disease, with success rates as low as 50% for Wilkes stage IV disease [20]. This highlights the importance of establishing an appropriate clinical diagnosis in order to determine and recommend appropriate treatment regimens.

Outcomes of disc repositioning using the Mitek anchor technique appear to be comparable to, if not more favorable than, those of traditional disc-repositioning techniques. Short-term and intermediate follow-up studies [38, 39] have shown up to 92 and 90% success in the elimination of joint pain and joint noise, respectively. Long-term studies show good stability of these favorable outcomes, with statistically and clinically significant improvement in joint pain, jaw function, diet, and disability scores [9, 40, 41]. Unlike traditional disc-repositioning techniques, the Mitek anchor technique appears to offer greater stability of the repositioned disc in the short and long term [39, 40]. Similar outcomes are reported when using this Mitek anchor technique with concomitant orthognathic surgery [7, 42]. Some studies show significantly improved stability in orthognathic surgery after concomitant treatment of internal derangement with the Mitek anchor technique, particularly in cases involving counterclockwise rotation of the maxillomandibular complex [43, 44].

Arthroplasty

Arthroplasty procedures include osseous recontouring of the articular surfaces of the TMJ apparatus, including the condyle, glenoid fossa, and articular eminence. Eminectomy has been used as a space-creating procedure to attempt to alleviate symptoms associated with internal derangement. While studies show clinically significant improvement in mandibular range of motion [22, 29], eminectomy appears to be less effective for joint pain relief. In one study, comparison of eminectomy with discectomy, with and without replacement, showed inferior pain relief, with 50% of cases deemed “unsatisfactory” [22].

6.4 Surgical Techniques

6.4.1 Arthrotomy

Discectomy and arthroplasty procedures share the same options for surgical access. The surgical approach may be performed via a preauricular, endaural, or postauricular access. Following skin marking, infiltration with local anesthesia is used for hemostasis and pain control postoperatively, as well as to identify the superior joint space using an “arthrocentesis” technique with insufflation to help

visualize the target of the dissection from the skin to the joint space. The local anesthesia could also be used in a subcutaneous fashion to "hydro-dissect" the skin which can be especially useful when employing an endaural approach. Using the standard preauricular approach, the incision begins using a #15 blade either in the temporal fossa or more conservatively at the location where the superior helix blends into the preauricular skin crease just above the helical crus. The incision continues inferiorly and follows the preauricular crease or enters into an endaural approach and then exits out onto the preauricular skin but ends at a position that is not caudal to the junction of the lobule and tragus. In the preauricular approach advocated by Al-Kayat and Bramley [45], in which the incision includes a releasing incision in the hairline in order to decrease neurapraxic (stretch) injury to the temporozygomatic branch of the facial nerve (VII), the scalpel is angled with beveling of the incision, in order to avoid transection of the hair follicles and incisional alopecia. The inferior extent of the incision is at the junction of the tragus and lobule. At the superior aspect of the wound, the dissection is directed through the skin, subcutaneous tissues, and temporoparietal fascia (superiorly) and the parotidomasseteric fascia (inferiorly) to expose the superficial layer of the deep temporal fascia which directed the dissection directly to the zygomatic arch. The inferior dissection is performed bluntly, anterior to the external auditory meatus in the avascular plane superficial to the tragal cartilage. Care is taken to proceed anteriorly (not posteriorly) to avoid iatrogenic injury to the external auditory meatus; therefore, the tendency to retract the helix posteriorly for visualization during the dissection should be avoided. In addition, upon exposure, the postglenoid tubercle should not be confused with the articular eminence since this might result in iatrogenic injury to the ear canal as well if it is believed that the glenoid fossa is posterior to the postglenoid tubercle. As the dissection proceeds in a combination of blunt and sharp dissection using a scalpel and curved mosquito hemostats with monopolar or bipolar cautery to avoid thermally induced nerve injury, the upper and lower preauricular dissection planes may be joined, and the parotidomasseteric fascia, parotid gland, facial nerve, and superficial soft tissues are retracted anteriorly using Senn retractors or Army-Navy retractors or toe-in Obwegeser retractors. Hemostasis is generally easily maintained in the previously unoperated joint since the dissection proceeds in an avascular plane and care is taken to avoid blind dissection and with protection of the superficial temporal vessels. The periosteum of the zygomatic arch is then incised, and the articular eminence and lateral capsule of the TMJ are identified using a periosteal elevator. A personal preference used is to insufflate the superior joint space with 2–3 mL of local anesthesia (e.g., 2% lidocaine, 1:100,000 epinephrine). Next, an approximately 3–5 mm horizontal incision is made inferior to the zygomatic arch through the lateral capsule, with liberation of the local anesthetic solution while leaving a portion of the lateral capsule attached to the inferior aspect of the zygomatic arch to facilitate closure of the joint space at the end of the intra-articular surgery. If the plan is for disc preservation, a "disc-sparing" incision is made in the lateral TMJ

capsule, approximately 1.0 cm inferior to the zygomatic arch that is carried deep, to the lateral pole of the condyle. This provides access to the superior and inferior joint spaces without iatrogenic damage to the disc. If the plan is for discectomy, a T-shaped incision is made, using a vertical incision from the middle of the initial horizontal incision down to the lateral cortex of the condylar neck. This provides excellent surgical access when compared to the limited "disc-sparing" capsular incision. The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

6.4.2 Discectomy

The joint space is accessed using the standard arthrotomy approach (with the T-shaped capsular incision) as outlined above. Initially, space is created in the superior joint space using a curved mosquito hemostats. The inferior joint space must be accessed via another incision below the disc through the lateral capsule. To facilitate joint space access, as well as to minimize iatrogenic damage to the articular surfaces, either manual digital pressure is applied to the ipsilateral mandibular posterior teeth or ridge to "distract" the condyle from the glenoid fossa. An alternative is to use a Wilkes retractor by placing a K-wire into the zygomatic arch and another K-wire into the condylar head and then applying the Wilkes retractor and sequentially opening the joint space. Once the joint space is accessed, the disc must be separated entirely from the lateral capsule and retrodiscal attachments, with meticulous hemostasis since the retrodiscal tissues are highly vascular. Perhaps the most challenging aspect of the discectomy procedure is the release of the anterior (lateral pterygoid muscle) and medial (medial capsular ligaments) attachments since access is limited and the potential for significant bleeding exists in both locations (e.g., branches of the maxillary artery). Using a combination of blunt and limited sharp dissection, the disc should be carefully freed from the medial and anterior attachments to avoid leaving a portion of the disc in situ which may lead to persistent joint symptoms postoperatively. Following discectomy, the disc itself should be confirmed to be "completely removed," and the entire joint space must be carefully inspected to ensure no disc remnants remain.

In the case of disc replacement, the disc substitute material is trimmed to the appropriate size and shape and placed into the joint space. The disc substitute can potentially be sutured to the retrodiscal tissue attachment remnants and the lateral pterygoid muscle and lateral capsule with nonresorbable sutures. Without any discal remnants remaining, it is difficult to place sutures to secure the disc replacement material on the medial aspect of the joint space. Some authors have advocated the use of postoperative intermaxillary fixation after replacement of the disc to allow initial stabilization to prevent immediate displacement with condylar function [28].

Finally, the wounds are irrigated with saline and suctioned, and some joint lubricant (e.g., sodium hyaluronic acid) may be placed into the joint space, and the capsule, fascia, subcutaneous tissues, and dermal layers are closed using resorbable sutures, and the skin is closed using resorbable or nonresorbable sutures. The wound is dressed with antibiotic ointment and gauze, with a pressure dressing. The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

6.4.3 Temporalis Myofascial Flap

As opposed to the techniques described for discectomy with or without replacement, it has been recommended that a 2.0 mm remnant of disc tissue should be left in situ when using a temporalis myofascial flap technique for disc replacement. This allows the flap to be sutured securely in position on the medial aspect of the joint space. The flap is outlined on the fascia using a skin marker (Fig. 6.1). The flap is finger-shaped and extends as far superiorly as necessary to provide the proper length in order to fill the joint space, with the recognition that the flap may contract as it is

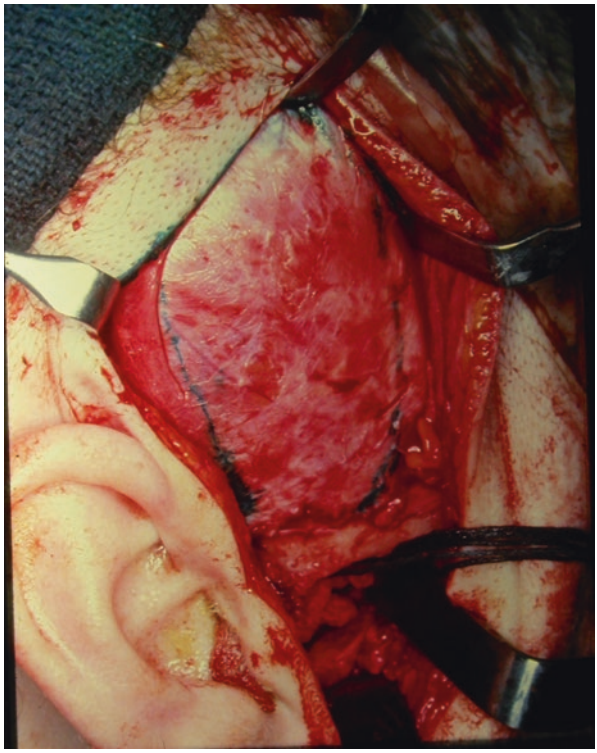

Fig. 6.1 The extent of the temporalis flap is outlined on the fascia

raised, so consideration should be given toward the creation of a flap that is at least 50% larger than required. The dissection is carried down to the appropriate depth including fascia only or muscle and fascia, as appropriate (Figs. 6.2 and 6.3). The flap is extended only to the level of the zygomatic arch. The flap is turned into the joint space, either over (Fig. 6.4) or under the arch of the zygoma and secured with six sutures (5-0 resorbable sutures such as polyglyconate or polydimethylsiloxane (PDS)): two sutures in the medial capsular region, two sutures in the anterior attachment, and two sutures in the posterior attachment. Other techniques have described removal of a portion of the zygomatic arch via ostectomy to facilitate placement of the flap into the appropriate position and then replacement of the zygomatic bone using rigid internal fixation. A gravity drain or suction drain may be used for 24–36 hours. The capsule is then repaired and sutured to the lateral aspect of the flap, and the wounds are closed in a layered fashion. The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

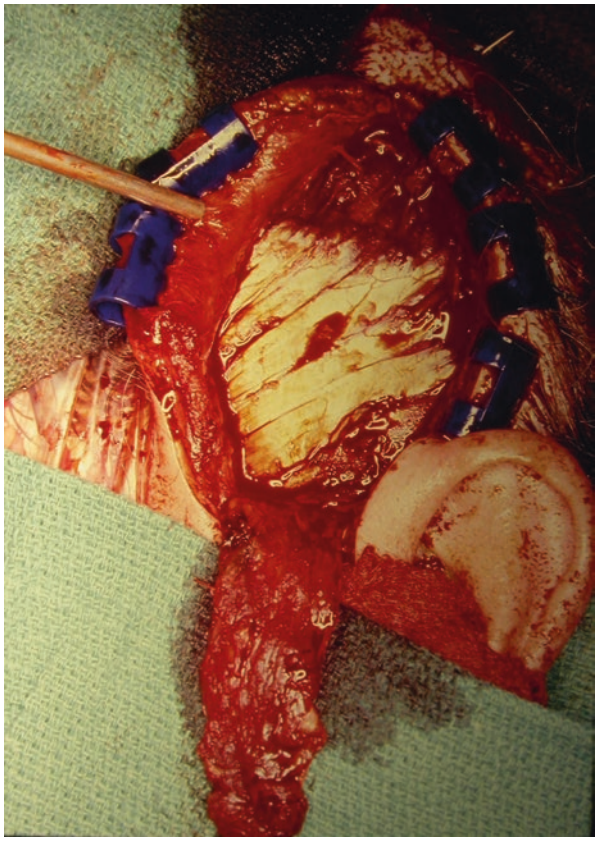

Fig. 6.2 A flap which incorporates fascia and the superficial layer of the temporalis muscle and shows the intermediate tendon of this bipennate muscle

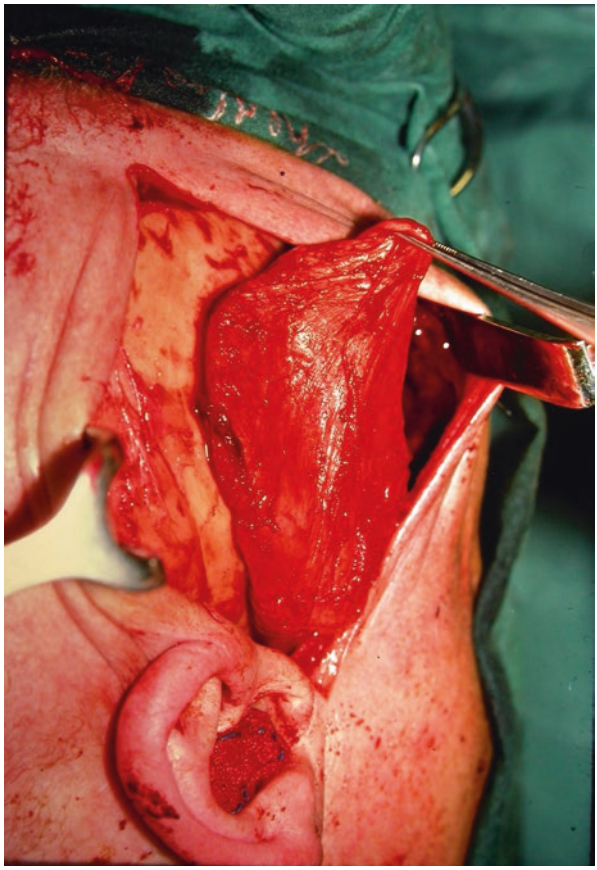

Fig. 6.3 A full thickness temporalis fascia and muscle flap showing the underlying temporal bone

6.4.4 Disc Repositioning

After exposure of the superior and inferior joint space using standard arthrotomy technique (using the "disc-sparing" capsular incision), the disc is carefully inspected to ensure there is minimal or no deformity. Once the disc is deemed salvageable, the redundant and stretched retrodiscal tissues are separated from the disc and resected. The disc is freed from the capsular attachments to ensure passive repositioning into its physiologic position. The posterior edge of the disc is secured to the retrodiscal tissues (or lateral pole of the condyle) using nonresorbable sutures. The arthrotomy wound is then closed in a standard layered fashion. The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

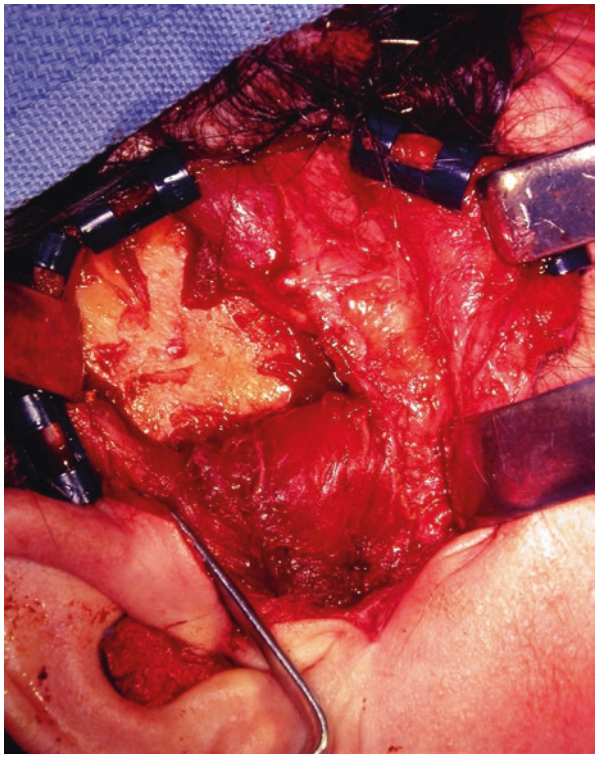

Fig. 6.4 A full thickness flap turned over the zygomatic arch and sutured to the remnants of the disc medially

6.4.5 Mitek Anchor Technique

The joint can be approached through a short endaural incision. After entry into the superior joint space, an incision is made just superior to the lateral pole of the condyle to enter the inferior joint space. The anterior, lateral, and occasionally the medial capsular ligament attachments require detachment to permit passive repositioning of the disc over the condylar head. The redundant bilaminar retrodiscal tissues above and behind the condyle are resected. In cases of anterior and anteromedial disc displacement, it is usually necessary to release the ligamentous attachment of the disc to the anterior surface of the articular eminence. The lateral pterygoid muscle attachment at the anterior portion of the disc is maintained as the muscle provides anterior stability to the disc and usually stretches adequately to permit passive repositioning of the disc over the condyle. When necessary, discoplasty may be indicated to maximize the fit of the anatomical morphology of the disc, condyle, and fossa relationship. Arthroplasty and eminoplasty are avoided, if possible, since these procedures will create postsurgical adhesions of the disc to the fossa and/or condyle, which may contribute to decreased TMJ mobility, degenerative joint disease, and possibly continued postsurgical pain.

A hole is created in the posterior head of the condyle with a standard Mitek drill bit (2.1 mm diameter) with a built-in stop, using a very slow drilling speed and copious irrigation. The position of the anchor may vary slightly from case to case but is generally positioned 8.0 mm below the superior aspect of the condylar head and just lateral to the mid-sagittal plane (Fig. 6.5d). It is not necessary to reflect soft tissue from the posterior condylar head for preparation of the hole, and generally the hole is drilled through the periosteum to maximize soft tissue attachment and maintenance of the blood supply to the condyle. Prior to placing the Mitek mini anchor, one 0 Ethibond (Ethicon, Inc., Somerville, NJ, USA) braided polyester suture is doubled and threaded through the eyelet of the anchor. The suture loop is then transected, thereby making two separate suture strands, and the anchor is placed into the inserting device. The Mitek mini anchor is then placed into the prepared hole in the condylar head, and using hand pressure, the trigger is advanced, delivering the anchor below the cortical bone level into the softer medullary bone within the condyle (Fig. 6.5b). The nickel-titanium wings that possess super-elastic properties are pressed against the body of the anchor as they pass through the more dense cortical bone and reopen when they enter the softer, medullary bone. This effectively locks the anchor in place within the condylar head. The sutures are pulled forcibly to ensure proper seating of the anchor against the inside cortex of the condylar head.

Next, the two sets of Ethibond sutures are attached to the disc with three throws for each suture. One end of the first suture is placed into a French eye needle (the needle is cut to approximately 8.0 mm length for easier manipulation in the joint space) and passed from beneath the disc, up through the medial aspect of the posterior band. The needle and suture are then passed through the posterior band two more times, in a slightly more lateral location with each throw. The second suture is then attached to the posterior band in the same fashion but in a more lateral position. The sutures are then tied posterior and inferior to the disc. Care is taken in placing the suture through the distal aspect of the posterior band in such a manner as to avoid direct functioning on the suture (Fig. 6.5b). The joint is then irrigated copiously with saline. The capsule and subcutaneous tissues are closed in layers using 4-0 PDS suture and the skin closed with 5-0 Prolene suture using a subcuticular suture method. The indicated orthognathic surgical procedures to maintain the original occlusion, or to correct coexisting dentofacial deformity, are performed next, if applicable. Postsurgical physical therapy may be indicated at the discretion of the surgeon. Postsurgical imaging may demonstrate the Mitek anchor in position with the condylar head (Figs. 6.6 and 6.7). The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

Mitek Anchor Case Presentation

This 18-year-old female reported the onset of her TMJ symptoms at about the age of 13 when her joints started to click and pop. By the age of 16, the clicking stopped, but her pain involving the TMJs and headaches had significantly

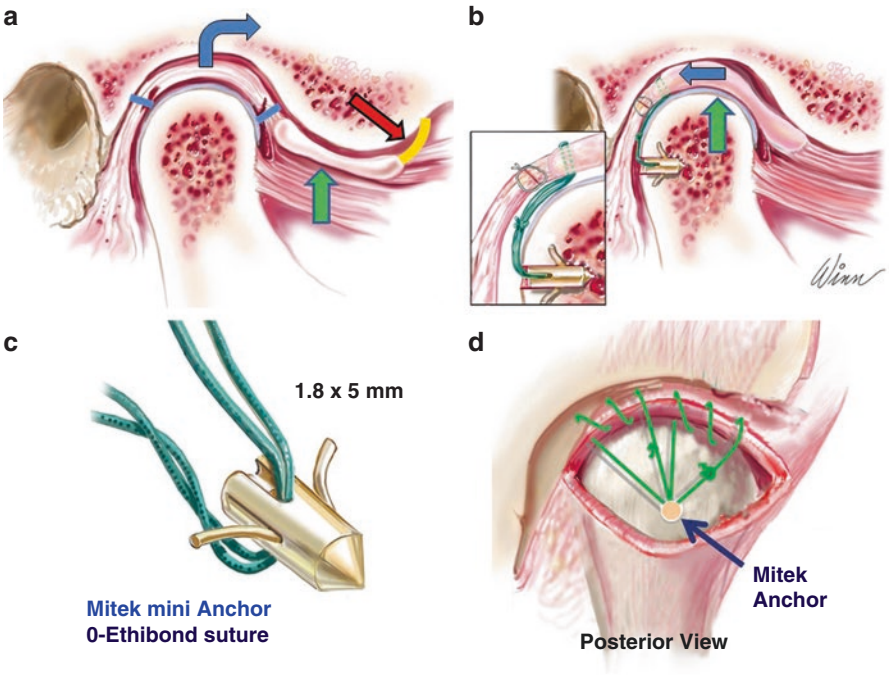

Fig. 6.5 (**a**) Sagittal view of the right TMJ. The TMJ articular disc is anteriorly displaced (green arrow). Bilaminar and synovial tissues cover the top of the condyle. This tissue is excised to eliminate excessive tissue when the disc is repositioned. The ligament that attaches from the anterior aspect of the disc to the anterior aspect of the articular eminence must be detached in order to mobilize the disc and reposition it passively over the condylar head (red arrow). (**b**) The disc has been mobilized and repositioned passively over the condyle. A hole is drilled into the posterior head of the condyle with the dedicated Mitek drill, and the Mitek anchor is inserted into the posterior head of the condyle into the medullary bone with the wings locking it in place against the cortical bone. The 0 Ethibond suture that was doubled and passed through the eyelet of the anchor provides two artificial ligaments to secure the disc in position. (**c**) The Mitek mini anchor is 1.8 mm in diameter and 5 mm in length. The body of the anchor is titanium alloy, and the wings are composed of nickel titanium with shape-memory technology to allow the wings to compress against the body of the device as it passes through the cortical bone of the condyle and then re-expand once into the medullary bone, locking the device in place against the cortical bone. (**d**) Posterior view of the anchor inserted into the condyle. The pilot hole is placed approximately 8 mm below the crown of the condylar head and just lateral to the midsagittal plane. The first suture (artificial ligament) is passed from beneath up through the posterior aspect of the posterior band of the disc toward the medial side. Two more throws are completed for a total of three throws. The second suture is passed in the same manner with three throws but positioned more laterally. The disc should be slightly overcorrected, and then the sutures are tied. Additional support sutures can be placed, for example, at the lateral pole area if additional support is required to stabilize the disc laterally. The 0 Ethibond suture can be passed through the lateral capsular tissue and up through the lateral aspect of the disc and secured to provide additional lateral support

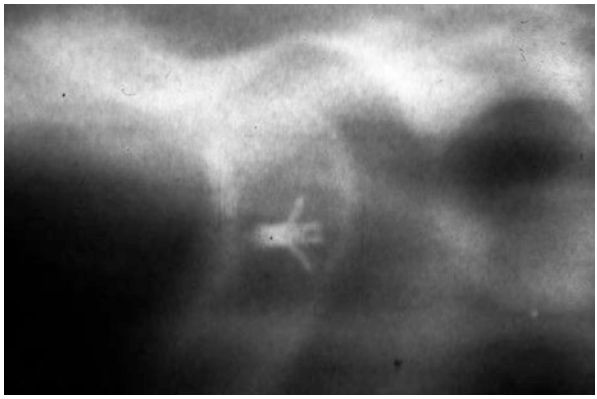

Fig. 6.6 A left lateral CT image shows the Mitek anchor in position in the head of the condyle. These anchors osseointegrate within 3 months post placement

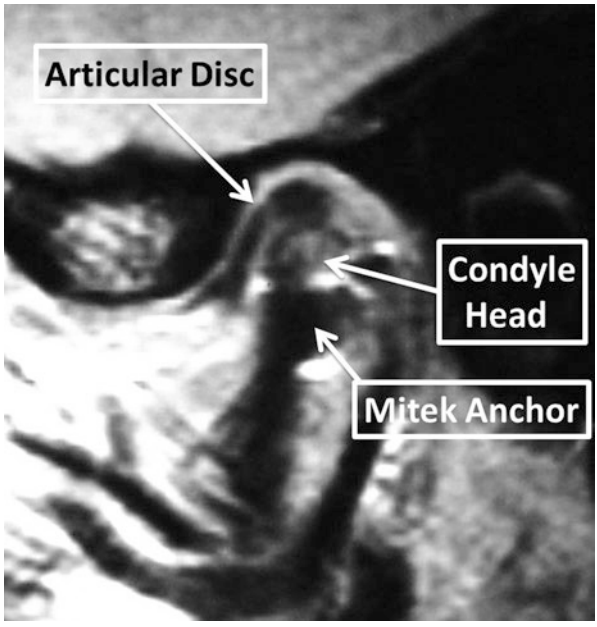

Fig. 6.7 An MRI image of the left condyle shows the articular disc in good position over the condyle. There is distortion of the condyle created by the metal Mitek anchor. There are no contraindications to perform MRI examinations in the presence of Mitek anchors in the mandibular condyles

increased. She was referred for treatment at the age of 18 years. Although she had good facial symmetry in the frontal view, in profile she had the high occlusal plane angle (HOP) facial morphology commonly seen with adolescent internal condylar resorption (AICR) with the retruded mandible and chin as well as an end-on Class II occlusion (Figs. 6.8a, c, e and 6.9a, c, e). On a scale of 0–10, where 0 equals no pain and 10 the worse pain imaginable, she rated her headaches at 6, TMJ pain at 7, and myofascial pain at 8. She had significant difficulties eating and chewing related to her pain issues and was on a relatively soft diet.

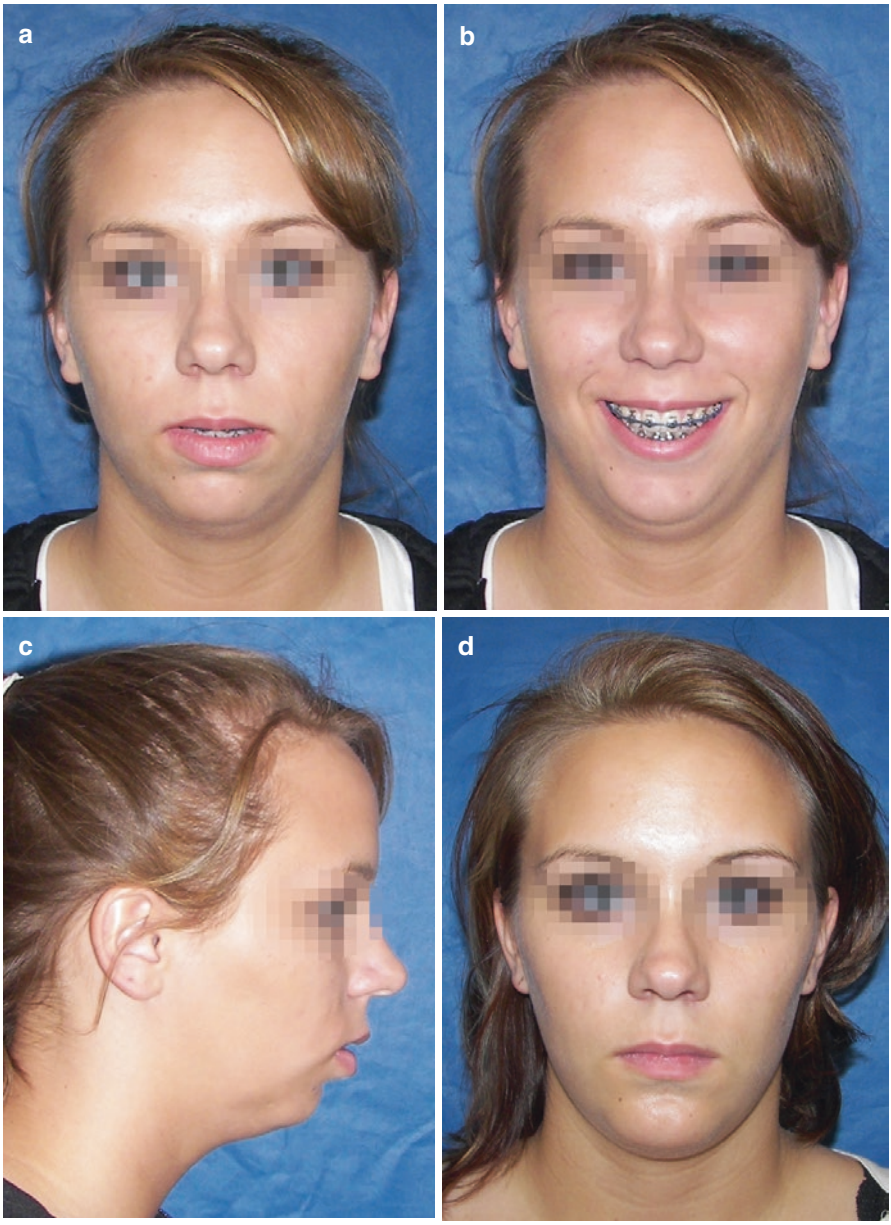

Fig. 6.8 (**a**, **b**) An 18-year-old female with AICR demonstrates good frontal facial symmetry. (**c**) In profile, the retruded mandible and HOP facial morphology are evident. (**d**–**f**) The patient is seen 3 years postsurgery demonstrating good facial balance

Fig. 6.8 (continued)

She rated her disability at 7, where 0 indicates no disability and 10 means totally disabled. She was in orthodontic treatment at the time of first evaluation. Her diagnoses consisted of the following: (1) bilateral TMJ AICR; (2) maxillary anteroposterior (AP) and posterior vertical hypoplasia; (3) mandibular AP and posterior vertical hypoplasia; (4) Class II end-on occlusion; (5) high occlusal plane angle (6) impacted third molars ×4; (7) hypertrophied turbinates with nasal airway obstruction; and (8) TMJ pain, myofascial pain, and headaches. The single-stage surgical treatment consisted of the following: (1) bilateral TMJ articular disc repositioning and ligament repair with Mitek anchors (Fig. 6.9), (2) bilateral mandibular ramus osteotomies to advance the mandible in a counterclockwise direction, (3) multiple maxillary osteotomies to downgraft the posterior aspect, (4) anterior mandibular horizontal osteotomy to augment the chin, (5) removal of impacted third molars ×4, and (6) bilateral partial inferior turbinectomy. The patient is evaluated 3 years postsurgery with the following findings: no TMJ pain, headaches, nor myofascial pain, incisal opening was 43 mm (presurgery was 28 mm), excursion movements of 5 mm in each direction, good jaw function and no disability, good facial balance (Fig. 6.8b, d, f), and stable occlusion (Figs. 6.9b, d, f, 6.10 and 6.11).

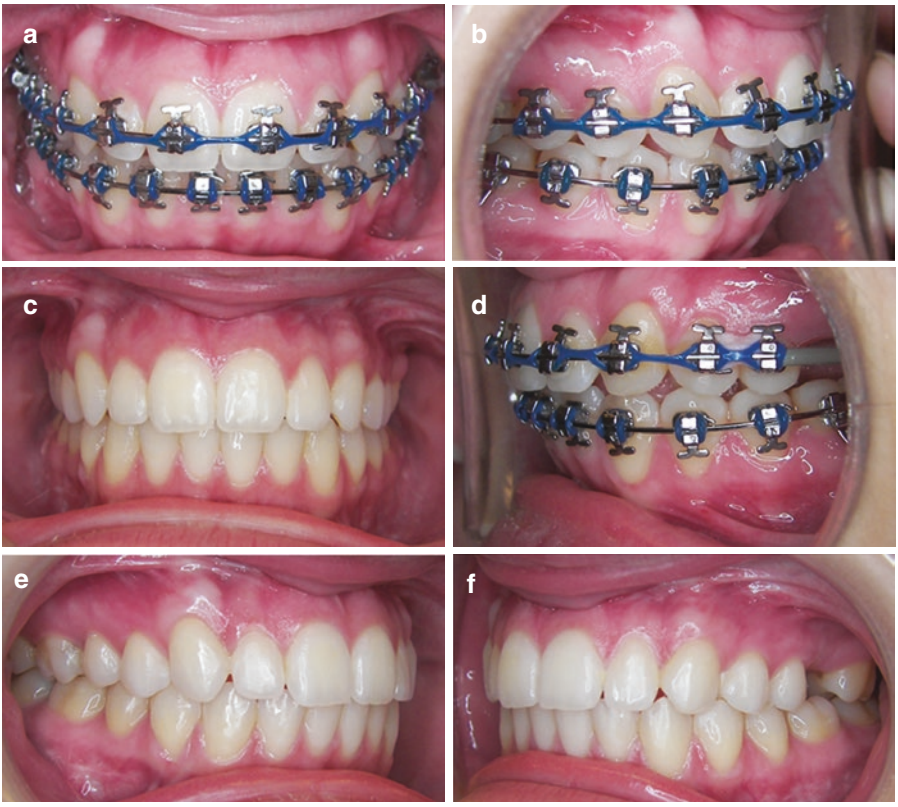

Fig. 6.9 (**a**–**c**) The Class II end-on occlusal relationship is noted that has been getting progressively worse. (**d**–**f**) At 3 years postsurgery, the patient is noted to have a good stable occlusal relationship

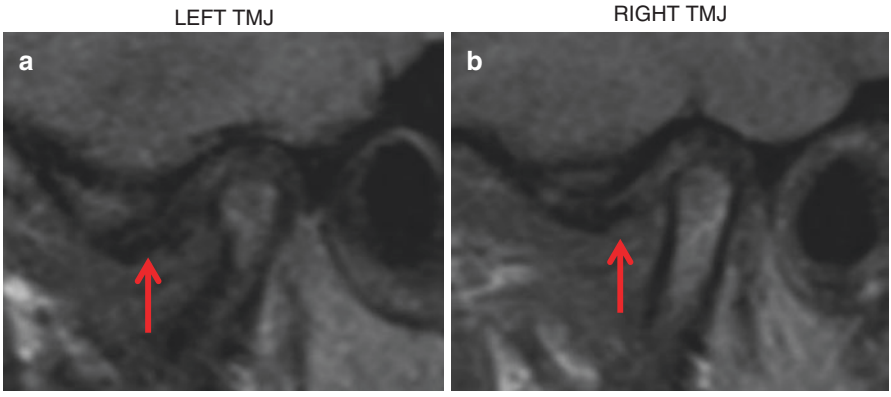

Fig. 6.10 (**a**) Presurgery cephalometric analysis demonstrates the HOP facial morphology with the retruded mandible. (**b**) The surgical prediction tracing illustrates the counterclockwise rotation of the maxillomandibular complex as well as repositioning the articular discs and augmentation genioplasty

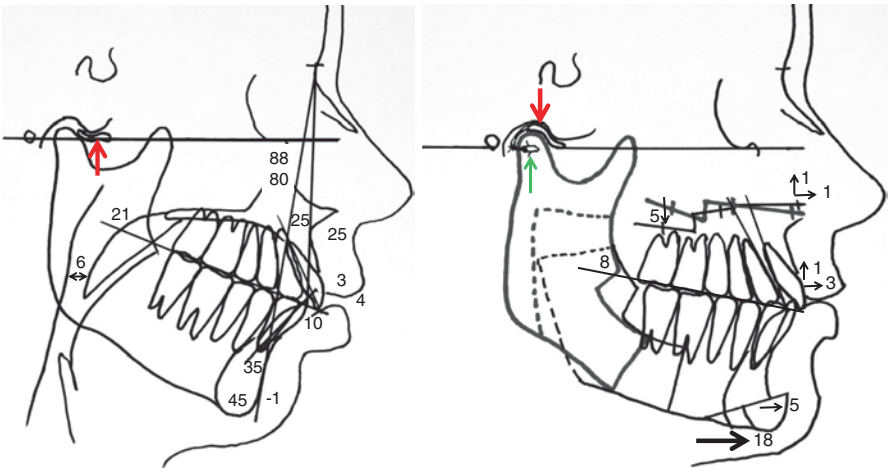

Fig. 6.11 Bilateral MRIs of a patient with AICR. The condyles appear small in size, and the cortical bone on top of the condyle is somewhat thin. The articular discs are anteriorly displaced (red arrows). In AICR patients, the articular discs may or may not reduce on opening

6.4.6 Arthroplasty

A standard arthrotomy approach can be used, using either a "disc-sparing" or a T-shaped capsular incision. The disc and the superior and inferior joint spaces are carefully visualized, and recontouring of the articular surfaces (with or without discectomy) is performed, as needed. Meticulous hemostasis is achieved, and closure of the arthrotomy wound is performed in a standard fashion.

When an eminectomy alone is performed, a subperiosteal dissection of the periosteum of the zygomatic arch is carried out, instead of a capsular incision. The articular eminence is exposed, and a retractor is placed to protect the superior aspect of the disc and the medial synovium. Distraction of the mandible inferiorly from the assistant, or the use of a Wilkes retractor, may further reduce the risk of iatrogenic damage to the fossa, condyle, and disc.

A 1.0 mm fissure bur, reciprocating saw, or piezosurgery saw is used to mark a horizontal osteotomy at the base of the eminence. Then, an osteotome is used to complete the eminectomy. The osteotome is angled inferiorly to avoid intracranial perforation through the thin squamous portion of the temporal bone. A large round or pineapple bur or reciprocating rasp or hand rasp is used to remove any irregularities or residual areas that may interfere with condylar rotation and translation. Specific attention should be directed to the medial aspect of the articular eminence which is frequently missed due to the depth of this area and the adjacent neurovascular structures which may be at risk for iatrogenic injury. All bony surfaces are rounded and smoothed, and meticulous hemostasis is maintained. Condylar motion should be observed directly while the mouth is opened, and mandibular excursions and translation are performed to ensure unimpeded movement and lack of interferences. The wounds are

irrigated and suctioned and closed in a layered fashion. The use of a postsurgical occlusal appliance and/or the commencement of postoperative physical therapy should be guided by surgeon preference and individual patient requirements.

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Part III

Total Temporomandibular Joint Replacement

Surgery of the Temporomandibular Joint: Virtual Planning

7

Larry Wolford and Jacinto Fernandez Sanroman

Abstract

Patients with temporomandibular joint (TMJ) pathology and coexisting dentofacial deformities can be corrected with concomitant TMJ and orthognathic surgery (C-TMJ-OS) in one surgical stage or separated into two surgical stages. The two-stage approach requires the patient to undergo two separate operations (one surgery to correct the TMJ pathology and a second operation to perform the orthognathic surgery) and two general anesthetics significantly lengthening the overall treatment time. Performing C-TMJ-OS in a single operation significantly decreases treatment time, provides better outcomes, but requires careful treatment planning and surgical proficiency in the two surgical areas. There are TMJ pathologies that require total joint prostheses for best results. The application of computer technology for TMJ and orthognathic surgical planning and implementation has significantly improved the accuracy and predictability of treatment outcomes.

7.1 Introduction

Correctly diagnosing, planning, and accurately producing surgical outcomes for patients with temporomandibular joint (TMJ) and associated dentofacial deformities are very important factors for optimal patient management [1]. Conventional

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two-dimensional (2D) computer-assisted imaging systems allow the surgeon a quick analysis of the surgical case and to perform treatment planning. However, in some cases, with significant facial deformity and asymmetry, the reliability of these 2D systems is suboptimal. In recent years, the development of 3D software systems (computer-assisted surgery systems—CASS) that integrates cone beam computerized tomography (CBCT) and computerized tomography (CT) images of the facial skeleton, CBCT/CT images of the dental casts or dental model surface scanning, and photographs (2D or 3D) of the patients has improved the methods in which patients can be diagnosed and virtually treatment planned [1–7]. Three-dimensional computer programs allow the surgeon to visualize the hard and soft tissue structures in 3D to aid and improve the diagnostic and treatment planning accuracy. Through computer-assisted surgical simulation (CASS) technology and virtual surgical planning (VSP) software programs, manipulation of the hard and soft tissue structures, simulating precise surgical movements, can be accomplished. These sophisticated programs allow segmentation of the maxillary and mandibular skeletal structures as determined in the presurgical planning and printing of surgical stabilizing appliances to reposition the jaw into predetermined positions, so accurate duplication of the indicated procedures can be accomplished at surgery. In addition, VSP will identify areas of hard tissue interferences or creation of bony gaps that may need to be addressed in order to meet the treatment goals and provide stability of the surgical results. For instance, if bone gaps are created in the maxilla, this could indicate a bone graft requirement for stability. In the mandible, for example, ramus sagittal split osteotomies used for correcting a posterior yaw may create bony interferences between the proximal and distal segments on the side to which the mandible is rotated toward, requiring additional ostectomies or bone recontouring for the segments to fit together. Predictions of soft tissue changes are also possible that may assist in positioning of the skeletal structures and identify areas that may require hard or soft tissue augmentation or reduction to maximize the esthetic outcomes.

CASS can be used in combination with rapid prototyping (RP) technology, robotics, and image-guidance systems (navigational surgery). Surgical templates fabricated by rapid prototyping (3D printing) technology permit a higher precision and predictability than those obtained with more traditional methods. Surgical cutting guides can also be constructed to mark the osteotomy lines, improving surgical accuracy and decreasing risk of injuries to facial nerves and vessels. Temporary positioning guides can help the surgeon to fix the bony segments in the ideal position previously determined. Finally, custom implants such as TMJ prosthesis, bone reconstruction, mandibular plates or miniplates, maxillary bone plates, custom alloplastic esthetic implants, etc. can be constructed before surgery to fit accurately into the surgical site.

Intraoperative navigation is also possible eliminating the need for surgical guides. Navigation systems can be used for intraoperative guiding as well as for validation of bone position [8–10].

Augmented reality tools for maxillary positioning in orthognathic surgery are currently under development and may be a valuable tool in the future for craniomaxillofacial surgery [11]. The final objective using these techniques is to enhance

an accurate diagnosis of the pathology and to improve safety and accuracy of the surgical procedures performed. Although these techniques are expensive and increase the time spent preparing surgery, they may permit less invasive approaches and reduce morbidity. Also, the technology facilitates better communication between the healthcare providers involved in the patient's treatment plan. Numerous CAD/CAM programs are currently available in oral and maxillofacial surgery (oncologic resection and reconstruction, orthognathic surgery, distraction osteogenesis, and TMJ surgery).

Patients with TMJ pathology, with or without a coexisting dentofacial deformity, can be corrected with only TMJ surgery or may require concomitant TMJ and orthognathic surgery. However, this chapter is directed to patients that have only TMJ pathologies surgically treated without including orthognathic surgical procedures. The combination of TMJ and orthognathic surgery will be presented in a subsequent chapter. Depending on the TMJ pathology and surgeon's experience and technical skills, TMJ surgery can be performed in one surgical stage or separated into two surgical stages. The two-stage approach requires the patient to undergo two separate operations (one surgery to eliminate the TMJ pathology and a second operation to reconstruct the TMJ) and two general anesthetics significantly lengthening the overall treatment time. Performing TMJ surgery in a single operation significantly decreases treatment time, provides better outcomes, but requires careful treatment planning and surgical proficiency in TMJ surgical techniques. There are TMJ pathologies that require total joint prostheses for best results. The application of computer technology for TMJ reconstruction surgical planning and implementation has significantly improved the accuracy and predictability of treatment outcomes.

This chapter presents the treatment planning and surgical protocols for patients only requiring TMJ reconstruction with the application of computer-assisted surgical simulation (CASS) and virtual surgical planning (VSP) programs for patient-fitted TMJ total joint prostheses. The CASS and VSP protocols decreases the preoperative workup time and increases the accuracy of model preparation fit of the prosthetic components and subsequent surgery [12, 13].

7.2 Indications for TMJ Total Joint Replacement (TJR)

Temporomandibular joint (TMJ) disorders or pathology without requiring additional orthognathic surgical procedures is common. The TMJ pathology can occur with no effect on the position of the jaws and occlusion or may be the causative factor for malalignment of the mandible in the presence of a normally positioned maxilla. The most common TMJ pathologies that can or cannot adversely affect mandibular position and occlusion, with or without the requirement for concomitant orthognathic surgery, include (1) articular disc dislocation, (2) adolescent internal condylar resorption (AICR), (3) reactive arthritis, (4) condylar hyperplasia, (5) trauma (Case 1, Figs. 7.1, 7.2, 7.3, and 7.4), (6) failed autogenous or alloplastic TMJ reconstruction (Cases 2 and 3, Figs. 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, 7.12, and

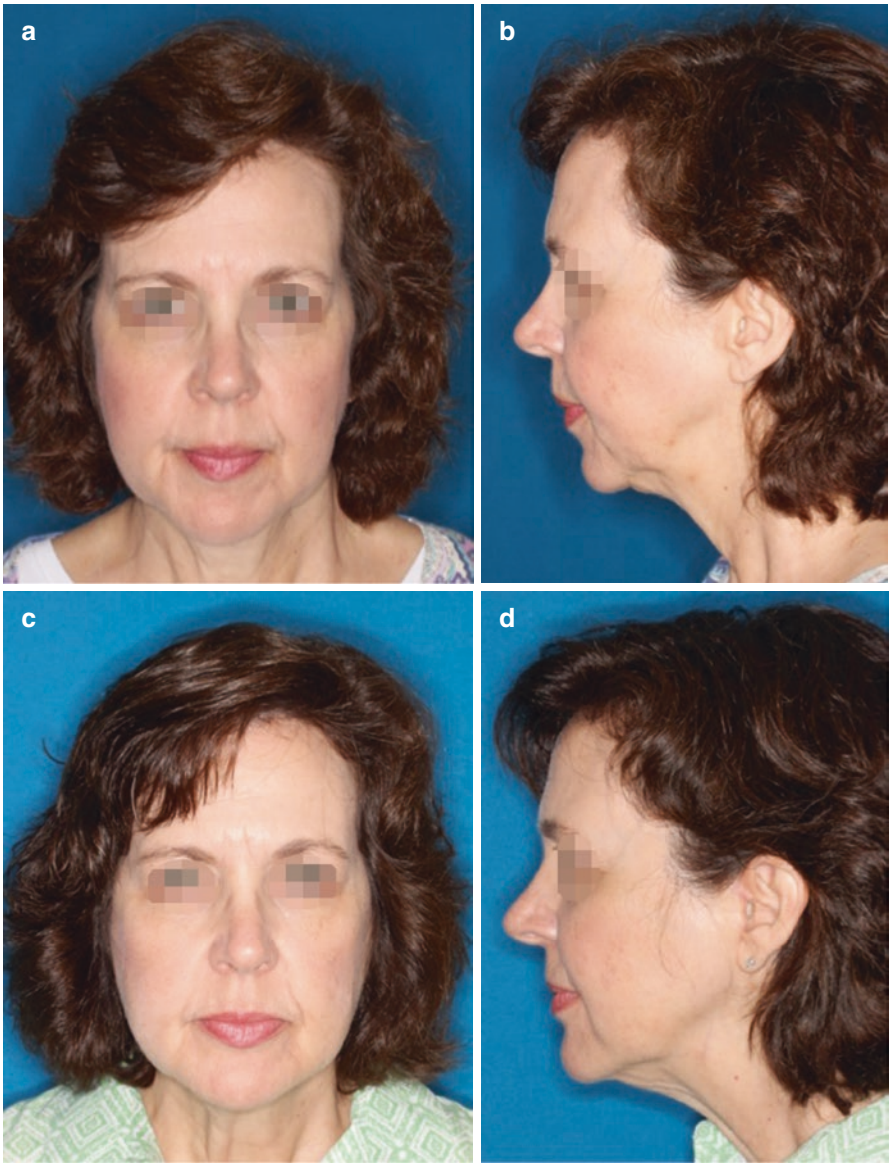


Fig. 7.1 Case 1. (**a**, **b**) A 56-year-old female who fell sustaining bilateral subcondylar fractures with resultant anterior open bite and retrusion of the mandible. (**c**, **d**) The patient is observed 1 year post-surgery with improvement in facial balance following counterclockwise rotation of the mandible into occlusion to close the open bite with bilateral TMJ Concepts total joint prostheses and bilateral TMJ fat grafts

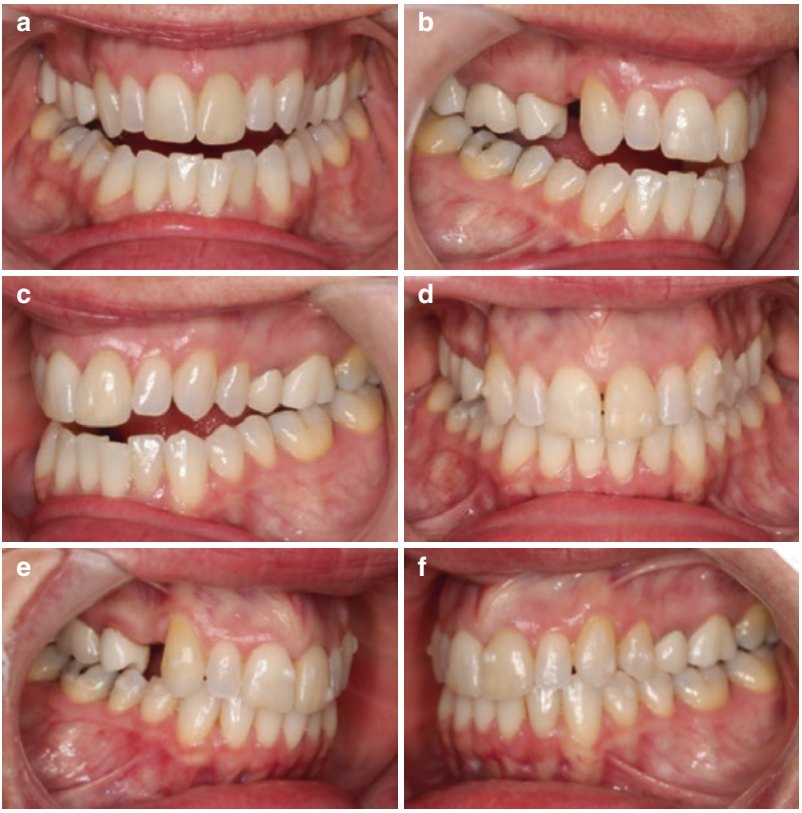


Fig. 7.2 Case 1. (**a–c**) Presurgical occlusion demonstrating the anterior open bite. The patient occludes only on the second molars bilaterally. (**d–f**) One year post bilateral TMJ reconstruction with counterclockwise rotation of the mandible utilizing TMJ Concepts custom-fitted total joint prostheses and bilateral TMJ fat grafts

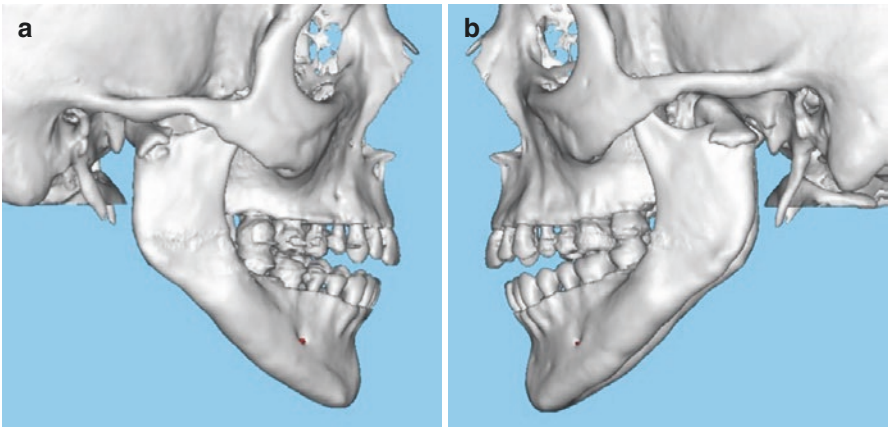
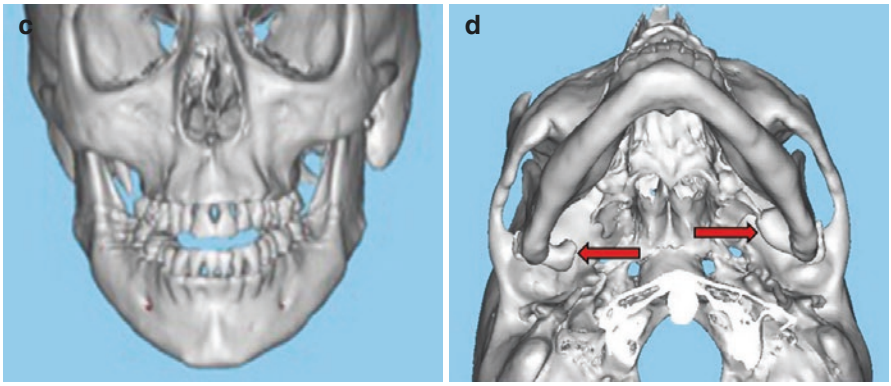


Fig. 7.3 Case 1. (**a–c**) CT scan demonstrates the retrusion of the mandible and anterior open bite as a result of the subcondylar fractures. (**d**) The submandibular view demonstrates the condylar displacement as a result of the subcondylar fractures (red arrows)



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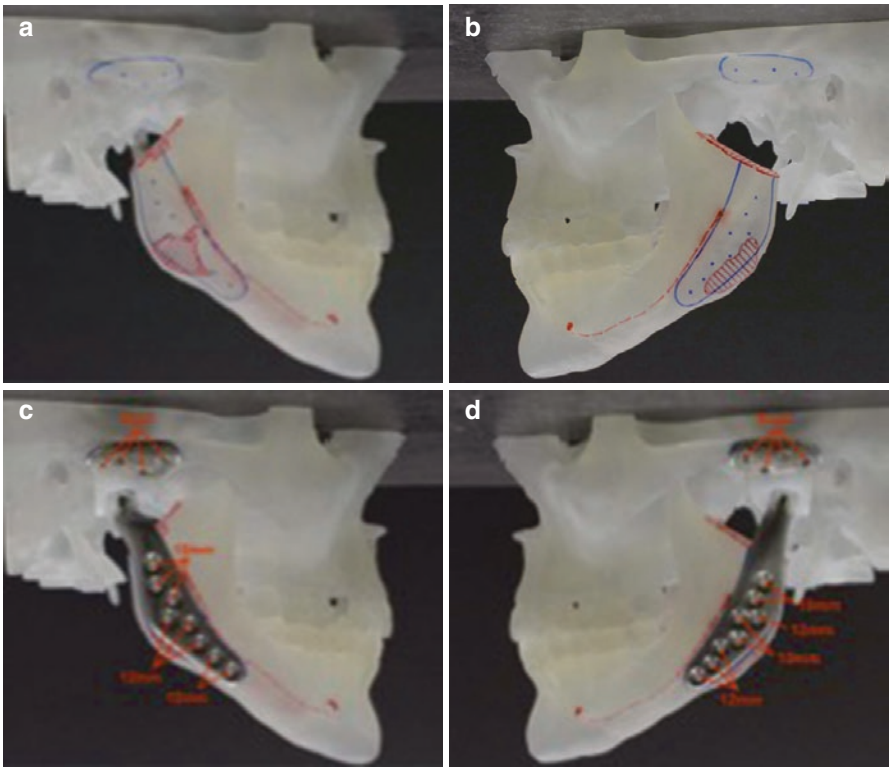


Fig. 7.4 Case 1. (**a**, **b**) The mandibular model was produced with the mandible repositioned into the best occlusal fit using CASS and VSP technology. The mandibular rami were prepared with the red marks indicating areas of bone recontouring to make the lateral aspect of the ramus as flat as possible to accommodate the prostheses. (**c**, **d**) TMJ prostheses have been manufactured and are custom fitted to the 3D stereolithic model

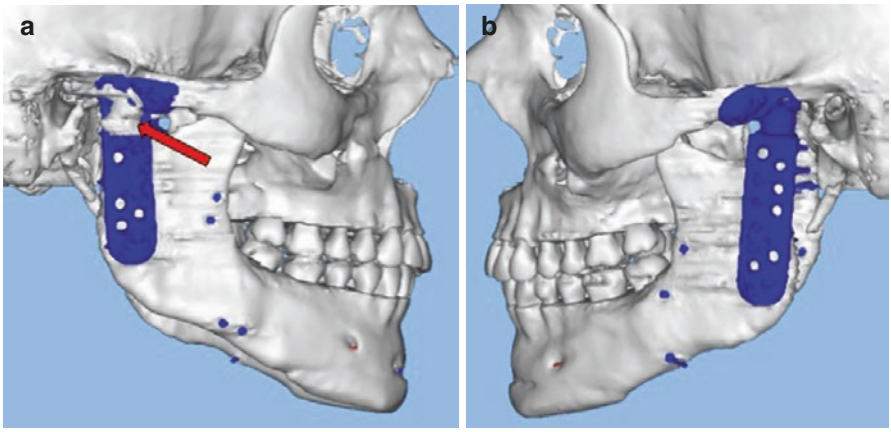


Fig. 7.5 Case 2. Records are from a 55-year-old female with failed Christensen metal-on-metal total joint prostheses. (**a**) Right TMJ Christensen prosthesis with a fractured fossa component but also with heterotopic bone that has grown around the medial posterior and lateral aspect of the prosthesis (red arrow). (**b**) Left TMJ failed metal prosthesis. Both joints produced metallosis from the metal-on-metal articulation

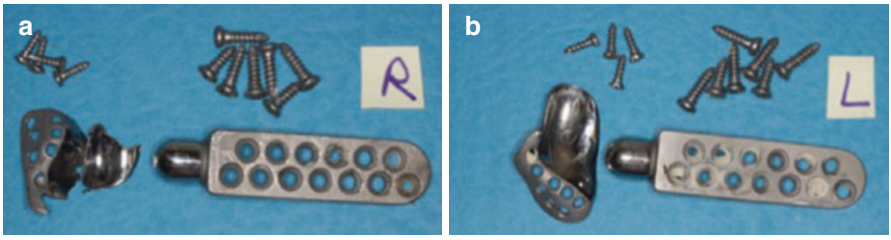


Fig. 7.6 Case 2. (**a**) Right TMJ failed Christensen total joint prostheses with the fractured fossa component. (**b**) Left TMJ failed Christensen prosthesis

7.13), (7) heterotopic bone and ankylosis (Case 4, Figs. 7.14, 7.15, 7.16, 7.17, 7.18, 7.19, 7.20, 7.21, and 7.22), (8) congenital deformation or absence of the TMJ, (9) tumors (Case 5, Figs. 7.23, 7.24, 7.25, 7.26, 7.27, 7.28, and 7.29), (10) connective tissue and autoimmune diseases, and (11) other end-stage TMJ pathologies [14, 15]. These TMJ conditions can be associated with dentofacial deformities, malocclusion, TMJ pain, headaches, myofascial pain, TMJ and jaw functional impairment, ear symptoms, sleep apnea, etc. Patients with these conditions may benefit from corrective surgical intervention, including TMJ reconstruction with or without the requirement for orthognathic surgery. Some of the aforementioned TMJ pathologies may have the best outcome prognosis using custom-fitted total joint prostheses for TMJ reconstruction [14, 15].

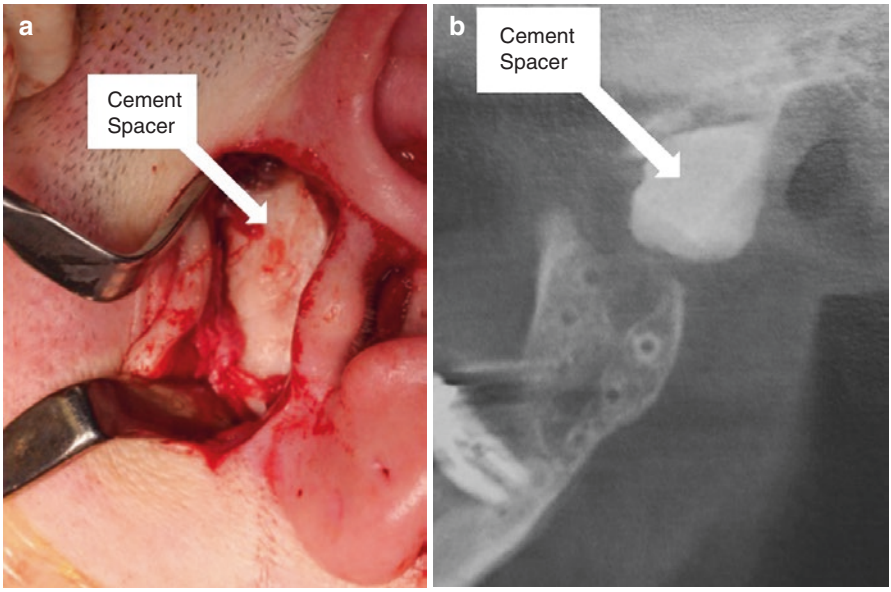


Fig. 7.7 Case 2. (**a**) Bone cement spacers were placed bilaterally to fill the osseous defects following removal of the TMJ failed Christensen prostheses. The cement spacer is seen on the left side. (**b**) Radiographically, the left cement spacer is seen positioned filling the gap between the fossa and left ramus of the mandible. The bone cement spacer serves to maintain the space and stabilize the mandibular position in preparation for the second stage of surgery

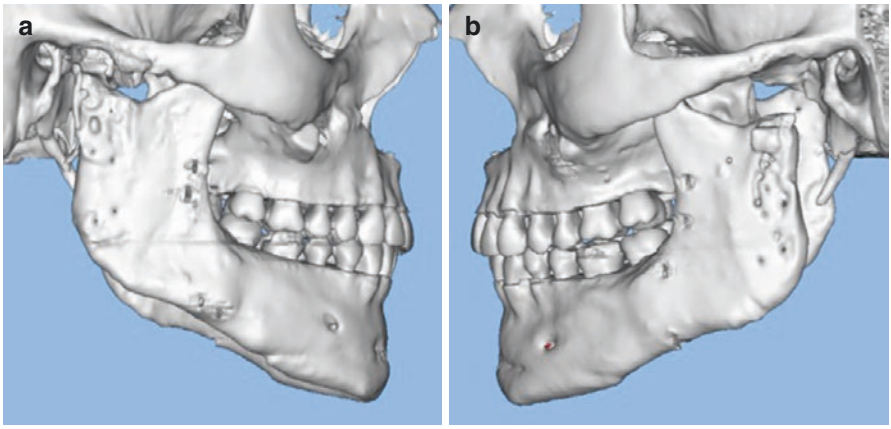


Fig. 7.8 Case 2. (**a**, **b**) CT scan of the jaws in preparation for production of the 3D stereolithic model

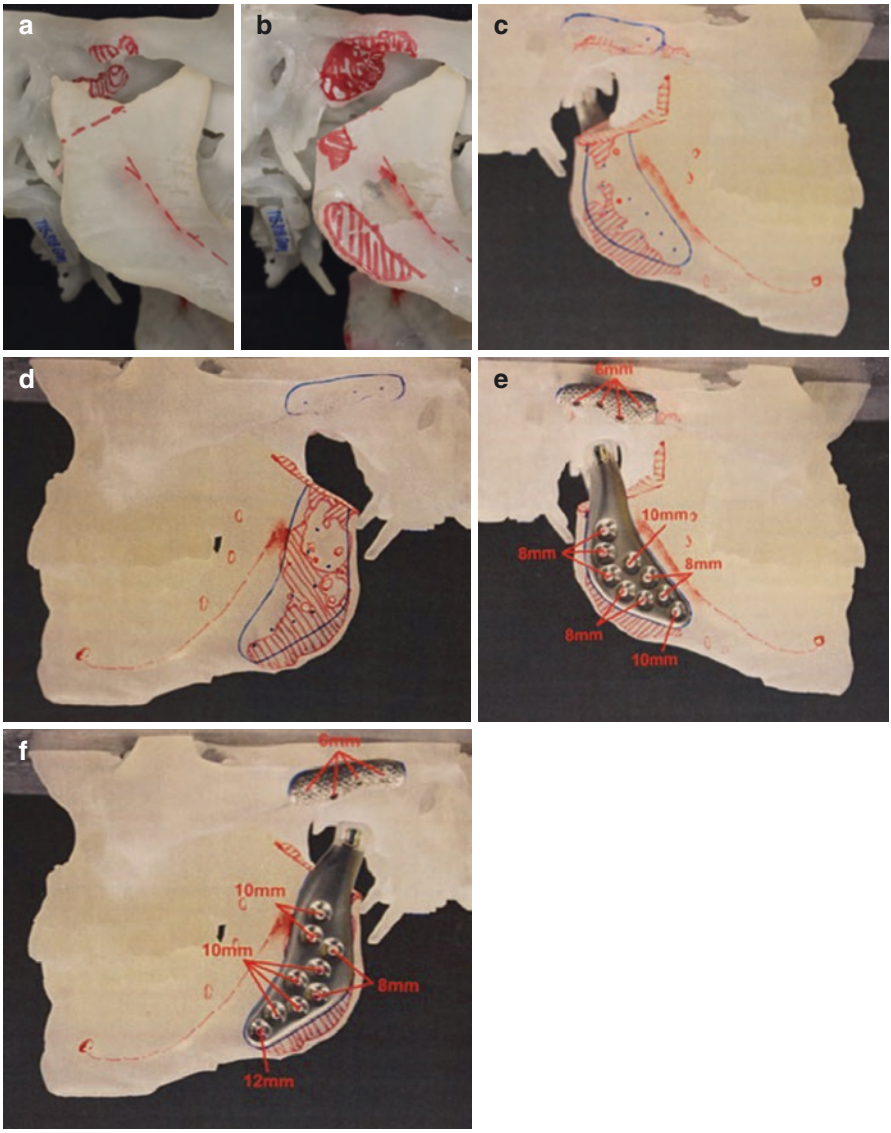


Fig. 7.9 Case 2. (**a**) Residuals of the condylar neck and heterotopic bone in the fossa are seen and require removal in preparation for the custom-fitted total joint prostheses. (**b**) Mandibular ramus and fossa prepared with removal of heterotopic bone in the fossa and recontouring the ramus in preparation of manufacturing the total joint prosthesis. (**c**, **d**) Right side in final preparation with removal of bone from the upper area of the ramus to create 20 mm of space between the fossa and ramus to accommodate the total joint prosthesis. (**e**, **f**) Bilateral TMJ Concepts custom-fitted total joint prostheses have been constructed on the 3D stereolithic model

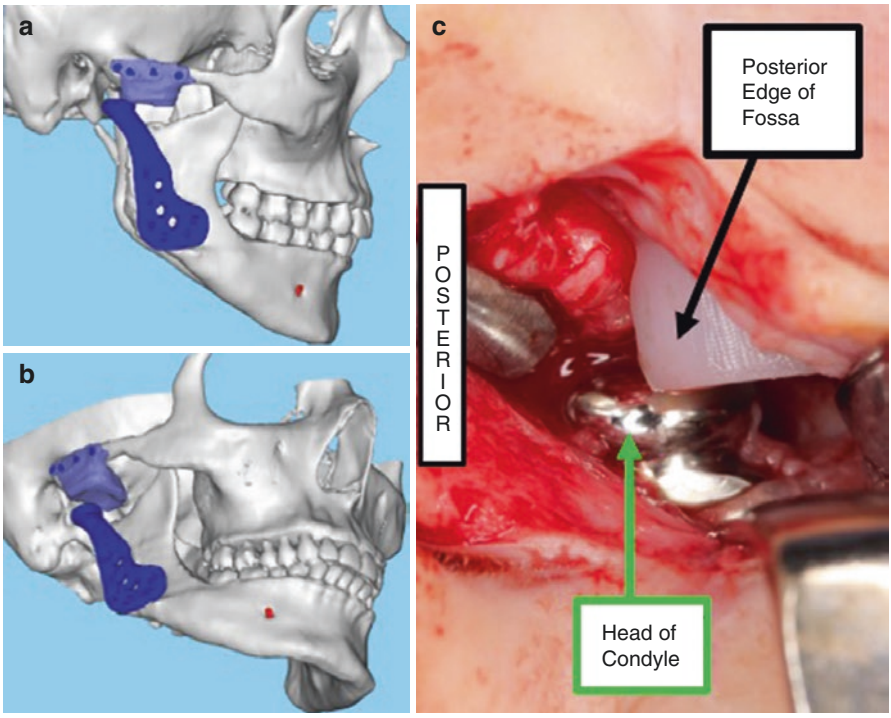


Fig. 7.10 Case 3. Records from a 46-year-old female with a failed Biomet prosthesis. (**a**, **b**) Unilateral right Biomet total joint prosthesis with a condyle positioned posterior to the fossa creating severe pain and functional issues. Although the mandibular component is metallic, the fossa component is polyethylene. (**c**) Clinical picture of the displaced mandibular component of the Biomet prosthesis

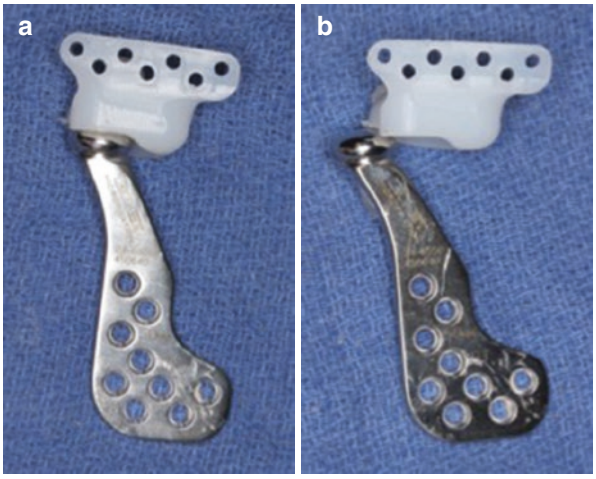


Fig. 7.11 Case 3. (**a**) Prosthesis removed demonstrating the normal articulation of the Biomet prosthesis. (**b**) Demonstrates the position of the mandibular component relative to the fossa in this patient's presurgical situation

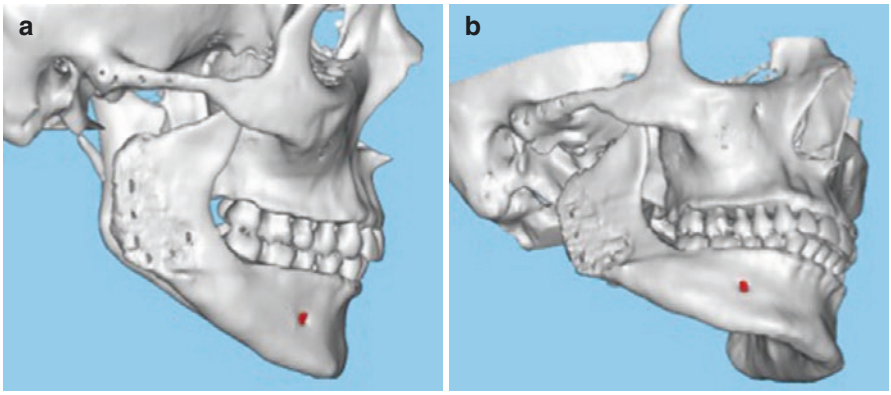


Fig. 7.12 Case 3. (**a**, **b**) CT scan of the patient's anatomy with the metallic mandibular component and polyethylene from the fossa electronically removed, rendering an accurate anatomical configuration of the fossa and ramus area allowing surgery to be done in a single-stage

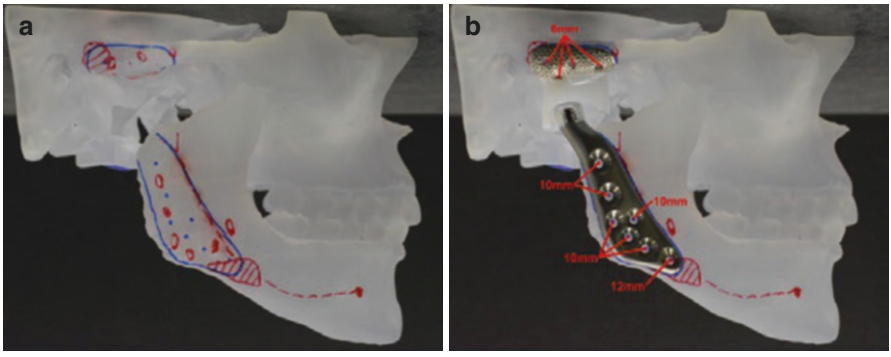


Fig. 7.13 Case 3. (**a**) 3D stereolithic model produced with the patient in maximal occlusal relationship with the ramus and fossa being appropriately modified. (**b**) Construction of the TMJ Concepts custom-fitted total joint prosthesis to adapt to this patient's specific anatomical requirements

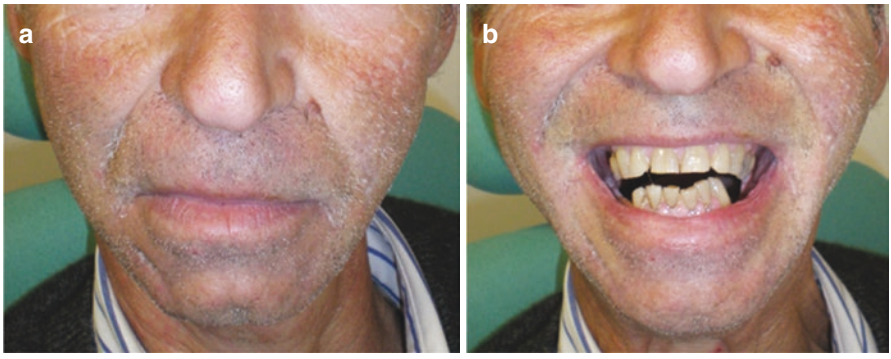
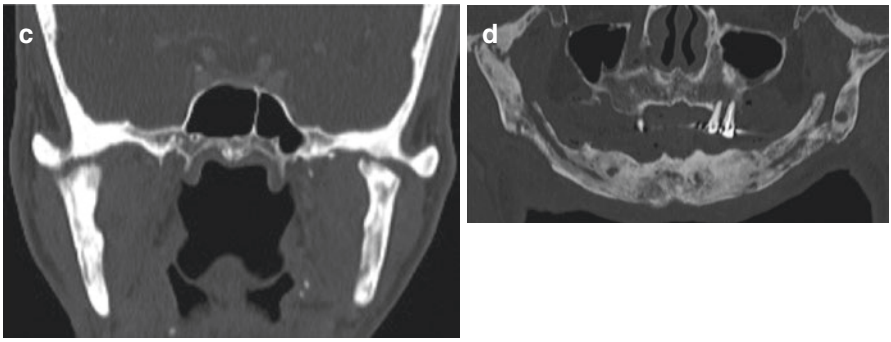


Fig. 7.14 Case 4. (**a**) A 53-year-old male with SAPHO syndrome (synovitis, acne, pustulosis, hyperostosis, and osteitis) and bilateral TMJ ankylosis. (**b**) Decreased preoperative maximal mouth opening (5 mm). (**c**, **d**) CT and panoramic images demonstrate bilateral osseous ankylosis with mandibular bony sclerosis



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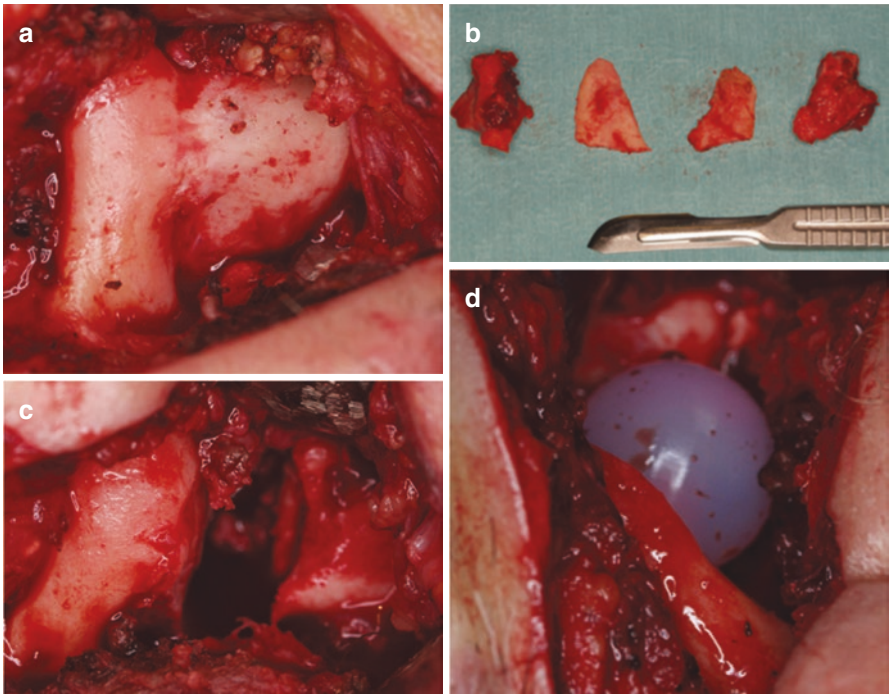


Fig. 7.15 Case 4. (**a**) Surgical view of the right TMJ ankylosis. (**b**) Ankylotic bone removed to free the right mandible. The gap arthroplasty is observed. (**c**) The bone and condyles removed from the bilateral TMJ resection to create the gap arthroplasty and the resected coronoid processes are seen. (**d**) The silicone ball spacer has been inserted into the osseous gap to maintain the space, stabilize the mandibular position, and decrease the risk of reankylosis during the intermediate stage in preparation for the second stage of surgery

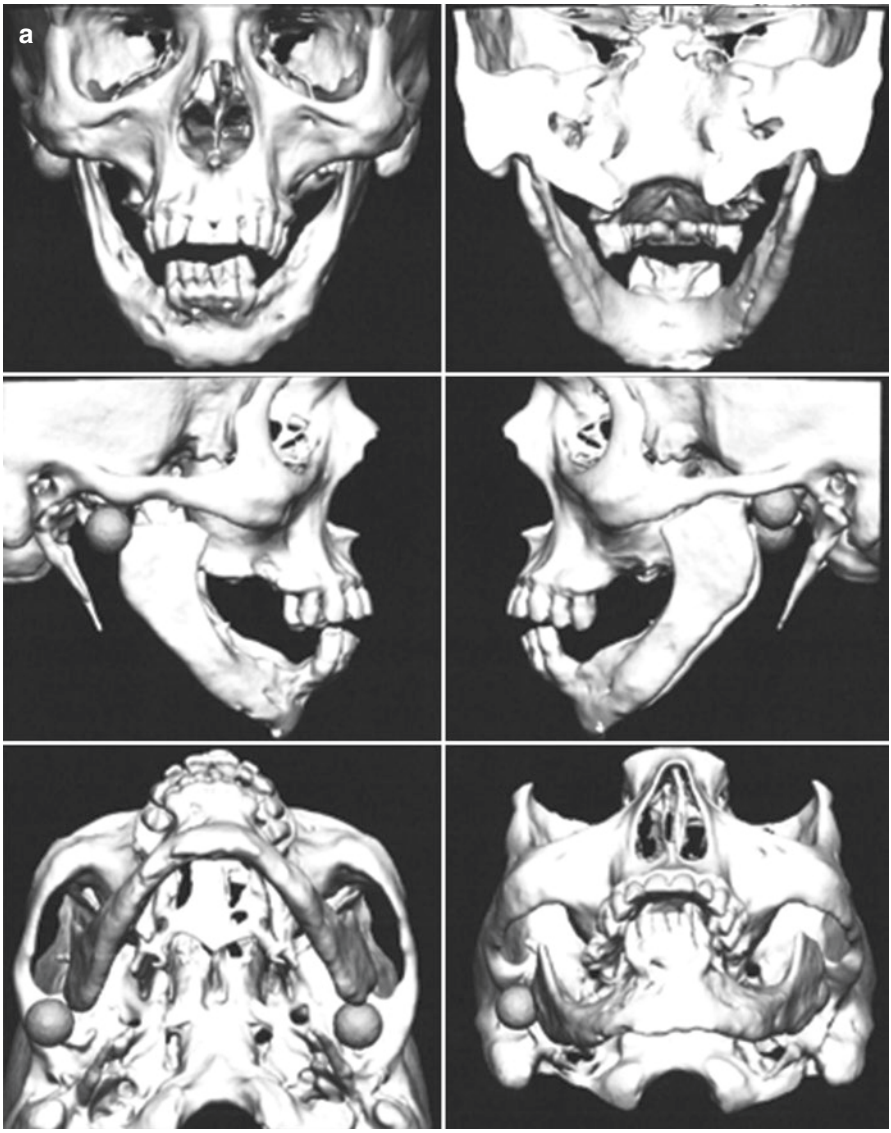
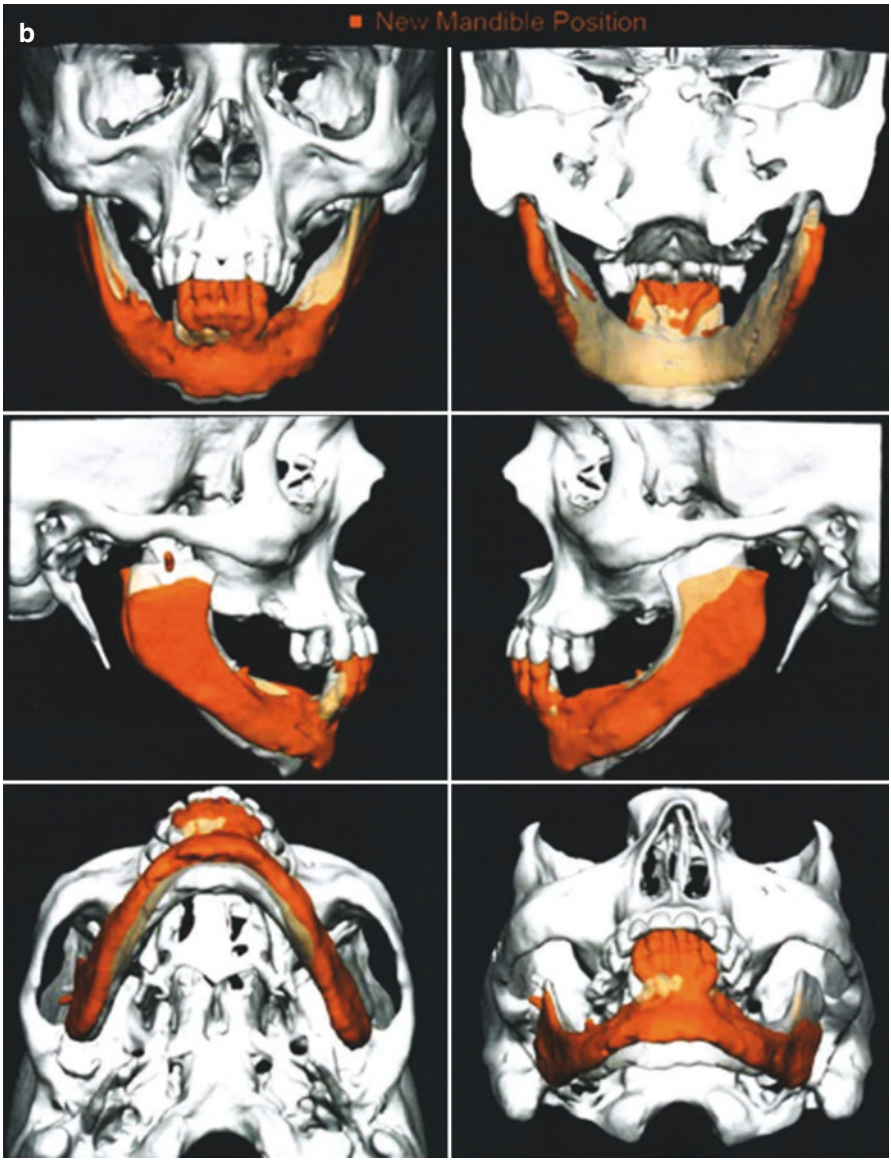


Fig. 7.16 Case 4. (**a**) CT scan, acquisitioned following the first surgical stage that included bilateral remove ankylotic bone, condylectomies, coronoidectomies, and placement of silicone balls into the created bone gap. (**b**) CASS and VSP technology used to place the mandible into the final surgical position (orange mandible), superimposed on the CT scan in Fig. 7.15a. From this position, it will be determined if additional bone resection and preparation of the fossa and ramus are required



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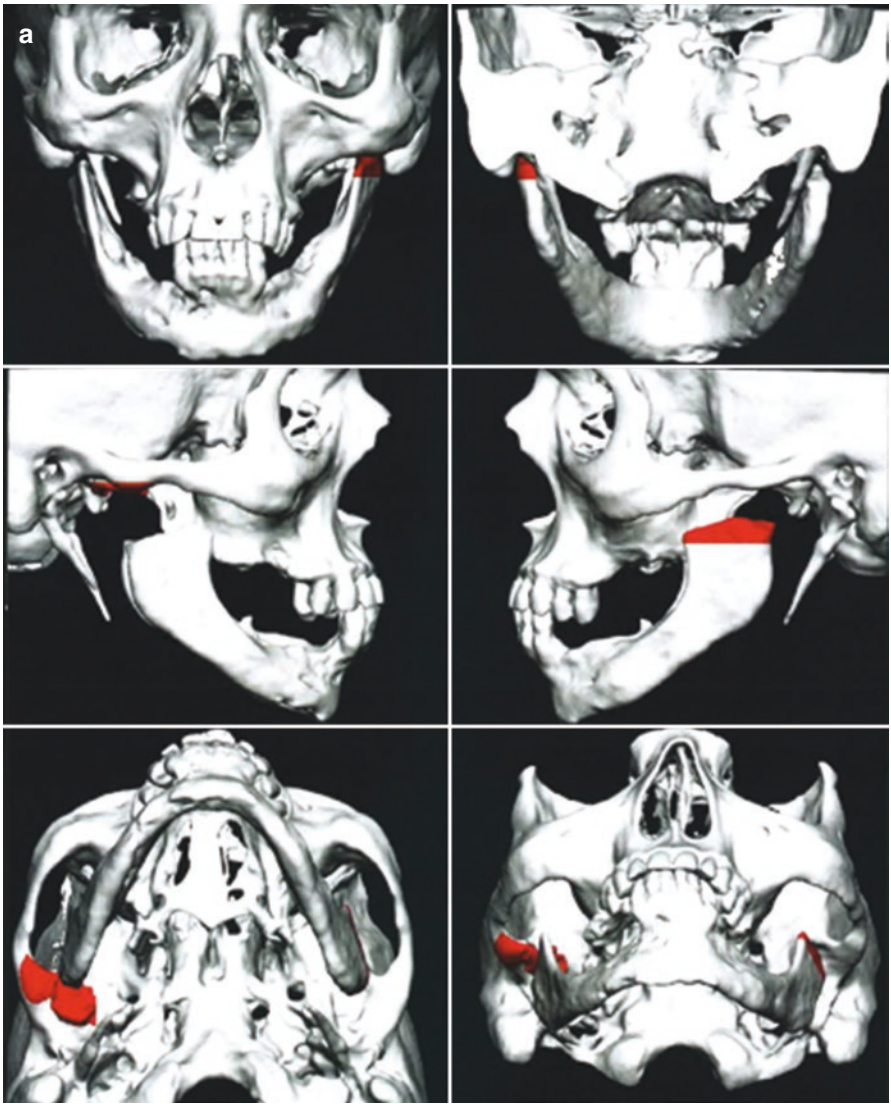
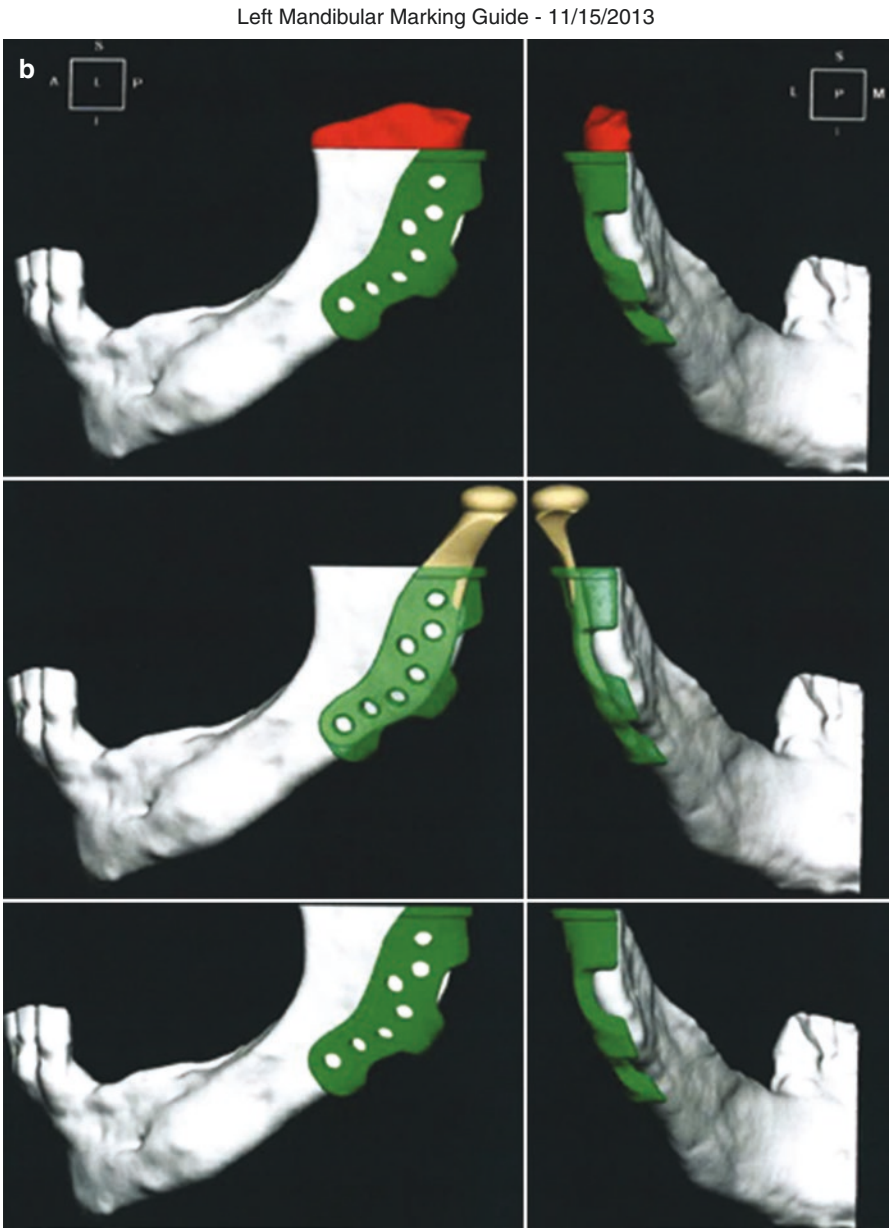


Fig. 7.17 Case 4. (**a**) 3D CT scan CASS preparation, illustrating the additional bone resection required (orange area at the superior aspect of the rami and in the right fossa) to accommodate the Biomet TMJ prostheses. (**b**) 3D CT scan CASS technology can provide computer-generated cutting guides to facilitate the accuracy of required bone resection on the ramus. Illustrated is the left ramus cutting surgical template (colored in green) for implementation during surgery



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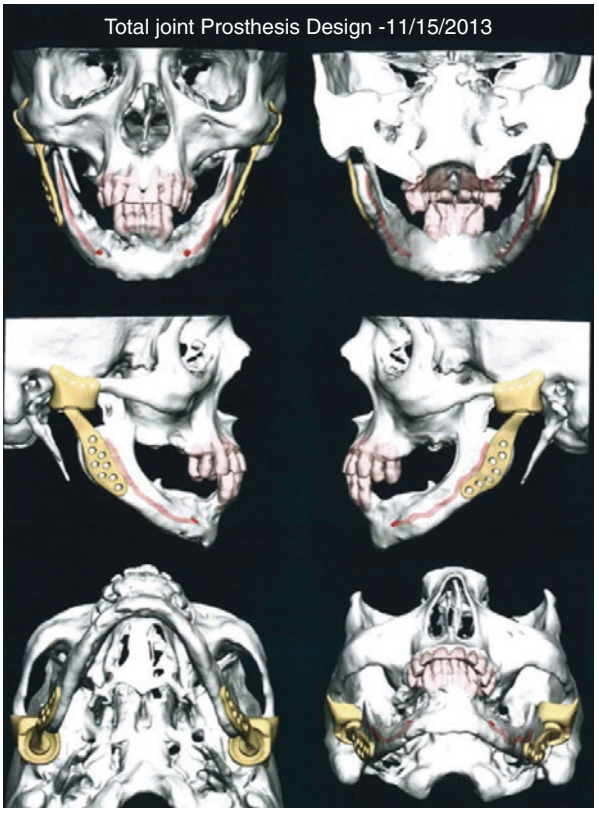

Fig. 7.18 Case 4. Computer-generated design of the bilateral Biomet custom-fitted total joint prostheses, including the fossa and mandibular components, based on the CASS and VSP placing of the mandible into the final surgical position

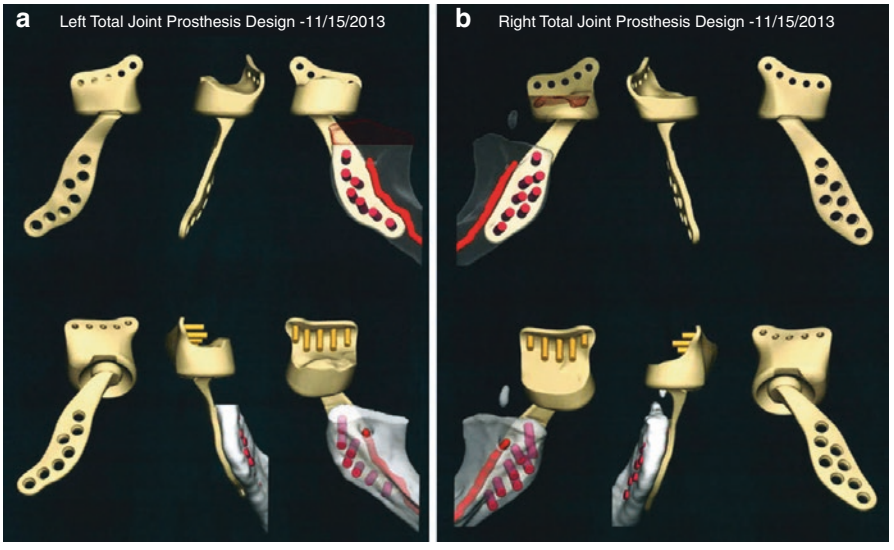

Fig. 7.19 Case 4. Computer design of the Biomet custom-fitted total joint prostheses from numerous views, including the medial view that demonstrates the planned position of the stabilizing screws for the mandibular components in relation to the rami and inferior alveolar nerves, (**a**) left side, (**b**) light side

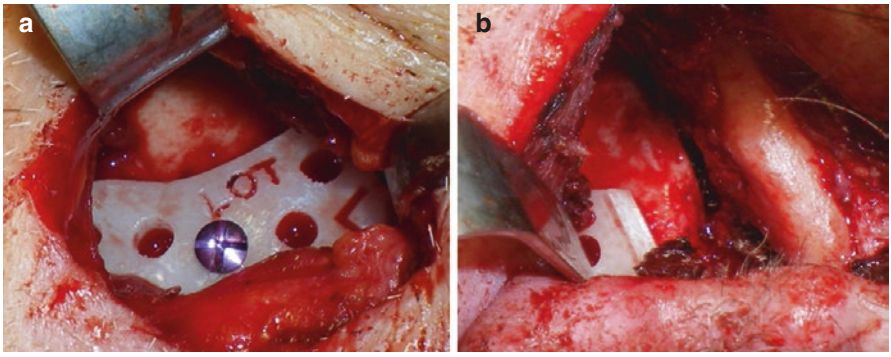

Fig. 7.20 Case 4. (**a**) Left surgical cutting guide stabilized onto the left mandibular ramus with a bone screw, viewed through the submandibular incision. (**b**) Superior extent of the surgical cutting guide marks precisely the osteotomy line of the bone at the superior aspect of the ramus that requires resection to accommodate the total joint prosthesis, as viewed through the preauricular incision

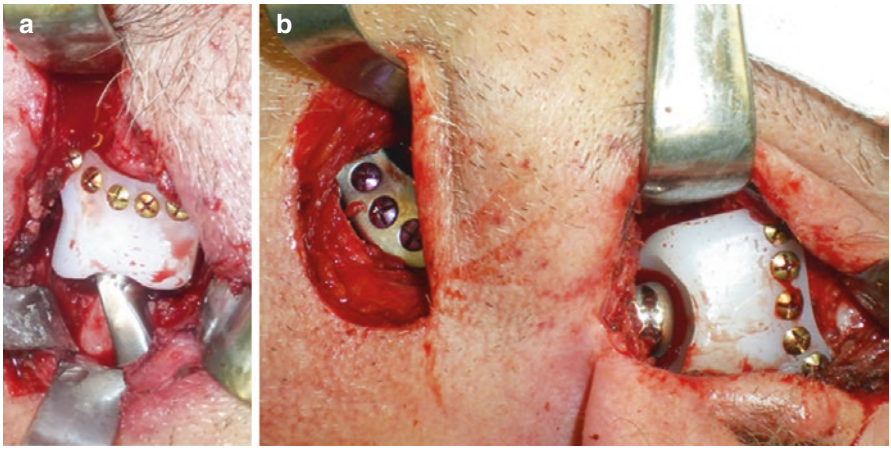

Fig. 7.21 Case 4. (**a**) Right TMJ Biomet total joint prosthesis stabilized in position, preauricular view. (**b**) Left TMJ Biomet total joint prosthesis observed through the submandibular incision and preauricular incision

7.3 TMJ Total Joint Replacement

There are basically two systems on the market for TMJ total joint prosthesis reconstruction: TMJ Concepts (Ventura, CA) and Biomet Microfixation (Jacksonville, FL). These two systems are approved by the Federal Drug Administration (FDA) in the USA and available internationally.

The TMJ Concepts total joint prostheses are patient-fitted devices, originally developed in 1989 by Techmedica (Camarillo, CA) and manufactured until July

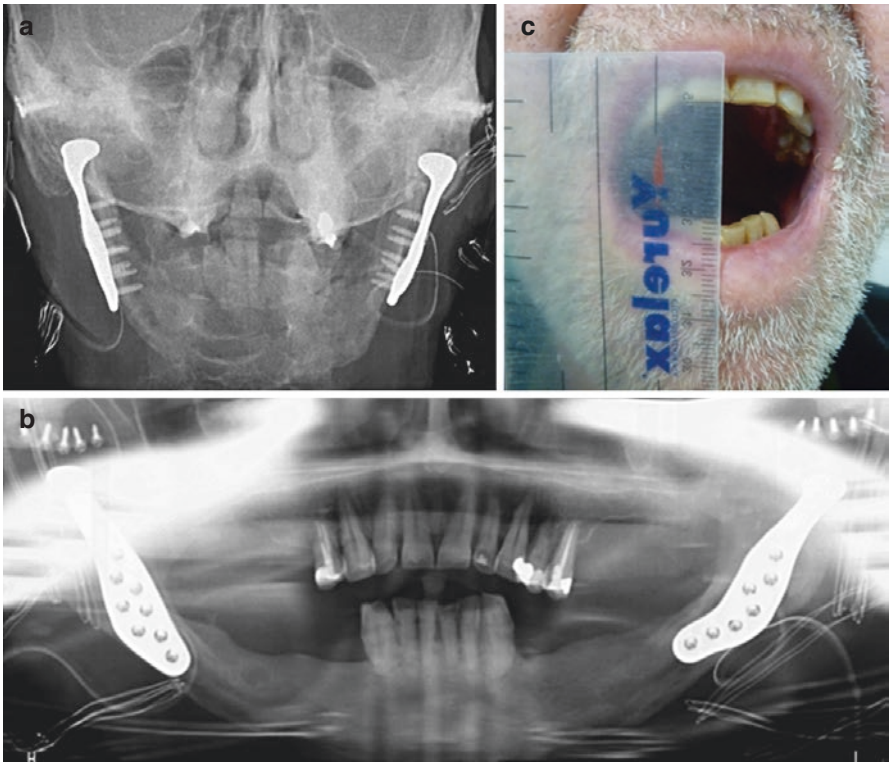

Fig. 7.22 Case 4. (**a**) Postoperative coronal radiograph shows the position of the bilateral Biomet total joint prostheses. The fossa component of polyethylene does not image on the X-ray. (**b**) Panogram shows the position of the bilateral Biomet TMJ prostheses. (**c**) Postsurgical maximal interincisal opening achieved was 32 mm

1993, when the US Food and Drug Administration (FDA) halted production of all TMJ devices. In 1996, the FDA permitted the new owners, TMJ Concepts (Ventura, CA), to manufacture the device under the 510 K provision and granted full approval of these Class III devices in 1999. The Techmedica and TMJ Concepts devices are computer-assisted designed (CAD) and computer-assisted manufactured (CAM) devices that fit the specific anatomic, functional, and esthetic requirements of each patient.

The TMJ Concepts custom-fitted total joint prostheses use design principles and materials that are proven highly successful and are the gold standard in orthopedic joint reconstruction for hip and knee replacements. The prosthesis consists of a fossa component with a commercially pure titanium framework covered with a mesh and an ultrahigh molecular weight polyethylene functional component fused to the mesh on the bottom side of the framework. The fossa component is attached to the lateral rim of the fossa with four 2-mm-diameter screws, usually 6 mm in length. The mandibular component is composed of a titanium alloy shaft with a

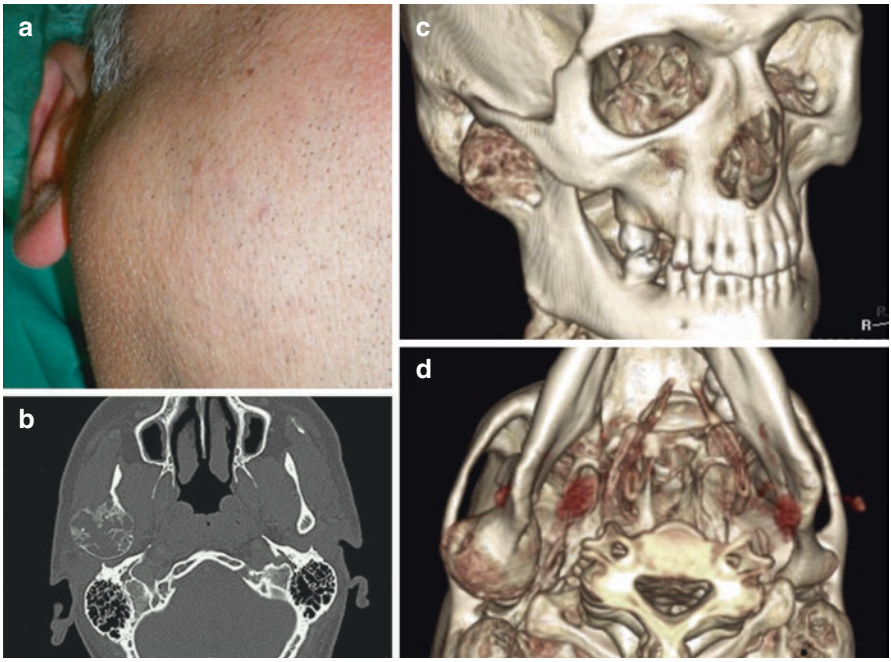

Fig. 7.23 Case 5. (**a**) A 42-year-old male presented with a right preauricular tumor, (**b–d**) CT scan imaging demonstrated an expansive osteolytic tumor located in the right mandibular condyle. Biopsy under local anesthesia demonstrated a fibrous benign tumor

cobalt-chromium alloy head with the prosthesis secured to the mandibular ramus with 8–9 2-mm-diameter bicortical screws, usually 8–12 mm in length (Fig. 7.4c, d). The fossa and mandibular components osseointegrate. Cases 1, 2, and 3 demonstrate the use of the TMJ Concepts prostheses.

The Biomet Microfixation TMJ Replacement System is a stock device (off the shelf) with fossa and mandibular components to choose from. Custom-fitted devices are available internationally, but not in the USA. Clinical trials for the stock device were initiated in 1995 and granted FDA approval in 2005. The ramus component is composed of a chromium-cobalt alloy. The ramus side has a titanium coating to help with osseointegration. The ramus component is available in three lengths: 45, 50, and 55 mm. There are three basic styles including standard, offset, and narrow. The fossa is composed of ultrahigh molecular weight polyethylene and does not osseointegrate with the fossa but is stabilized to the lateral rim of the fossa with bone screws. There are three fossa sizes to choose from including small, medium, and large. The prosthesis is metal-on-polyethylene articulation, which is the gold standard in orthopedics. The mandibular component is stabilized to the ramus with 2.7-mm-diameter screws, and the fossa component is secured to the lateral rim of the fossa with 2.0-mm-diameter screws (Fig. 7.11a). Cases 4 and 5 demonstrate the use of the Biomet prostheses.

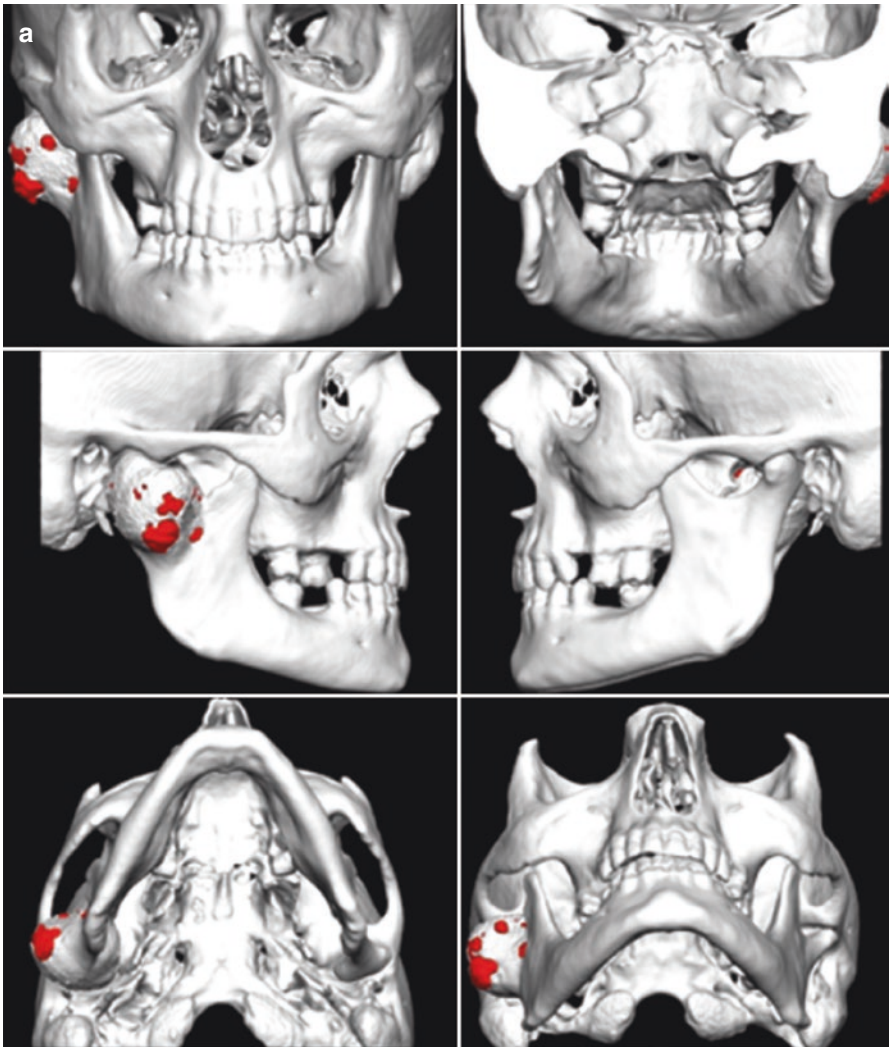

Fig. 7.24 Case 5. (**a**) 3D CT scan showing the location of the mandibular tumor, (**b**) 3D CT scan illustrating the planned level of condylectomy and tumor resection. The patient is planned for a single-stage, unilateral right TMJ reconstruction with a Biomet custom-fitted total joint prosthesis

Treatment planning for cases needing TMJ total joint replacement without the requirement for orthognathic surgery is based on radiographic and MRI imaging, cephalometric analysis, prediction tracing, clinical evaluation, and dental model assessment, which provide the templates for movements of the upper and lower jaws to establish optimal treatment outcome in relation to function, facial harmony, occlusion, and oropharyngeal airway dimensions. For patients who require total

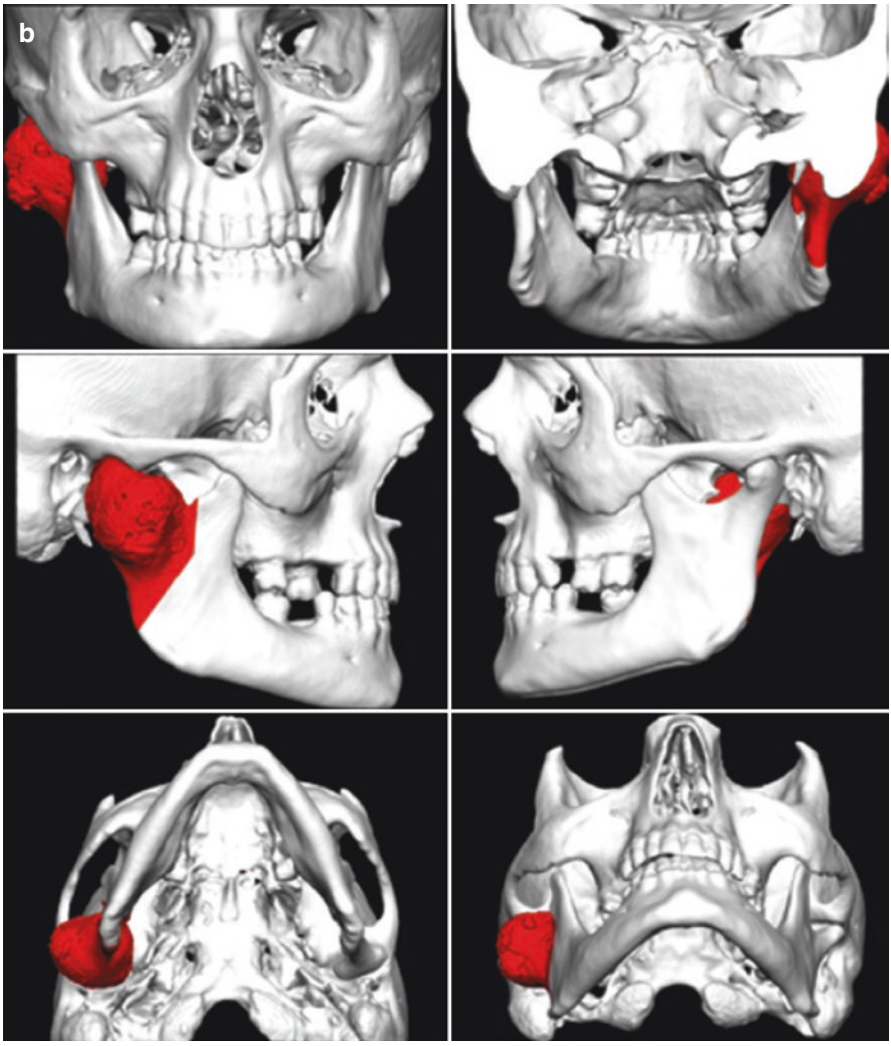

Fig. 7.24 (continued)

joint prostheses, a medical grade computerized tomography (CT) scan with 1 mm overlapping cuts is recommended of the maxillofacial region that includes the TMJs, maxilla, and mandible.

The surgeon has two options for model preparation to aid in the construction of patient-fitted total joint prostheses using the TMJ Concepts system. We have previously published the traditional protocol technique versus the CASS protocol [12, 13]. In this chapter, we will present only the CASS technique for patients requiring TMJ reconstruction without additional orthognathic procedures such as maxillary and mandibular osteotomies.

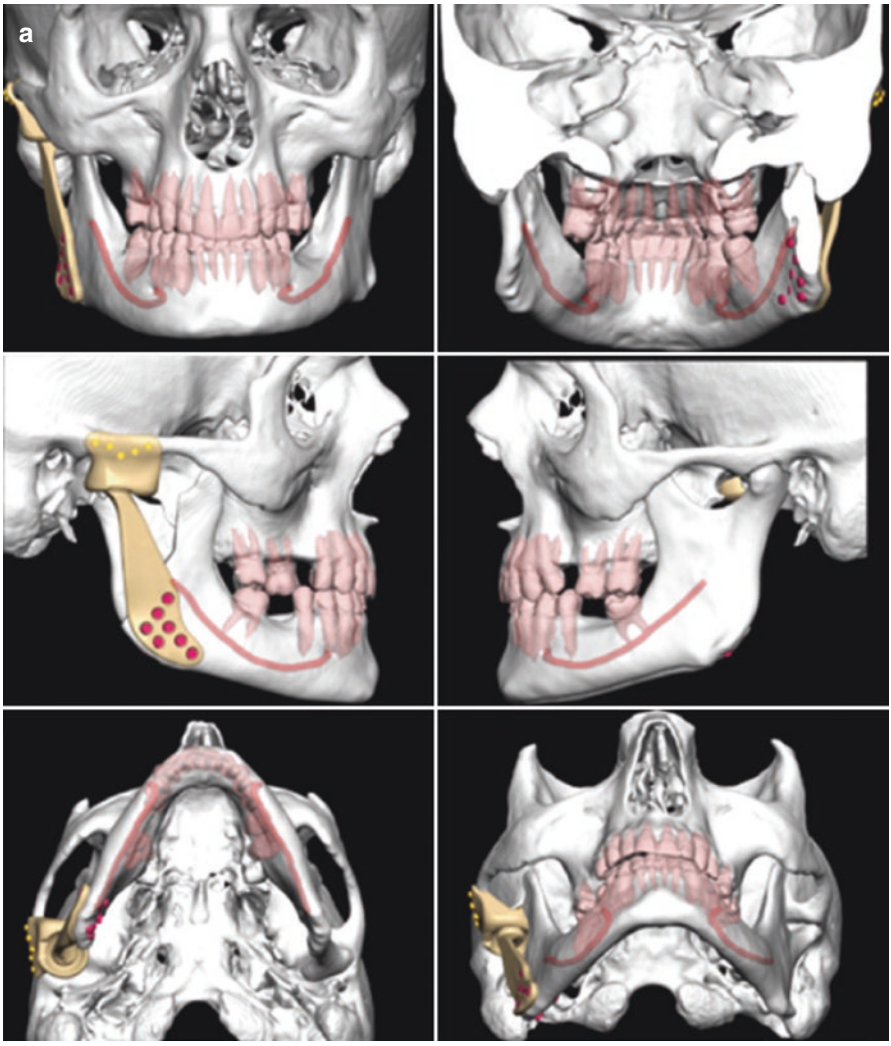

Fig. 7.25 Case 5. (**a**) Using CASS and VSP technology, the right mandibular condylar tumor was electronically removed, occlusion set, and the Biomet custom-fitted total joint prosthesis designed for a single-stage reconstruction procedure of the right TMJ. (**b**) Numerous views of the computer design of the right TMJ Biomet prosthesis are observed including screw positioning in relation to the inferior alveolar nerve and ramus

7.4 Protocol for TMJ Reconstruction

For TMJ reconstruction cases, the surgery is planned using CASS and VSP technology and moving the mandible into the final position (if malaligned with the maxilla) in a computer-simulated environment (Figs. 7.3 and 7.4).

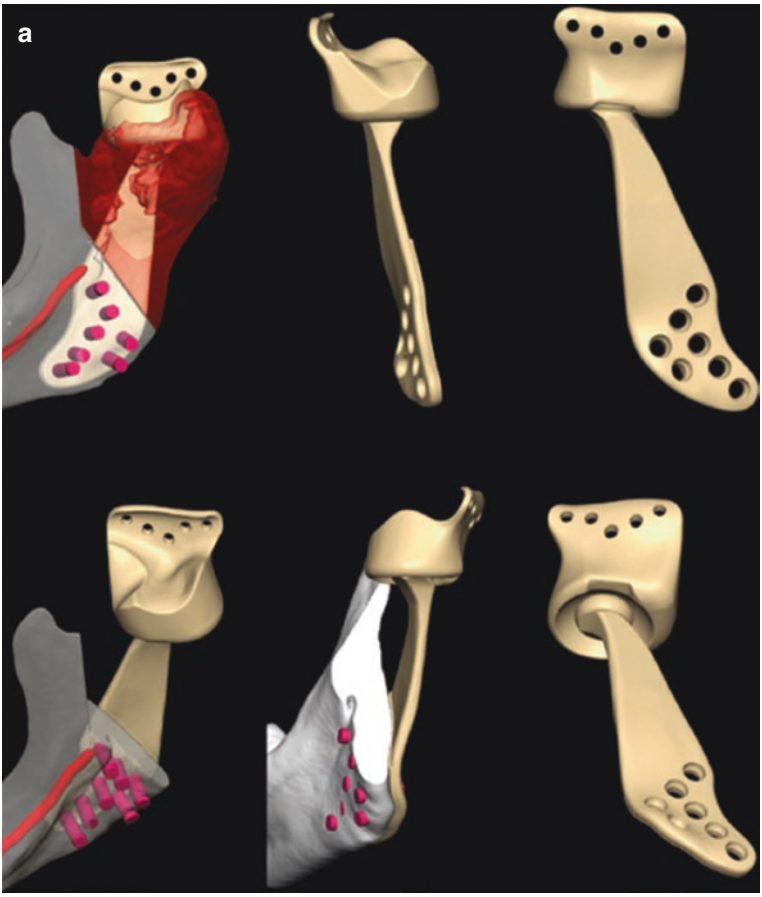

Fig. 7.25 (continued)

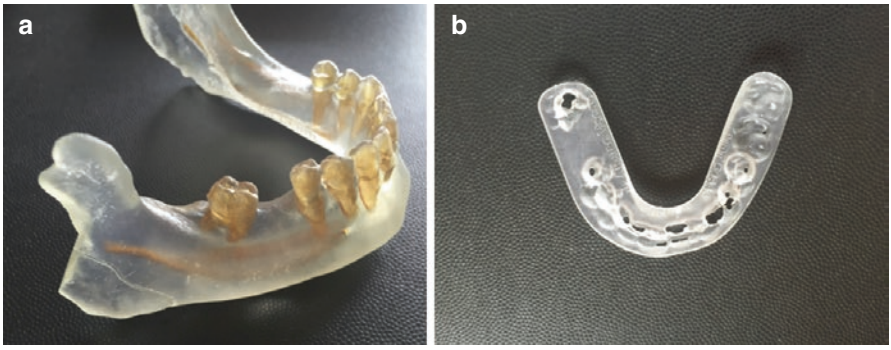

Fig. 7.26 Case 5. (**a**) 3D stereolithic model of the mandible produced after electronic resection of the tumor. (**b**) Computer-generated and computer-printed occlusal splint to aid in positioning of the mandible during insertion of the right Biomet total joint prosthesis

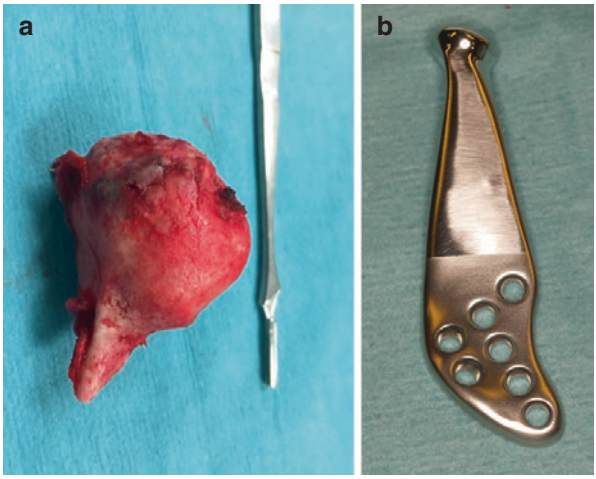

Fig. 7.27 Case 5. (**a**) Resected condylar tumor, (**b**) Mandibular component of the Biomet custom-made joint prosthesis

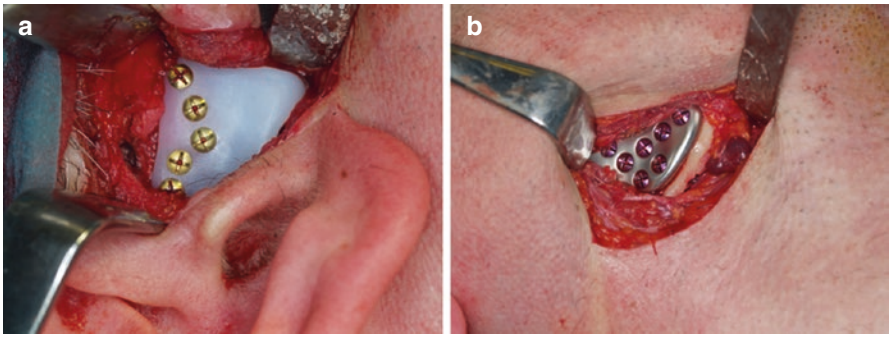

Fig. 7.28 Case 5. (**a**) Right TMJ Biomet fossa component in position, stabilized to the lateral rim of the fossa with five bone screws, viewed through the preauricular incision. (**b**) Mandibular component in position, stabilized to the ramus with seven bone screws, as viewed from the submandibular incision

Using Digital Imaging and Communications in Medicine (DICOM) data, the stereolithic model is produced with the mandible properly aligned with the maxilla in the final position and provided to the surgeon for removal of the condyle(s) and recontouring of the lateral rami and fossae if indicated. For simpler cases, the condylectomies can be done virtually as well as the recontouring of the lateral aspect of the ramus with VSP technology, thus eliminating the step of sending the model to the surgeon for these processes, although the procedures must be approved by the surgeon. The stereolithic model is sent to TMJ Concepts (Ventura, CA) for the design, blueprint, and wax-up of the custom-fitted prostheses. Using the Internet, the design is sent to the surgeon for approval. Then, the prostheses are manufactured (Fig. 7.4). It takes approximately 12 weeks to manufacture the total joint custom-fitted prostheses.

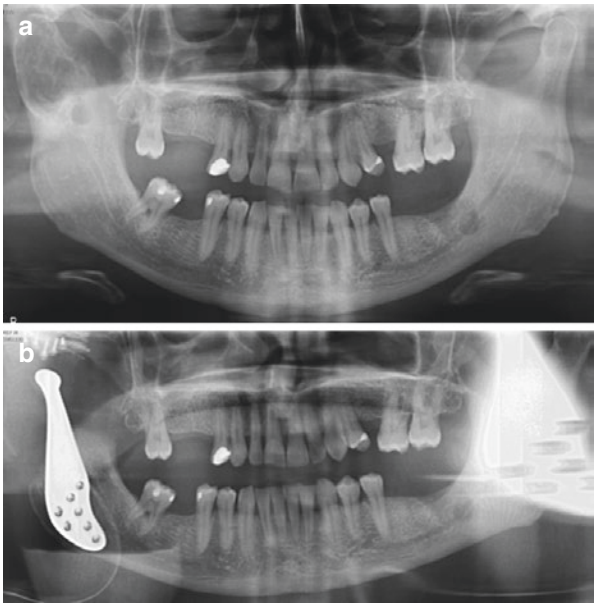

Fig. 7.29 Case 5. (**a**) Presurgery panogram shows the right condylar tumor. (**b**) Post-surgery panogram shows the right TMJ condylectomy, tumor resected, and reconstruction with a Biomet custom-fitted TMJ total joint prosthesis

Presurgical orthodontic preparation may or may not be required to obtain the best occlusal outcome and, of course, is case dependent. Usually, a surgical stabilizing splint is not required when the occlusion is good or only the mandible requires repositioning to create a stable occlusion. However, indications for a surgical splint include (1) unstable occlusion with the mandible in the final position; (2) missing posterior teeth; (3) lack of dental units to provide a stable occlusion; (4) significant periodontal issues with unstable dental units; (5) significant changes in the positions of the teeth from the presurgery orthodontics; (6) edentulous patients; and (7) surgeon's preference. If a splint is required, there are two approaches for providing accurate dental models: (1) provide standard dental models or (2) scan the dentition with an optical scanner and sending either printing models or the scan data to the VSP company. The first option requires that approximately 2 weeks before surgery, final dental models are produced. Equilibration of the teeth on the model is done if indicated. Usually only one set of models is required when the occlusion is good, or only the mandible needs to be repositioned. The second option involves optical scanning of the occlusion, with or without printing of dental models, or scanning of dental models from impressions. The models are either sent to the VSP company or digitally sent for incorporation into the computer model. If a surgical splint is required, the splint is then printed from the computer model. The dental models, splint, and images of the CASS workup are sent to the surgeon for implementation during surgery. For patients with severe decreased incisal opening, such as in TMJ

ankylosis cases, where dental models and optical scanning cannot be acquired, the surgical splints can be produced from the computer model, although there could be inaccuracies as compared to dental model acquisition.

The 3D stereolithic model may require preparation of the rami and fossae. In the fossa, heterotopic bone deposition or unusual anatomy may require recontouring so that the custom-fitted fossa component can be precisely adapted to the bony anatomy. The mandibular ramus may need recontouring as well (Fig. 7.9). It is advantageous to modify the ramus to make the contour fairly flat in the area where the prosthesis will be placed. This is to eliminate any depressions, humps, bumps, or curvatures (particularly at the inferior border of the angle). This provides some leeway if the mandible is not perfectly positioned at surgery compared to the stereolithic model. Otherwise, the prosthesis may not fit on the ramus properly with the condyle head seated properly in the fossa, or if the mandibular component is properly seated on the ramus, the head may not be seated in the fossa correctly. Flattening of the lateral aspect of the ramus eliminates potential prosthesis positioning issues.

To follow are the protocols for single-stage or two-stage surgical approaches to TMJ reconstruction with TMJ total joint prostheses. The decision between the protocols is dependent on the TMJ pathology, previous surgical procedures patient has endured, and the surgeon's skills, experience, and comfort zone.

Indications for two-stage surgery may include (1) significant heterotopic bone deposition in and around the TMJ/fossa area; (2) ankylosis; (3) major altered anatomy requiring significant bony modification, recontouring, or bone grafting; (4) removal of failed alloplastic total joint prosthesis; and (5) removal of failed autogenous graft such as a rib graft or sternoclavicular graft, where the surgeon would prefer to remove the graft and recontour the fossa and ramus prior to CT scan acquisition.

A major potential risk to patients receiving TMJ total joint prosthesis is infection. The occurrence rate is less than 2% with greater risk for patients on immunosuppressant medications such as rheumatoid patients or others with connective tissue/autoimmune diseases. Bacterial or viral contamination of the prosthesis can occur during surgery or develop at a later time from bacterial seeding through a hematological route or localized bacterial sources. As a result, strict adherence to sterile technique for the procedures performed can help prevent or reduce the chance of infection (Table 7.1).

7.5 Surgical Procedure

The surgical description to follow assumes that if a two-stage procedure was indicated, the first stage has been completed, prostheses manufactured, and the patient is ready to undergo Stage 2. If surgery is a single-stage, the following protocol applies. So, not to duplicate other figures in this book, the following protocol will refer to figures from with the appropriate references.

Table 7.1 Step-by-step surgical sequencing for TMJ reconstruction

1. Presurgical orthodontics completed with appliances remaining in place or application of arch bars or other method for skeletal and dental stabilization if orthodontic appliances not applied
2. Condylectomy (or removal of TMJ spacer if two-stage approach), joint debridement, and recontour fossa if indicated
3. Coronoidectomy if the mandible is significantly advanced or ramus lengthened vertically, to detach the temporalis muscle or if the coronoid process is hyperplastic creating interference with the zygoma. Otherwise, a coronoidectomy is not indicated
4. Detach the masseter muscle from the ramus. The media pterygoid muscle is detached only if the mandible is significantly advanced or ramus lengthened vertically
5. Recontour ramus if indicated from the stereolithic model preparation
6. Mobilize mandible if indicated (i.e., significant anterior open bite requiring counterclockwise rotation of the mandible)
7. Contralateral mandibular ramus sagittal split osteotomy if only a unilateral TJP and the mandible is malaligned
8. Maxillo-mandibular fixation and placement of the surgical splint, only if indicated. With a good dentition, a splint is usually not necessary
9. Contralateral mandibular ramus osteotomy, application of rigid fixation, and closure of the intraoral incision, if only a unilateral total joint prosthesis
10. Placement of total joint prosthesis(es)
11. Reattach masseter muscle(s) to angle of mandible and close submandibular incision(s)
12. TMJ fat graft (harvested from the abdomen, buttock, or elsewhere) and packed around the articulation area of the prosthesis(es). Closure of incisions
13. Remove maxillo-mandibular fixation. Completion of surgery

1. After surgical prepping including the face, neck, mouth, ears, ear canals, nose, endotracheal tube, and abdomen, the abdomen and the face and neck are draped, and the mouth and nose are isolated by application of a Tegaderm film dressing (Fig. 7.15a), and the ear canal is cleaned with chlorhexidine and gently packed with cotton soaked in betadine solution.
2. The TMJs are approached through an endaural (Fig. 7.16) or preauricular incision to perform the condylectomy, discectomy, joint debridement, and also a coronoidectomy when the mandible is significantly advanced or vertically lengthened (Fig. 7.17). The condylectomy and debridement of the joint is performed first. Placing medial retractors and packing Surgicel or similar material medial to the condylar neck will help protect the nerves and vessels medial to the surgical area, while the condylectomy cut is being completed. The fossa is debrided and recontoured if indicated by the preparation on the stereolithic model. There is a requirement of 20 mm space between the fossa and the top of the ramus when the mandible is in its new position to accommodate the prosthesis, or there could be interferences that won't allow the prosthesis components to be properly seated. Be sure an adequate amount of bone is removed for the superior aspect of the ramus to meet the space requirement. Using cutting guides can improve the accuracy for adequate bone removal.

   The coronoidectomy is usually not required with only TMJ reconstruction unless a significant counterclockwise rotation of the mandible is required or the coronoid process is hyperplastic and interfering with mandibular function. If

indicated, then the coronoidectomy is preformed through the endaural incision using a reciprocating saw or piezo cutting device, with the cut extending from the anterior aspect of the coronoid into the sigmoid notch (Fig. 7.17). Using a medial retractor or packing Surgicel or Gelfoam medial to the coronoid will protect the vessels and other soft tissue structures, while the cut is made. Risks associated with this part of the surgery include facial nerve injury and bleeding as the facial nerve branches and maxillary artery and branches are in close proximity. Facial nerve involvement can be minimized by understanding the anatomy, employing small incisions, using a nerve stimulator when appropriate, careful surgery, and avoiding heavy-handed inferior retraction toward the earlobe as this can cause damage to the main branch of the facial nerve. Avoid bleeding by using retractors that surround the medial side of the condyle and neck for the condylectomy. When using a reciprocating saw for the condylectomy and coronoidectomy, packing Surgicel or Gelfoam around the medial side of the condylar neck and medial to the ramus, sigmoid notch area, and coronoid will help prevent encountering the major vessels in the area by displacing the vessels more medially and placing a physical barrier between the bone cuts and the vessels. Using piezo technology can also be of benefit.

3. A submandibular incision (Fig. 7.16) is used to access the ramus. A nerve stimulator is used to identify the branches of the facial nerve as the various tissue layers are incised. After cutting through the platysma muscle, blunt dissection to the pterygoid-masseteric sling will reduce the risk of nerve and vascular injury. Cutting through the sling to the inferior aspect of the angle gives access to the ramus for detachment of the masseter muscle. The medial pterygoid muscle is detached only if the mandible is to be vertically lengthened or advanced significantly as in closing an anterior open bite with a counterclockwise rotation of the mandible. The lateral aspect of the ramus is recontoured using a reciprocating bone file to duplicate the alterations made on the stereolithic model to provide a relatively flat contour of the ramus where the mandibular component will be positioned. The mandible is mobilized in a downward and forward direction only if indicated to significantly advance or vertically lengthen the ramus and achieve a passive ideal occlusal relationship. Potential risk factors during this aspect of the surgery include facial nerve damage and bleeding. The use of a nerve stimulator during dissection to the angle area will help identify the nerve branches and help in injury avoidance.
4. The oral cavity is isolated by draping with sterile towels, exposing from commissure to commissure (Fig. 7.15b). The Tegaderm is cut through and the oral cavity is entered. If the case includes bilateral total joint prostheses, the surgical splint is inserted (only if required, as in an unstable bite or multiply missing teeth) and maxillo-mandibular fixation applied. This requires the presence of orthodontic appliances placed prior to surgery or the application of arch bars to the maxillary and mandibular teeth (or other methods of applying stabilizing devices to control the occlusion) that can be placed at the beginning of surgery prior to patient surgical preparation. If the case is a unilateral total joint

prosthesis, then go to Step 5. If the case is bilateral total joint prostheses, then go to Step 6.

5. For unilateral total joint prosthesis, when the mandible requires repositioning to obtain a good occlusion, using separate instrumentation, a contralateral mandibular ramus sagittal split osteotomy may be indicated to achieve a good stable occlusion, and the mandible is mobilized on that side. The surgical splint, if required, and maxillo-mandibular fixation are applied. Rigid fixation is placed to secure the mandibular segments and incision closed.
6. The temporary drapes are removed, surgeon changes gloves and gown, the face is re-prepped and redraped, and the mouth and nose are sealed off once again with a Tegaderm film dressing.
7. The total joint prosthesis fossa component is inserted, properly positioned, and fixated usually with four 6-mm-length, 2-mm-diameter bone screws. The mandibular component is inserted through the submandibular incision placing the head into the fossa and against the posterior stop and aligning to the ramus as dictated by the surgical plan. Bone screws (2 mm diameter and usually 8–12 mm in length) are inserted in all of the available holes (usually eight) to stabilize the component to the mandible. Usually it is difficult to reach the top holes in the mandibular component through the submandibular incision. So, a stab incision can be made about 1 cm below the earlobe and a trocar (KLS Martin) inserted to place screws in the holes at the top of the prosthesis that are difficult to access from the submandibular incision (Fig. 7.19).
8. The submandibular surgical areas are thoroughly irrigated with saline and a final rinse using betadine solution. The masseter muscle is reattached to the mandible by placing 3–4 bicortical holes through the inferior border of the mandibular angle area where the muscle was originally attached. 2-0 PDS suture is used to tie the masseter muscle to the bone using the transosseous holes (Fig. 7.20). The submandibular incisions are closed in layers.
9. Fat grafts are harvested from the abdomen through incisions in the suprapubic region (see Fig. 7.21), previous scar line, umbilical area (Fig. 7.22), or buttock with establishment of good hemostasis and closure of the incisions. A small drain and vacuum bulb can be inserted in the donor area if good hemostasis cannot be achieved. An abdominal dressing and abdominal binder are applied at completion of surgery to help prevent hematoma and seroma formation.
10. The articulating area of the prosthesis is thoroughly irrigated with saline through the endaural or preauricular incisions with a final rinse using betadine solution. The fat grafts are packed around the articulating area of the prostheses (Fig. 7.23) and the incisions closed in layers.
11. The oral cavity is then entered, maxillo-mandibular fixation released, and intermediate splint removed unless required for occlusal stability. Surgery is completed.

Since the muscles of mastication including the medial pterygoid and temporalis muscles are not usually detached, vertical support to the mandible and occlusion is usually good. Using elastics post-surgery would only be indicated for

occlusion control, patient comfort, or to help control an unstable joint secondary to inadequate placement of the prostheses. If orthodontic appliances are present, postsurgical orthodontics are continued with usual orthodontic mechanics to finalize the occlusion and retain. Postsurgically, light force vertical elastics (recommend 3½ oz., 3/16-in. diameter) can be used to support the mandible for patient comfort and to finalize the occlusion. Postsurgical patient management is the same as routine orthodontics [16, 17].

7.5.1 Fat Grafts

Early on in the use of total joint prostheses, a common problem encountered in approximately 35% of the patients was postsurgical fibrosis and heterotopic bone formation around the prostheses causing jaw dysfunction, decreased incisal opening, and pain [18, 19]. In 1992, Wolford developed a technique to place fat grafts (harvested from the abdomen or buttock) around the articulating area of the total joint prosthesis to eliminate the dead space. This prevents blood clot formation in the space around the prosthesis that could provide a matrix for fibrous ingrowth and pluripotential cells migrating into the area that could develop heterotopic bone and dense fibrotic tissues. Also, in patients with previous failed alloplastic implants, the fat graft blocks out a large area in which the foreign-body giant cell reaction and reactive bone may otherwise redevelop [18, 19].

7.6 Case Presentations: Figs. 7.14, 7.15, 7.16, and 7.17

Case 1: Bilateral Mandibular Subcondylar Fractures
This 56-year-old female fell, sustaining bilateral mandibular subcondylar fractures (Figs. 7.1a, b, 7.2a–c, and 7.3a–d). The injury created significant displacement of the fractured condyles that were treated initially elsewhere with closed reduction, but without reduction of the displaced segments, resulting in a large anterior open bite (Fig. 7.2a–c). She was subsequently referred for management of her TMJ and jaw deformity at 3 months post injury. At the initial consult, she reported that since her accident, she had developed headaches, myofascial pain, occluded only on the left second molars, snoring, and sleep apnea. Her incisal opening was 40 mm and excursions 2 mm to the right and 4 mm to the left. Her diagnosis included (1) bilateral mandibular subcondylar fractures; (2) mandibular A-P and posterior vertical hypoplasia; (3) anterior open bite of 4 mm; (4) occluding only on the left second molars; and (5) decreased oropharyngeal airway with sleep apnea symptoms. Radiographic evaluation confirmed the significantly displaced subcondylar fractures (Fig. 7.3a–d). A CT scan was obtained and CASS technology used to assess the injury and reposition the mandible into centric occlusion and the 3D stereolithic model produced with the mandible in the corrected position. The surgeon then prepared the model and sent it to TMJ Concepts for manufacturing of the bilateral TMJ custom-fitted total joint prostheses (Fig. 7.4a, b).

Her surgery included (1) bilateral TMJ reconstruction with counterclockwise rotation of the mandible, using TMJ Concepts custom-fitted total joint prostheses (Fig. 7.4c, d); (2) bilateral TMJ fat grafts packed around the articulating area of the prostheses, harvested from the abdomen; (3) application of maxillary and mandibular arch bars; and (4) removal of arch bars at completion of surgery.

The patient was reevaluated at 1-year post-surgery. She was pain free, incisal opening at 47 mm, excursive movements 3 mm to the right and left, stable Class I occlusion, improved facial balance, and elimination of sleep apnea symptoms (Figs. 7.1c, d and 7.2d–f).

Case 2: Failed Bilateral Metal-on-Metal Total Joint Prostheses

This case demonstrates the protocol for patients that have failed metal-on-metal (Christensen System) total joint prostheses or prostheses with a fossa component that contains a metal base with polyethylene attached (TMJ Concepts). The records used here are of a 55-year-old female that presented 18 years post-bilateral TMJ reconstruction with Christensen total joint prostheses with metal-on-metal articulation. She did fairly well for the first 8 years but, during the past 10 years, has suffered from severe pain issues, periodic bleeding from the right ear, and limited jaw function. She developed debilitating headaches, TMJ pain, myofascial pain, and limited jaw function and was on total disability. Her occlusion and facial balance remained stable. Incisal opening was 15 and 0 mm excursions. Radiographic evaluation shows the presence of bilateral Christensen total joint prostheses with the right fossa component fractured and heterotopic bone surrounding the medial, posterior, and lateral aspect of the functional area (Fig. 7.5a, b). The diagnosis for this patient included (1) failed bilateral TMJ Christensen total joint prostheses including metallosis, fractured right fossa component, and right-sided heterotopic bone; (2) severe headaches, TMJ pain, and myofascial pain; and (3) severe limited jaw function.

Because of the presence of the metal-on-metal prosthesis, the patient required two-stage surgery. Although the CASS system can adequately remove the metal from the ramus, it cannot accurately remove the metal from the fossa, so the bony anatomy of the fossa cannot be accurately duplicated. Thus, these cases with metal fossae require a two-stage surgical approach to remove the prosthesis so an accurate CT scan can be acquired to reproduce the bony anatomy accurately, followed by the second surgery stage to reconstruct the TMJ. For this case, the two-stage surgical protocol (Table 7.2) was used. In the first stage, the failed bilateral TMJ Christensen prostheses were removed (Fig. 7.6), bilateral TMJ debridement and placement of bone cement spacers (Fig. 7.7). A CT scan was taken and submitted for CASS, where VSP placed the mandible into the best occlusal fit with the stable maxilla (Fig. 7.8). A stereolithic 3D model was constructed with the maxilla and mandible in the final postsurgical position (Fig. 7.9a–d). The final preparation of the model was completed with recontouring of the fossa and ramus as required, in preparation for the manufacturing of the total joint prostheses (Fig. 7.9a–d). The superior aspect of the ramus was removed to create 20 mm of vertical space between the fossa and ramus to accommodate the TMJ Concepts custom-fitted total joint prostheses. The devices are then designed and manufactured on this model (Fig. 7.9e, f). Surgery

Table 7.2 Two-stage: protocol for TMJ reconstruction using CASS

Surgery Stage 1
1. Remove heterotopic bone, failed autogenous grafts, failed alloplastic devices, and bone plates/screws in the mandible that may interfere with placement of the total joint prosthesis
2. Condylectomy if condyle still present
3. Extensive TMJ debridement
4. Placement of bone cement, acrylic, Silastic, or silicone spacer in the TMJ bony defect area to maintain joint space and mandibular position
Preparation of prosthesis
1. CT scan of the entire mandible, maxilla, and TMJs (1 mm overlapping cuts)
2. Processing of DICOM data to create a computer model in CASS environment
3. Correction of the malpositioned mandible, if present, with final positioning of the mandible to the stable maxilla, with CASS and VSP. Virtual condylectomy and model preparation can be performed in less complex cases with the 3D stereolithic model sent directly to TMJ Concepts, bypassing Step 4
4. Stereolithic model constructed with jaws in final position and sent to surgeon for condylectomy and rami and fossae recontouring if indicated
5. Model sent to TMJ Concepts for prostheses design, blueprint, and wax-up
6. Surgeon evaluation and approval of design and wax-up via the Internet
7. TMJ prostheses manufactured and sent to hospital for surgical implantation
8. Two weeks before surgery, acquisition of final dental models if a surgical stabilizing splint is required, equilibration of the models if indicated, or optical scanning of the occlusion and models sent or data forwarded to the VSP company. If the occlusion is unaltered or the repositioned mandible produces a good occlusion, then a surgical splint and this step are not required
9. Models incorporated into computer-simulated surgery for construction of the surgical splint if required
10. Models, splints, and printouts of computer-simulated surgery sent to surgeon
Surgery Stage 2
1. TMJ reconstruction with TMJ custom-fitted total joint prosthesis(es)
2. TMJ fat grafts, harvested from the abdomen or other donor site

Stage 2 included (1) application of maxillary and mandibular arch bars; (2) removal of TMJ spacers; (3) application of maxillo-mandibular fixation; (4) bilateral TMJ reconstruction with TMJ Concepts custom-fitted total joint prostheses; (5) bilateral TMJ fat grafts packed around the articulating area of the prostheses, harvested from the abdomen; and (6) removal of maxillo-mandibular fixation and arch bars for completion of the surgery.

Case 3

This case is to demonstrate the protocol for patients that have failed prosthesis with polyethylene fossa and metal condylar component (Biomet system) total joint prostheses. The records used here are of a 46-year-old female that was referred for consultation 3 years post placement of a right Biomet total joint prostheses with metal-on-polyethylene articulation with the surgery performed at a different institution. She had severe pain since waking up from surgery. At 3 years post-surgery, she had debilitating right-sided headaches, TMJ pain, myofascial pain, and limited jaw function (22 mm incisal opening) and was on total disability and on heavy doses of narcotics. Her occlusion and facial balance remained relatively stable. Radiographic

evaluation showed the presence of displaced right mandibular condylar head of the mandibular component total joint prosthesis relative to the fossa component (Figs. 7.10 and 7.11) The diagnosis for this patient included (1) displaced right mandibular component of the Biomet prosthesis; (2) severe headaches, TMJ pain, and myofascial pain; and (3) limited jaw function.

CASS technology was used in preparation of this case. Because of the presence of a polyethylene fossa, these patients can be treated with one-stage surgery protocol (Table 7.3). A CT scan was taken and submitted for CASS. The metal mandibular component and the polyethylene fossa component were electronically removed from the computer model, and VSP placed the mandible into the best occlusal fit with the maxilla (Fig. 7.12). A stereolithic 3D model was constructed, and the final preparation of the model completed by the surgeon with additional recontouring of the ramus and fossa was required, in preparation for the manufacturing of the TMJ Concepts total joint prosthesis (Fig. 7.13a). The prosthesis was then designed and manufactured on this model (Fig. 7.13b). The surgery included (1) orthodontic appliances were already present on the teeth; (2) removal of failed prosthesis; (3) TMJ reconstruction with TMJ Concepts custom-fitted total joint prosthesis; and (4) TMJ fat graft packed around the articulating area of the prosthesis, harvested from the abdomen.

Case 4

This 53-year-old male was diagnosed with (1) SAPHO syndrome (synovitis, acne, pustulosis, hyperostosis, and osteitis) [20], (2) bilateral TMJ arthritis, (3) right TMJ ankylosis, and (4) maximal incisal opening of 5 mm (Fig. 7.14a, b). A-P tomograms and panogram demonstrate the bony morphological changes resultant from the

Table 7.3 Single-stage: protocol for TMJ reconstruction using CASS

1. CT scan of the entire mandible, maxilla, and TMJs (1 mm overlapping cuts)
2. Processing of DICOM data to create a computer model in CASS environment
3. Correction of the malpositioned mandible, if present, with final positioning of the mandible to the stable maxilla, with CASS and VSP. Virtual condylectomy and model preparation can be performed in less complex cases with the 3D stereolithic model sent directly to TMJ Concepts, bypassing Step 4
4. Stereolithic model constructed with jaws in final position and sent to surgeon for condylectomy and rami and fossae recontouring if indicated
5. Model sent to TMJ Concepts for prostheses design, blueprint, and wax-up
6. Surgeon evaluation and approval of design and wax-up via the Internet
7. TMJ prostheses manufactured and sent to hospital for surgical implantation
8. Two weeks before surgery, acquisition of final dental models if a surgical stabilizing splint is required, equilibration of the models if indicated, or optical scanning of the occlusion and models sent or data forwarded to the VSP company. If the occlusion is unaltered or the repositioned mandible produces a good occlusion, then a surgical splint and this step are not required
9. Models incorporated into computer-simulated surgery for construction of the surgical splint if required
10. Models, splints, and printouts of computer-simulated surgery sent to surgeon. With CASS technology, the company performing the CASS planning manufactures the splints
11. Surgery for TMJ reconstruction

SAPHO syndrome (Fig. 7.14c, d). CT images demonstrated bilateral osseous ankylosis with mandibular bony sclerosis. The patient was treated with two surgical stages that consisted of Surgery Stage 1, resection of bilateral TMJ bony ankylosis, bilateral condylectomies, coronoidectomies (Fig. 7.15a–c), and silicone ball insertion into the bony defect (Fig. 7.15d). The silicone ball spacers were inserted into the osseous gap to maintain the space, stabilize the mandibular position, and decrease the risk of reankylosis during the intermediate stage in preparation for the second stage of surgery.

CT scan of the patient was acquisitioned following the first surgical stage (Fig. 7.16a). CASS and VSP technology were used to place the mandible into the final surgical position (orange mandible), with the best occlusal fit, and are superimposed on the post-surgery CT scan, demonstrating the positional changes (Fig. 7.16b). From this position, it is determined if additional bone resection and preparation of the fossa and ramus are required to accommodate the total joint prostheses.

The CASS- and VSP-corrected CT images show the osseous defects after bilateral condylectomy and coronoidectomy with the silicone balls in place (Fig. 7.17a). The cutting guides (colored green) are manufactured to accurately identify additional bone required for removal from the ramus to accommodate the prostheses (Fig. 7.17b). The Biomet bilateral prostheses were computer designed as custom-fitted total joint prostheses to accommodate to the patients' specific anatomical requirements (Figs. 7.18 and 7.19). At surgery, the left cutting guide is inserted and secured to the ramus with a bone screw as seen through the submandibular incision (Fig. 7.20a). The top of the cutting guide is seen through the preauricular incision, demonstrating the amount of bone required to be removed to accommodate the TMJ prosthesis (Fig. 7.20b). The prostheses are inserted and stabilized with bone screws. The placement of the right prosthesis is seen through the preauricular incision (Fig. 7.21a), and the left side prosthesis is seen through the submandibular and preauricular incisions (Fig. 7.21b). Postoperative coronal radiograph shows the position of the bilateral Biomet total joint prostheses. The fossa component of polyethylene does not image on the X-ray (Fig. 7.22a). Panogram shows the position of the bilateral Biomet TMJ prostheses (Fig. 7.22b). Postsurgical maximal interincisal opening achieved was 32 mm (Fig. 7.22c).

Case 5

This 42-year-old male was diagnosed with a right preauricular tumor (Fig. 7.23a). CT scan images including 3D imaging demonstrate an expansive osteolytic tumor located in the right mandibular condyle (Fig. 7.23b–d). Biopsy under local anesthesia demonstrated a fibrous benign tumor. Surgery was planned as a single-stage procedure for resection of the tumor and immediate reconstruction of the right TMJ with a Biomet custom-fitted total joint prosthesis using CASS with VSP. The right mandibular condylar tumor is seen, and the level of mandibular osteotomy to remove the tumor is designated in preparation for electronic removal (Fig. 7.24a, b). The tumor is electronically removed, occlusion set, and the Biomet custom-fit total joint prosthesis designed for a single-stage reconstruction procedure of the right

TMJ (Fig. 7.25a, b). The Biomet prosthesis was custom-designed on the computer to fit this patient's specific anatomical requirements. The shape of the mandible and location of the inferior alveolar nerve were identified and figured into the equation for mandibular component design (Fig. 7.25b). A 3D mandibular stereolithic model was produced demonstrating the tumor resection to aid in surgery (Fig. 7.26a). A computer-generated and computer-printed occlusal splint was produced to aid in positioning of the mandible during insertion of the right Biomet total joint prosthesis (Fig. 7.26b). At surgery, the tumor was resected and removed (Fig. 7.27). The right TMJ Biomet fossa component was positioned and stabilized to the lateral rim of the fossa with five bone screws, as viewed through the preauricular incision. The mandibular component was positioned and stabilized to the ramus with seven bone screws, as viewed from the submandibular incision (Fig. 7.28). Pre- and post-surgery panograms demonstrate the original tumor and subsequent removal and right TMJ reconstruction with the Biomet custom-fitted total joint prosthesis (Fig. 7.29).

7.7 TMJ Ankylosis

TMJ heterotopic bone refers to calcifications that develop in and around areas of the joint that are normally void of bone. The development of heterotopic bone within the confines of a joint or in the surrounding area can cause joint dysfunction, pain, as well as progression to ankylosis. TMJ ankylosis is a condition where the condyle is fused to the fossa by bony or fibrotic tissues creating a debilitating condition that can interfere with jaw function, mastication, speech, oral hygiene, growth and development, breathing, and normal life activities and cause pain. There are numerous surgical techniques that have been proposed to manage heterotopic bone and TMJ ankylosis with varying outcomes reported. The most common post-surgery complications are limited jaw function, pain, and reankylosis.

TMJ ankylosis treatment requires resection of the ankylotic bone creating a gap arthroplasty. In many cases resecting bone formation at the skull base is difficult [12, 13, 21–23]. There is a high risk of damaging the internal maxillary artery and nerve injuries or even duramater exposure with secondary cerebrospinal fluid leak. Surgical cutting guides and image-guided navigation are useful tools in these surgical procedures. Reconstruction of the mandibular condyle can be performed with autologous grafts or alloplastic materials, but total joint prostheses have a significantly higher success rate than autogenous tissues [24, 25]. In most adolescent and adult cases, a TMJ total joint prosthesis along with fat grafts packed around the articular area of the prostheses to maximize success and eliminate the risk of reankylosis is the treatment of choice [18, 19, 24–27]. Surgery can be performed in one or two surgical stages. Custom-made prostheses or stock prostheses can be used to reconstruct the resected mandible and the skull base. In one-stage procedures, the use of custom-made prostheses works well in the hands of the experienced surgeon but, for less experienced surgeons, could be more difficult because the resection must be exactly the same as performed presurgery on the 3D stereolithic model.

In some cases, a stock prosthesis can be adapted to the new anatomic configuration with less accuracy requirements. In the case of two-stage surgical approach, both custom-made and stock prosthesis can be used, but for most cases a custom-made prosthesis is recommended to provide the optimal outcome. In the first surgical stage, only resection of the ankylosed bone is performed, creating a gap between the skull base and the mandibular ascending ramus. To maintain this gap and avoid reankylosis, an acrylic, silicone ball, or orthopedic bone cement spacer can be placed into the gap so as to help maintain the mandibular position and eliminate dead space until the second stage of surgery can be performed. A CBCT or CT is obtained after the first surgical stage to facilitate the manufacture of a custom-made prosthesis. Once the prosthesis is manufactured, the second-stage surgery to place the prosthesis and concomitantly reposition the mandible, if indicated, can be completed along with the fat grafts packed around the articulating area of the prostheses as shown in (Fig. 7.23). The protocol of using custom-fitted total joint prostheses in conjunction with packing fat grafts around the functional aspect of the prostheses in a single-stage or two-stage procedure provides the best prognosis in the management of TMJ ankylosis [24–27].

7.8 TMJ Tumors

Tumors of the mandibular condyle are uncommon. Osteochondroma is one of the most common benign tumors of the general skeleton and also the most common tumor to develop in the mandibular condyle [14, 28, 29]. This condylar pathology can develop at any age (although more commonly during the teenage years), with a unilateral vertical overgrowth deformity of the jaws, although a horizontal growth vector can occasionally occur. The growth process can continue indefinitely with progressive worsening of the facial asymmetry. There are two subcategories dependent on the morphology of the tumor. According to Wolford's classification [28, 29], CH Type 2A indicates a predominant vertical direction of condylar tumor development with relatively normal condylar morphology, although enlarged. CH Type 2B indicates a significant horizontal exophytic tumor mass growing from the condyle in addition to the vertical growth component. CH Type 3 are benign tumors other than osteochondroma (Case 5, Figs. 7.23, 7.24, 7.25, 7.26, 7.27, 7.28, and 7.29), and CH Type 4 are malignant tumors.

Although many surgeons prefer to treat only the TMJ pathology and ignore the associated dentofacial deformity, the definitive surgical protocol recommended to treat this pathology and associated dentofacial deformity has been previously published [28, 29] and includes (1) low condylectomy removing the ipsilateral condyle at the condylar base, preserving the condylar neck; (2) reshaping the condylar neck to function as the new condyle; (3) repositioning the articular disc over the top of the condylar neck and stabilize with a Mitek anchor; (4) repositioning the articular disc on the contralateral side with a Mitek anchor, when displaced; (5) double-jaw orthognathic surgery to correct the associated maxillary and mandibular deformities using VSP; and (6) inferior border ostectomy on the ipsilateral side to reestablish

vertical height balance of the mandibular ramus, body, and symphysis if indicated. For the purpose of this chapter, Case 4 represents the treatment of this pathology with removal of a right TMJ tumor and immediate reconstruction with a Biomet total joint prosthesis without orthognathic surgery.

An alternative approach that some surgeons prefer for these types of cases is to treat in two stages where the low condylectomy and disc repositioning are performed at the first stage and the orthognathic surgery is completed at the second stage. In these cases, VSP and guiding surgical templates facilitate the diagnosis of the facial deformity, treatment planning, accurate osteotomies, and contouring of the mandibular border, when indicated [6, 8, 21–23, 28, 29].

7.9 TMJ Arthroscopy

Computer-assisted arthroscopy [6] may help guiding the position of the arthroscope and the instruments used in difficult clinical cases (obese patients, ankylosis, or patients previously treated with severe fibrosis of the TMJ). The main drawback of this technique is that only bony structures can be used as reference points. Also, some authors have described the use of navigation to enhance different TMJ arthroscopic procedures, eliminating the possibility of error in access [23].

7.10 Treatment Outcomes with TMJ Reconstruction

Most of the studies on treatment outcomes for TMJ total joint prostheses also include concomitant orthognathic surgery procedures. Dela Coleta et al. [30] evaluated 47 female patients for surgical stability following bilateral TMJ reconstruction using TMJ Concepts patient-fitted TMJ total joint prostheses, TMJ fat grafts, and counterclockwise rotation of the maxillo-mandibular complex with Menton advancing an average of 18.4 mm and the occlusal plane decreasing an average of 14.9°. Average follow-up was 40.6 months. Results demonstrated minor maxillary horizontal changes, while the mandibular measurements remained very stable.

Pinto et al. [31] evaluated the same 47 female patients relative to pain and dysfunctional outcomes. Patients were divided into two groups based on the number of previous surgeries: Group 1 had 0–1 previous surgeries, while Group 2 had two or more previous surgeries. Significant improvements (37–52%) were observed for TMJ pain, headaches, jaw function, diet, and disability. MIO increased 14%. Group 1 patients had better pain and jaw function results than Group 2 patients. For patients who did not receive fat grafts around the prostheses and had previous failure of PT-SR TMJ implants, more than half required secondary surgery including TMJ debridement for removal of FBGCR, fibrosis, and/or heterotopic bone formation. Following the secondary surgery consisting of joint debridement and placement of fat grafts, the patients had significant improvement, with no recurrence of the heterotopic bone. These two studies demonstrated that end-stage TMJ patients could be treated in one operation with TMJ Concepts patient-fitted TMJ total joint

prostheses, fat grafts, and maxillo-mandibular counterclockwise rotation, for correction of an associated dentofacial deformity with good stability and improvement in pain and TMJ function.

Although the life expectancy of the TMJ Concepts device is unknown, Wolford, et al. [32] published a 20-year follow-up study of 56 patients who had received the Techmedica total joint prostheses between 1989 and 1993. There were statistically significant improvements in all parameters including incisal opening, jaw function, TMJ pain, and diet, with 85.7% of the patients reporting significant improvement in their quality of life. The greater the number of previous TMJ surgeries, patients reported a lower degree of subjective improvement, but they did report increased objective mandibular function and improved quality of life. There were no reports of device removal due to material wear or failure.

Numerous studies have been published in reference to outcome data using patient-fitted TMJ total joint prostheses. A summary of these publications has produced the following facts in reference to the TMJ Concepts total joint prostheses:

1. TMJ Concepts prostheses are superior to autogenous tissues for end-stage TMJ reconstruction relative to subjective and objective outcomes.
2. After two previous TMJ surgeries, autogenous tissues have a very high failure rate, whereas patient-fitted total joint prostheses have a high success rate.
3. No donor site morbidity.
4. Increased number of previous TMJ surgeries produces a lower level of improvement related to pain and function outcomes compared to patients with 0–1 previous TMJ surgeries.
5. Failed TMJ alloplastic reconstruction (i.e., P/T, Silastic, metal-on-metal articulation, etc.) can create a foreign-body giant cell reaction and/or metallosis, best treated by joint debridement and reconstruction with patient-fitted total joint prostheses.
6. Fat grafts packed around the articulating area of the prostheses improves outcomes relative to decreased pain, improved jaw function, and decreased requirement for repeat surgery.
7. Osseointegration of the TMJ Concepts fossa and mandibular components occurs and is important for long-term stability.
8. Posterior stop on the fossa component is important to stabilize the joint, jaw position, and occlusion.
9. Concomitant orthognathic surgery can be performed at the same time as the TMJs are reconstructed.
10. A 20-year follow-up study that demonstrated improvements in pain, jaw function, diet, incisal opening, and quality of life.

During the past 28 years, major advancements have been made in TMJ diagnostics and the development of surgical procedures to treat and rehabilitate the pathological, dysfunctional, and painful TMJ. Research has clearly demonstrated that TMJ and orthognathic surgery can be safely and predictably performed at the same operation, but it does necessitate the correct diagnosis and treatment plan, as well as

requires the surgeon to have expertise in both TMJ and orthognathic surgery. The surgical procedures can be separated into two or more surgical stages, but the TMJ surgery should be done first. With the correct diagnosis and treatment plan, combined TMJ and orthognathic surgical approaches provide complete and comprehensive management of patients with coexisting TMJ pathology and dentofacial deformities. The application of computer-assisted surgical simulation (CASS) with virtual surgical planning (VSP) for C-TJR-OS cases requiring TMJ reconstruction with patient-fitted total joint prostheses and orthognathic surgery has significantly improved treatment quality by decreasing the preoperative workup time and increasing the accuracy of surgical preparation and subsequent surgery.

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Autogenous Tissues Versus Alloplastic TMJ Condylar Replacement

8

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Abstract

End-stage temporomandibular joint (TMJ) disease due to a multitude pathophysiologic process can benefit from TMJ replacement. The traditional method has been used to reconstruct the TMJ using autogenous tissues from various donor sites in the body. However, as materials and understanding how to use those materials have advanced, the pendulum is now moving much more toward alloplastic reconstruction. This chapter will compare and contrast the two types of reconstruction methods for reconstructing the diseased TMJ.

8.1 Introduction

End-stage temporomandibular joint (TMJ) pathology or conditions that may benefit from TMJ condylar replacement include (1) TMJ arthritis with non-salvageable articular discs; (2) advanced stages of adolescent internal condylar resorption (AICR); (3) traumatic injuries; (4) reactive arthritis; (5) osteoarthritis; (6) tumors; (7) absent or deformed anatomical structures resulting in loss of posterior mandibular vertical dimension (i.e., fractured displaced condyles, absence of condyles and portions of the ramus/body as the result of previous trauma, surgery, pathology, or congenital deformity); (8) high or low inflammatory, metabolic arthritic diseases; (9) connective tissue/autoimmune diseases (i.e., rheumatoid arthritis, juvenile idiopathic arthritis, scleroderma, Sjogren's syndrome, lupus, etc.); (10) fibrous or bony ankylosis; (11) multiply operated TMJs (two or more previous surgeries); (12) failed autogenous grafts; (13) failed TMJ alloplastic implants; and (14) other

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end-stage TMJ pathologies. The purpose of this chapter is to describe the various methods of condylar replacement using autogenous tissues or alloplastic total joint replacement and present reports on outcomes of the various techniques.

For many years, the primary method to replace the mandibular condyle when affected by any of the aforementioned conditions and pathologies was to use autogenous tissue grafts. There have been numerous biological structures used for condylar reconstruction, and these include (1) costochondral (rib) graft, (2) sternoclavicular graft (SCG), (3) coronoid graft, (4) chondro-osseous iliac crest graft, (5) vertical ramus osteotomy, (6) distraction osteogenesis, (7) vascularized metatarsal graft, and (8) vascularized fibula graft. There is scant literature on outcome data available to evaluate these various autogenous condylar replacement techniques. Indications of using bone grafting as a condylar replacement include the following: (1) condylar replacement required, (2) pain, (3) zero to one previous TMJ surgeries (for free grafts), (4) good vascular bed (for free grafts), (5) need for hard and soft tissue grafts (vascularized fibula grafts), (6) growth center transplant (rib, SCG), (7) total joint prosthesis unavailable, (8) allergy to metals in total joint prostheses, and (9) patient preference. The types of autogenous grafts used for TMJ condylar replacement and published outcomes will be reviewed.

8.2 Costochondral (Rib) Grafts

Rib grafts are the most common type of autogenous graft used for TMJ condylar replacement (Fig. 8.1). Commonly the sixth or seventh rib is harvested including a section of cartilage attached, with the cartilage portion placed into the fossa and the bone portion on-laid over the lateral aspect of the ramus and stabilized with interosseous wires, bone screws, or bone plate and screws. When the anatomy of the ramus and fossa interrelationship is not compatible with this lateral placement of the rib, then the graft can be placed at the posterior border of the mandible (may require

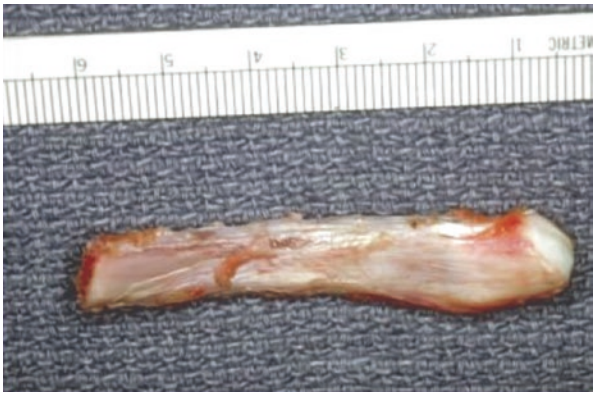

Fig. 8.1 Rib grafts have been the most popular autogenous tissues used for condylar replacement, and the sixth or seventh ribs are the most common area of harvest

removal of a portion of the posterior border of the mandible) or placed on the medial side of the ramus to align with the fossa. In growing patients, growth of the rib may or may not occur. If growth occurs, it is often excessive as the graft grows like a rib, not like a mandibular condyle. This causes the ipsilateral mandible to overgrow, shifting the mandible toward the contralateral side or vertically elongating the ipsilateral side (vector of growth dependent on orientation of graft placement) requiring further surgery (Fig. 8.2a–d). When the graft does not grow, there will be a resulting underdevelopment of the ipsilateral side of the mandible. With excessive overgrowth, further surgery may be required to remove the growth center which is at the epiphyseal center of the rib graft and, as with deficient growth, may require orthognathic surgery after cessation of normal growth to optimize jaw function and esthetics.

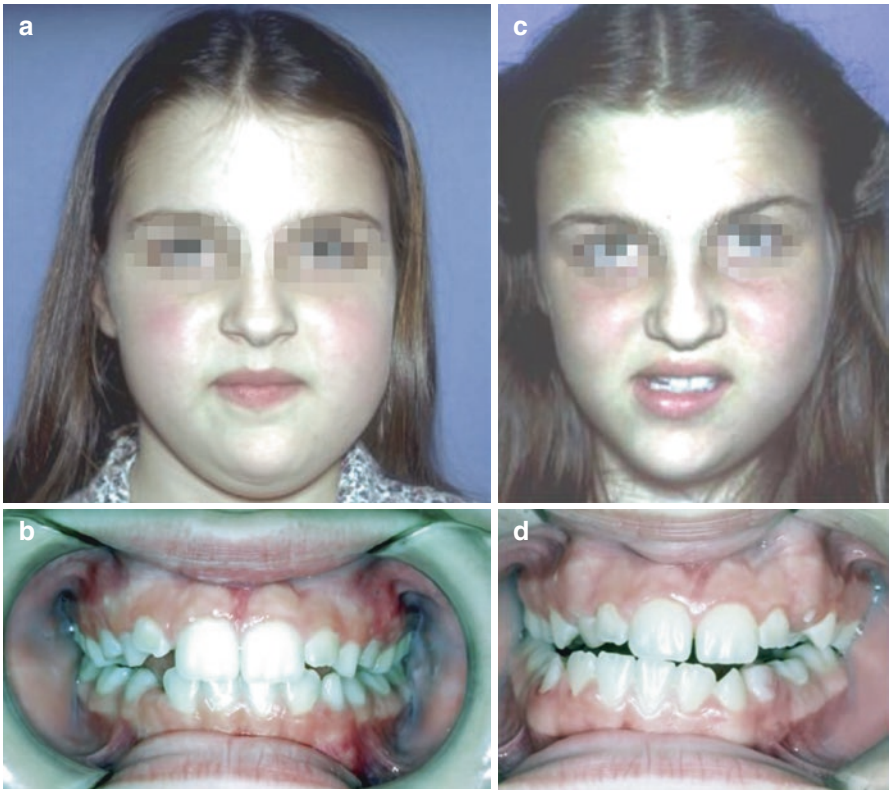

Fig. 8.2 (**a**) A 12-year-old female with a left-sided bony ankylosis. The patient is seen here immediate post rib graft to replace the left mandibular condyle. (**b**) Immediate postsurgical occlusion shows that the dental midlines are congruent. (**c**) Eighteen months post surgery, a significant facial asymmetry is noted related to the overgrowth of the left costochondral graft. (**d**) A significant change in the occlusion is noted with the mandibular dental midline shifted approximately 8 mm toward the right side and the left occlusion developing into a Class III occlusion illustrating significant overgrowth of the left mandibular costochondral graft

In cases of ankylosis treated with rib grafts, the risk of re-ankylosis is high, particularly in growing patients. In the presence of reactive arthritis and connective tissue/autoimmune diseases, rib grafts are susceptible to the same diseases that created the TMJ pathology that required the condylar reconstruction in the first place. The overall failure rate of rib grafts is high. Donor site complications can include pleural tear and effusions, pneumothorax, hemothorax, atelectasis, pneumonia, intercostal nerve injury, etc. At the joint American Society of TMJ Surgeons (ASTMJS) and the European Society of TMJ Surgeons (ESTMJS) held in Lille, France, May 18–20, 2017, there was a strong consensus that alloplastic total joint prostheses outcomes were far superior to rib grafts. Rib grafts were only recommended when alloplastic total joint prostheses were not available or the patient had hypersensitivity to the metals in the prosthesis.

There are a few studies in the literature purporting the efficacy of rib grafts. Perrott, Umeda, and Kaban [1] published a study on 26 patients, 33 grafts, 7 of the patients growing, and average follow-up was 48 months. The incisal opening improved from a range of 10–46 mm to a range of 27–51 mm. The authors state that the disc was maintained in ten cases, and in the others temporalis muscle flaps were performed. The authors reported good results. Maintaining the articular disc or placing an inter-positional soft tissue graft between the fossa and graft may improve the outcomes.

Saeed et al. [2] published a study on 57 patients utilizing 76 costochondral grafts with a minimum follow-up of 2 years. The incisal opening improved from 21 to 24 mm. Pain improved from 6.7 to 3.5 (0 = no pain, 10 = worst pain), but the diet worsened from 2.2 to 3.0 (0 = no restrictions, 10 = liquid only). Previous failed alloplastic implants and ankylosis produced a significantly higher complication rate and a significant increase in additional surgery where over 50% of the patients that received costochondral grafts required additional surgery.

Troulis et al. [3] reported on 15 patients with idiopathic condylar resorption receiving costochondral grafts. The mean age was 24 years. The patients all had Class II occlusions with anterior open bites. The average follow-up was 34 months, range 12–84 months. Incisal opening at longest follow-up was 39 mm. The authors reported stable Class I occlusions with no open bite redevelopment.

Advantages:

1. Native tissue
2. Growth potential
3. Relatively easy to harvest
4. Fits well into the fossa with proper orientation of the graft although ramus modification may be required

Disadvantages:

1. Can correct a mild to moderate dentofacial deformity but may be difficult to maintain a stable skeletal and occlusal result.
2. Graft weak, flexible and elastic, subject to deformation and fracture.

3. Cortical bone may be very thin and medullary bone exhibits light density.
4. Subject to physiological loading and adaptations.
5. Growth unpredictable.
6. High recurrence rate when used for TMJ ankylosis.
7. Risk of donor site complications such as pneumothorax, plueral effusion, hemothorax, intercostal nerve injury, esthetic defect.

8.3 Sternoclavicular Grafts (SCG)

Sternoclavicular grafts (SCG) are probably the most ideal autogenous free grafts for TMJ condylar replacement. Development and growth of the sternoclavicular joint are the most similar to the TMJ than any other joint or potential graft system in the body. There is an articular disc present that can also be harvested. Usually the upper half of the clavicle is harvested with half of the articular disc (Fig. 8.3). The cortical bone is quite thick and strong, filled with lots of medullary bone. The thick cortical bone requires placement of multiple holes to aid in revascularization (Fig. 8.4a, b). The SCG adapts well to the fossa if it is rotated 90° and placed along the posterior border of the mandible (may require partial resection of the posterior border for best adaptation into the fossa and bony interface with the ramus). It can be attached to the mandible with bone plates (Fig. 8.4c). The donor site is quite weak as a result of the harvest and susceptible to fracture. Figure-of-eight bandage and arm sling are required to decrease the risk. Clavicular fracture may require bone plate stabilization. Although significant dentofacial deformities can be corrected by advancing the mandible with SCGs, physiological loading and associated effects on this biological tissue may cause some bony adaptation resulting in difficulty controlling the skeletal and occlusal relationship (Figs. 8.5, 8.6, and 8.7).

Wolford et al. [4] in 1994 published a study on 38 patients receiving 52 SCGs with a mean age of 25.9 years with a mean follow-up of 45 months. Success was determined by decrease in pain, stable occlusal outcome, and incisal opening greater than 30 mm. The patients were divided into three groups. Group 1 composed of 14

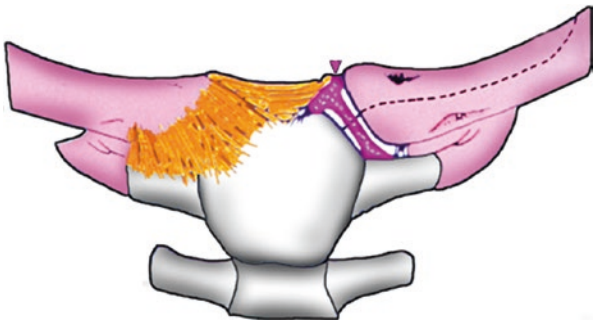

Fig. 8.3 In procuring a sternoclavicular graft, usually the upper half of the clavicle including the adjacent articular disc is harvested

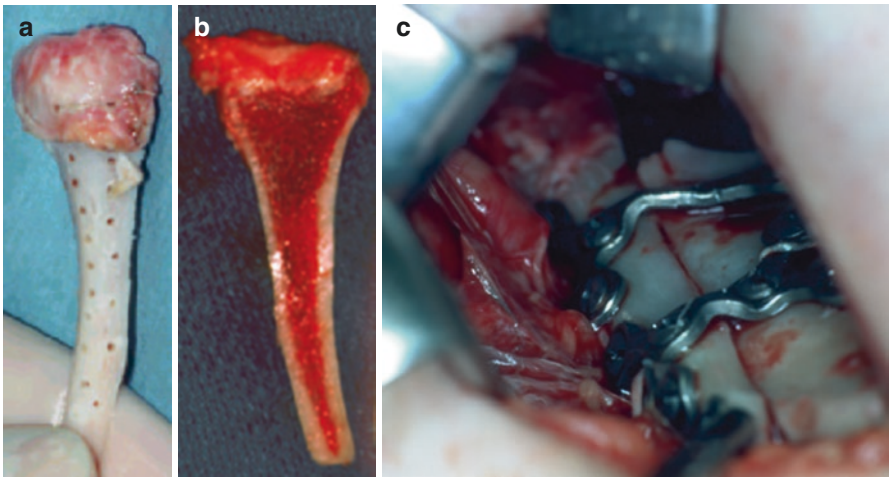

Fig. 8.4 (**a**) A harvested sternoclavicular graft is prepared. The cortical bone is quite thick so placing multiple interosseous holes helps with revascularization. (**b**) Shows the thickness of the cortical bone but also the plentiful medullary bone present in this graft. At the top of the condyle, the articular eminence is noted. (**c**) Sternoclavicular graft is placed against the modified posterior border of the right mandibular ramus and stabilized in position with bone plates. Notice a nice adaptation of the graft to the posterior border of the mandible

patients that had received previous Proplast Teflon TMJ devices (Vitek Inc., Houston, TX, USA) as inter-positional implants or total joint prostheses. Although the joints were thoroughly debrided at the time of placement of the sternoclavicular grafts, the success rate was only 29%. The high failure rate was related to the foreign body giant cell reaction that developed in these joints with these failed alloplastic materials. Although the joints were thoroughly debrided, it is impossible to remove all this material, and the foreign body giant cell reaction can be reinitiated, thus, affecting the outcomes of autogenous joint reconstruction. Group 2 consisted of patients with inflammatory disease processes such as reactive arthritis and connective tissue autoimmune disease such as rheumatoid arthritis, psoriatic arthritis, juvenile idiopathic arthritis, etc., and consisted of ten patients. In this group, the success rate was only 50% as a result that disease processes will attack autogenous tissues put into joint areas. Group 3 consisted of patients who had no previous alloplastic implants and no inflammatory process, and in most all of the patients, this was their first operation with 14 patients included in this group. The success rate was 93%, showing that this graft protocol worked well when there was no previous failed alloplastic implants, inflammatory disease issues, connective tissue/autoimmune diseases, and particularly when performed as the first operation.

The SCG was harvested from the superior half of the clavicle including the associate articular disc. This graft was then inserted into the TMJ area generally posterior to the mandibular ramus and rotated 90° to fit into the fossa, or in cases such as hemifacial microsomia, the SCG was placed on the medial side of the ramus with the condyle positioned against the skull base. Because the graft consisted of the

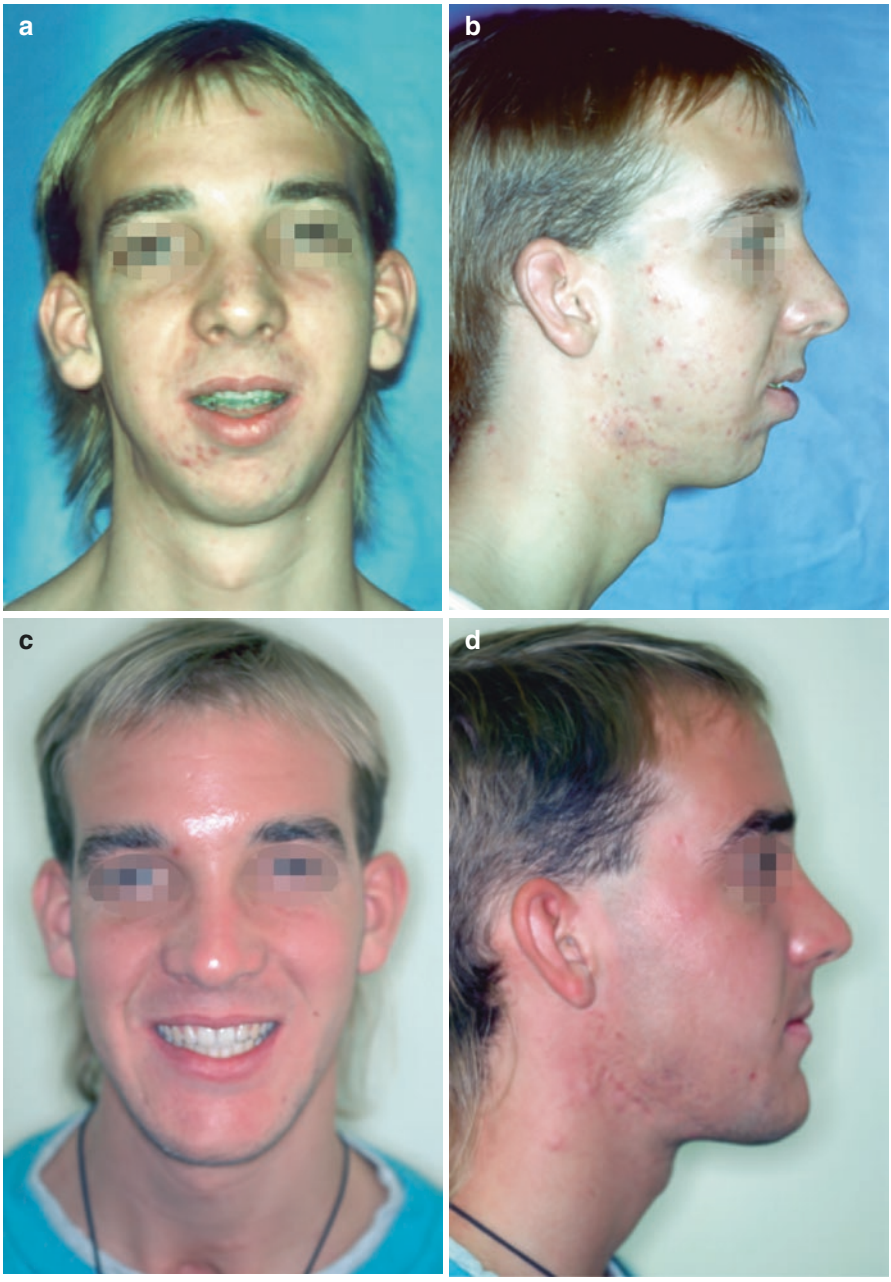

Fig. 8.5 (**a**) A 19-year-old male with juvenile idiopathic arthritis resulting in severe condylar resorption, a retruded mandible, and anterior open bite. (**b**) Profile view shows the retrusion of the maxilla and mandible. (**c**) The patient seen 2 years post surgery showing improved appearance from the frontal view. (**d**) Illustrates the 2-year post surgery profile. Pogonion was advanced forward a total of 34 mm

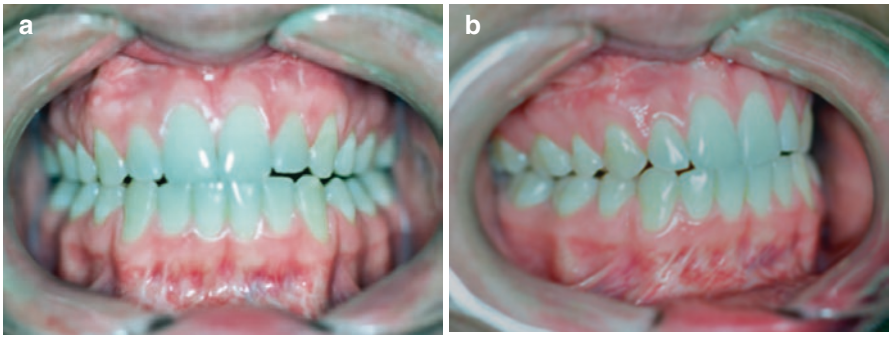

Fig. 8.6 (**a, b**) Occlusion at 2 years post surgery noting the mid-buccal open bite tendency. Using autogenous grafts for mandibular advancement can create significant issues with maintaining an ideal occlusion as the grafts are subject to physiological changes from stresses placed on the graft with significant advancements. Lateral view shows the bite is slightly open in the mid-buccal segments

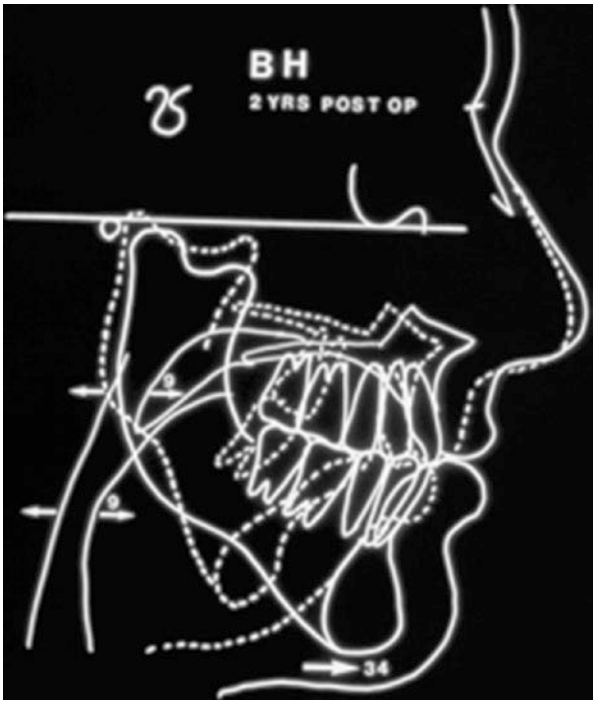

Fig. 8.7 Pre- and post surgery cephalometric super-imposition. The dotted line illustrates the presurgical cephalometric tracing, while the solid line represents 2 years post surgery illustrating the significant changes that can be accomplished with these autogenous sternoclavicular grafts

upper half of the clavicle, this severely weakened the remaining clavicle. Although patients were placed in figure-of-eight supportive bandages and arm slings to reduce loading of the clavicle, there were still five fractured clavicles (10%) that occurred post surgery.

Singh et al. [5] published a study on 15 patients with unilateral TMJ ankylosis and had 15 joints reconstructed with sternoclavicular grafts. Age range was 10–18 years with a mean follow-up of 27.4 months. Incisal opening had an initial range of 0–5 mm, and immediately post surgery, the incisal opening was 34.9 mm. The authors reported that there was no change in this opening long term. One case was classified as a failure. Donor site morbidity included two fractured clavicles (13%).

Advantages:
1. Native tissue
2. Growth potential more consistent of a growth rate similar to the TMJ condyle
3. Strong cortex
4. Significant amount of medullary bone
5. Fits well into the fossa with proper orientation of the graft
6. Articular disc present

Disadvantages:
1. Can correct a significant dentofacial deformity but may be difficult to maintain a stable skeletal and occlusal result
2. Subject to physiological loading and adaptations
3. Risk of donor site fracture

8.4 Coronoid Grafts

There have been two methods for condylar replacement using the coronoid process: a free graft and a pedicled graft. For the free graft, the coronoid process is harvested, and the tip of the coronoid is placed in the fossa to function as the point of articulation and then attached to the ramus via interosseous wires, bone screws, or bone plates. The pedicled graft keeps the temporalis muscle attached to the coronoid as it is positioned in the fossa and stabilized in the same manner as the free graft. The coronoid graft has a very narrow and small articulating surface that may cause some issues post surgery, such as perforation of the disc or any other soft tissue graft to replace the disc. A couple studies have evaluated the outcomes of these techniques.

Zhu et al. [6] reported using free coronoid grafts to reconstruct the TMJs in 15 patients with TMJ ankylosis. Follow-up average was 22 months. The authors state that the native discs or temporal muscle flap was used to provide tissue between the

grafted coronoid section and the fossa. The authors report satisfactory results. All cases exhibited bone resorption of the grafts, but the authors stated there were no occlusal changes.

Liu et al. [7] reported on the use of a pedicled coronoid graft to reconstruct the TMJ in 24 patients and 28 joints. A temporal muscle flap was placed in the glenoid fossa. This study compared free grafts with pedicle grafts, and it was noted there was more bone resorption in the free grafts, and there was a better overall outcome using the pedicle grafts.

Advantages:
1. Native local tissue
2. Can be pedicled to help eliminate vascular compromise and bone resorption

Disadvantages:
1. Narrow-pointed functional head
2. No growth potential
3. Cannot correct even mild dentofacial deformity
4. Subject to physiological loading and adaptation

8.5 Chondro-Osseous Iliac Crest Graft

This little used technique involves harvesting a graft from the iliac crest including the cartilage surface and underlying bone. The graft is inserted into the fossa and secured to the ramus.

Kummoona [8] used a chondro-osseous iliac crest graft in six children with TMJ ankylosis with a mean follow-up of 18 months. The incisal opening improved from a range of 0–5 mm to 34–43 mm. The authors reported growth was seen in all cases with full functional activity with protrusion. There was no recurrence of ankylosis reported.

Advantages:
1. Native tissue
2. Claimed growth potential

Disadvantages:
1. Requires harvesting of the graft.
2. Difficult to control growth vector.
3. Cannot predictably correct dentofacial deformity.
4. Subject to physiological loading and adaptation.
5. Only six patients had been reported in the literature that received this procedure.

8.6 Vertical Ramus Osteotomy

Following the performance of a condylectomy, the TMJ can be reconstructed by doing a vertical ramus osteotomy and reposition the proximal segment superiorly into the fossa and apply rigid fixation. There is very little data in the literature supporting this technique.

Liu et al. [9] published a study involving 18 patients and 21 ankylosed joints with a 36-month follow-up. The authors state they either maintained the native disc or performed a temporal fascia muscle flap to place into the joint area. The mean incisal opening was improved from 5 to 36 mm with no re-ankylosis.

8.7 Distraction Osteogenesis

Although distraction osteogenesis has been used to lengthen the mandible and sometimes the maxilla, its application for replacement of the TMJ condyle has received little attention. The technique involves performing an osteotomy involving the posterior border of the ramus and applying a distractor device and following distraction protocol. The design of the operation includes performing the condylectomy followed by an osteotomy in the posterior ramus of the mandible, preserving the angle of the mandible, but performing a reverse L-type bone cut and adapting the distraction device. Post surgery after a latent period, the device is activated, displacing the new neo-condyle superiorly up toward the fossa area.

Schwartz and Relle [10] reported on 12 patients and 13 joints, with a follow-up of 7–56 months. They used inter-positional fat grafts or temporal fascia muscle flap within the joint area. Incisal opening presurgery had a range of 3–46 mm and final outcome ranged from 20 to 53 mm. Most patients were reportedly asymptomatic at longest follow-up. One bilateral rheumatoid arthritis patients had postoperative condylar resorption and relapsed.

Cheung and Lo [11] presented five unilateral ankylosed patients with five treated joints by distraction osteogenesis with an age range of 3–51 years and a follow-up of 1–2 years. Latency period was 7 days. Total activation was 8–19 mm. Incisal opening improved from an average of 14 to 38 mm at longest follow-up. The mean satisfaction score was 8.6 out of 10.

Advantages:

1. Native tissue.
2. No bone harvest required.
3. With careful surgery, the graft can remain pedicled to help with vascular viability.

Disadvantages:

1. Requires two operations: One to place the distraction device and a second procedure to remove it.

2. Difficult to control the vector of distraction.
3. Cannot correct a major dentofacial deformity.
4. Narrow mediolateral width of the neo-condyle.
5. Long treatment time.
6. Subject to physiologic loading and adaptations.

8.8 Vascularized Metatarsal Graft

This technique involves harvesting the second metatarsal (toe) including the distal joint and associated vessels providing the vascularity. The graft is transplanted to the TMJ and anastomosed to the temporal vessels or other vasculature in the area. The graft can be positioned so that the distal metatarsal joint functions as the new TMJ. This allows only hinge movement of the new joint. There are three studies in the literature using this technique.

Landa et al. [12] reported on four patients with five joints reconstructed with a vascularized metatarsal graft. Mean age of 29 years with a range of 17–45 years. Median length of operation was 6.5 h with a mean follow-up of 12.5 years. Incisal opening presurgery was 12 mm and at longest follow-up had a mean of 48.5 mm. The function was rated as acceptable.

Potter and Dierks [13] reported on 9 patients and 11 joints with 2 patients being bilateral. They reported good results in the use of this vascularized grafting system to reconstruct the TMJ (see Chap. 10).

Bunke et al. [14] reported that non-vascularized metatarsal grafts had severe degenerative changes and re-ankylosis, whereas the vascularized metatarsal grafts had much better outcomes.

Advantages:
1. Native tissue
2. Vascularized graft
3. Good fit in the fossa
4. Works well in areas where there is decreased vascularization

Disadvantages:
1. Creates a significant foot deformity
2. Cannot correct large dentofacial deformities
3. Cannot reconstruct large mandibular defects
4. Subject to physiological loading and adaptations

8.9 Vascularized Fibula Grafts

The vascularized fibula graft for TMJ reconstruction is more appropriate when there is an associated large mandibular bone defect involving the condyle, ramus, and body. These are long involved operations, often requiring two surgical teams, with

extended hospital stays and increased expenses. This technique should be reserved for the large defects where bone is required for reconstruction, bone and soft tissue required for reconstruction, vascular compromise in the surgical area, and irradiated tissue (see Chap. 10, and for an alternative approach in osteoradionecrosis patients, see Chap. 11).

Gonzalez-Garcia [15] reported on six patients receiving a vascularized fibula graft to reconstruct the TMJ. The author states that the articular discs were preserved and placed on the graft head. The author reported results that five of the patients had adequate function, but one patient ankylosed.

Guyot et al. [16] reported on 11 patients with 11 joints treated with vascularized fibula grafts. The age range was from 17 to 36 years with a follow-up of 12 to 60 months. The authors state that the articular disc was maintained in the joint. The neo-condyle was rounded off and narrowed to better fit within the glenoid fossa. Incisal opening reported changed from 33 to 34.6 mm.

Wax et al. [17] reported on 17 patients with 13 radiation treatments with a mean age of 62 years. Hospital stay was 11.6 days. Outcome data showed 10 patients could chew a regular diet, 7 a soft diet, 4 full liquid, and 4 remaining on tube feedings.

Advantages:
1. Native tissue
2. Vascularized graft
3. Good in vascular compromised areas
4. Can reconstruct large mandibular defects with both hard and soft tissues

Disadvantages:
1. Unsightly donor site scar
2. Long procedure
3. Increased costs and hospitalization time
4. Requires two surgical teams
5. Graft subject to physiological loading and adaptations

8.10 Contraindications for Free Autogenous TMJ Condylar Replacements

The contraindications to using free bone grafts for TMJ reconstruction include the following: (1) multiply operated TMJs (two or more previous TMJ procedures), (2) connective tissue autoimmune disease and inflammatory diseases, (3) previously failed TMJ alloplastic implant or prosthesis, (4) conditions causing decreased vascularization and prolonged healing, (5) patient with polyarthropathies, and (6) requirement of concomitant TMJ and orthognathic surgery to reconstruct the TMJs and associated dentofacial deformity.

8.11 Common Complications with Autogenous Grafting for Condylar Replacement

There are numerous complications that can occur with the harvesting and grafting of autogenous tissues used for TMJ condylar reconstruction. This includes, but not limited to, (1) excessive growth (rib grafts) or no growth, (2) donor site complications, (3) improper position/fit of graft, (4) supporting hardware failure, (5) fracture or failure of the graft, (6) avascular necrosis. (7). heterotopic bone/fibrosis resulting in ankylosis, (8) adverse physiological effect (warpage, resorption, fracture), (9) infection, (10) CN V and VII nerve injuries, (11) skeletal relapse and malocclusion, and (12) requirement for additional surgical procedures.

8.12 Condylar Replacement with Total Joint Prostheses

There are two basic types of TMJ prostheses: stock (off-the-shelf devices) and patient-fitted systems. Components of the stock prostheses come in various sizes and shapes so that the surgeon then selects the fossa and mandibular components that best fit the presenting anatomy. This approach does not require significant presurgical preparation, may require significant intraoperative bony preparation, but does require an inventory of "parts" for selection. The patient-fitted devices are custom-designed to fit the patient's specific anatomical requirements providing a good fit of the components to the anatomical structures. However, this method requires presurgical preparation that may include TMJ and orthognathic surgical planning, virtual surgical planning (VSP), printing of a 3D stereolithic model, and surgical simulated preparation of the 3D model on which the patient-fitted prostheses will be manufactured. The presurgical time commitment for preparation is much greater compared to the stock prostheses, but the fit of the components is superior. These two types of prostheses, indications, advantages and disadvantages of each system and the outcome literature available for these devices will be presented.

The aforementioned TMJ pathologies and conditions can significantly alter the anatomy in the TMJ area and mandible resulting in an associated dentofacial deformity, malocclusion, functional impairment, airway obstruction, and pain. Mandibular advancement and/or counterclockwise rotation (rotating the anterior aspect of the maxillomandibular complex upward and/or the posterior aspect downward) may be necessary to correct such deformities in order to achieve an optimal functional and esthetic result. These repositioning movements can create a large gap between the fossa and mandibular ramus/condyle structures. In these circumstances as well as those with altered anatomy from the TMJ pathology, a patient-fitted total joint prosthesis can provide accurate adaptation of a TMJ TJR device to the anatomical structures for each individual patient.

There are three TMJ total joint prostheses currently available in the US market. These are manufactured by the following three companies: (1) Nexus CMF (Salt Lake City, UT, USA), the devices were previously manufactured by TMJ Implants Inc., (Golden, CO, USA) and commonly referred to as the "Christensen"

prostheses; (2) Biomet Microfixation (Jacksonville, FL, USA); and (3) TMJ Concepts Inc. (Ventura, CA, USA). These three devices will be independently presented including composition, presurgical and intraoperative preparation, published outcome data, as well as the advantages and disadvantages of each system.

8.13 Nexus CMF (Christensen) TMJ Replacement System

The Nexus CMF (Christensen) TMJ replacement system is a stock (off the shelf) device, although patient-fitted devices are available. The ramus and condylar head of the mandibular component are composed of chromium cobalt alloy with vertical lengths of 45, 50, and 55 mm. The fossa component is a chromium cobalt alloy with 44 different configurations. Surgeon must pick the fossa and mandibular components that best fit the anatomical configuration of the patient's fossa and mandibular ramus. This device is a metal-on-metal articulation (Fig. 8.8). Screws are made of chromium cobalt alloy and are 2.7 mm diameter for the mandibular component and 2 mm in diameter for the fossa component. There is no stable posterior stop on the fossa.

Chase et al. [18] in 1995 presented data of 21 patients with 34 joints. The authors reported a 95% decrease in pain, 86% increase in ability to eat, and 91% increase in

Fig. 8.8 The Nexus CMF (Christensen) prostheses have a metal-on-metal articulation. There are numerous fossa designs (approximately 40) and three mandibular components of different sizes to choose from

incisal opening. The second study on the Nexus CMF website [19] in 2014 presented outcomes on 42 patients, although the number of joints was not included. Follow-up was 36 months, and genders were also not identified. This was a mixed sample with 18 patients with total joint prostheses and 24 patients who received just the fossa implant only. This study stated a pain reduction from 8.0 to 2.7 on a 0–10 scale (0 = no pain, 10 = worst pain). Incisal opening in the 18 total joint prostheses patients improved from 10.8 to 31.0 mm.

Wolford et al. [20, 21] evaluated 76 joints that received Christensen total joint prostheses with metal-on-metal articulation, with the average patient follow-up of 31.2 months. MIO increased by 3.5 mm (23.6–27.1 mm), and the jaw function improved by 1.9 levels (7.7–5.8), where 0 = normal jaw function and 10 = no jaw function. There was a statistically significant improvement for MIO and patient perception of jaw function. There were 25 Christensen prostheses (33%) removed because of elevated pain levels due to device failure (Fig. 8.9) and/or metal hypersensitivity due to metallosis.

Advantages of the Nexus system:

1. Off-the-shelf product, ready for immediate use.
2. Patient-fitted devices are available.
3. 44 fossa and three mandibular component configurations to choose from for best fit of the stock prosthesis.
4. No presurgical preparation.

Disadvantages of the Nexus system:

1. Metal-on-metal articulation can cause metallosis, and fracture of the fossa component can occur. Metal-on-metal articulating devices have been removed from the market in orthopedic surgery.
2. Requires large inventory of parts.

Fig. 8.9 Potential complications of these devices are metallosis and fracture of the fossa component

3. Inadequate posterior stop in the fossa component that may limit potential to advance and vertically lengthen the mandible.
4. Not indicated for patients who have significantly altered TMJ and mandibular anatomy.

8.14 Biomet Microfixation TMJ Replacement System

The Biomet Microfixation TMJ replacement system is a stock device (off the shelf) with fossa and mandibular components to choose from. Patient-fitted devices are available, but not in the USA. Clinical trials for the stock device were initiated in 1995 and granted FDA approval in 2005. The ramus component is composed of a chromium cobalt alloy, but the ramus side has a titanium coating to help with osseointegration. The ramus component is available in three lengths: 45, 50, and 55 mm. There are three basic styles including standard, offset, and narrow. The fossa is composed of ultrahigh molecular weight polyethylene, and there are three fossa sizes to choose from including small, medium, and large. This is metal-on-polyethylene articulation, which is the gold standard in orthopedics (Fig. 8.10a, b). The mandibular component is stabilized to the ramus with 2.7 mm diameter screws, and the fossa component is secured to the lateral rim of the fossa with 2.0 mm diameter screws.

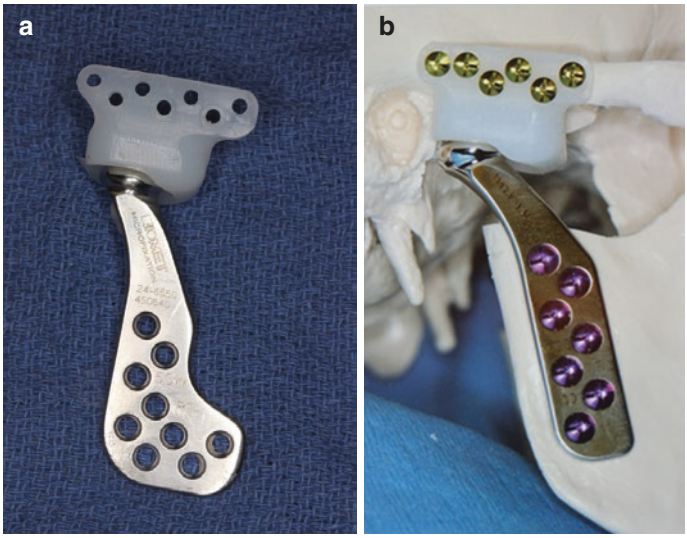

Fig. 8.10 (**a**) The Biomet micro fixation standard prosthesis is composed of a polyethylene fossa component and a chromium cobalt alloy mandibular component. The mandibular component comes in three lengths and also comes with an offset of the condylar head. (**b**) Demonstrates the "narrow" mandibular component of the Biomet system

Giannakopoulos [22] reported on 204 patients with a 3-year follow-up following the placement of the devices. The mean age was 41 years and 89% were female. The mean number of prior surgeries was 4.9 per joint. Presurgery pain was at 8.0 and decreased to 2.6 long term. Jaw function improved from 8.2 to 2.5. Maximum incisal opening improved from 20.4 to 29.5 mm. 3.2% of the implants were removed. Machon et al. [23] presented a European multi-institutional study with 27 patients and 38 joints with an average of 24 months follow-up. Four of the patients had custom-made devices, and the others were stock devices. There were 21 females with a mean age of 42.6 years. Incisal opening improved from 17.7 to 29.1 mm. Relative to pain, 15 patients improved from 4 to 2 (0–5 scale), 4 patients developed worse pain, and 8 patients had no pre- or postoperative pain.

Aagaard et al. [24] reported on 61 patients using the custom-made Biomet prosthesis with a mean follow-up of 14 months. There was significant improvement in incisal opening at longest follow-up, and there was significant decrease in pain. Approximately 19% of the prostheses were associated with complications. Leanardo et al. [25] reported outcomes on 300 patients (201 unilateral and 99 bilateral) with a mean follow-up of 3.5 years. Incisal opening, function, speech, and diet showed improvement over 3 years. Pain improved, and no patients reported severe pain at 6 months post surgery. Dimitroulis [26] reported a study for end-stage TMJ disease comparing three groups: condylectomy only, rib grafts, and Biomet stock prostheses. Condylectomies resulted in best range of motion, and rib grafts experienced the greatest number of complications requiring reoperation (44% of cases). The prosthesis group had the best mean aggregate score on quality of life, but was not statistically significant. Range of motion of the prosthetic patients was no better than the rib graft patients.

Westermark [27] reported on 12 patients (5 unilateral and 7 bilateral) receiving Biomet prostheses with follow-up of 2–8 years. Ankylosed patients' incisal opening improved to 30 mm, and the other patients maintained an opening of more than 35 mm. The author states that joint-related pain and interference with eating were eliminated. Sanovich et al. [28] reported on 36 patients (26 bilateral and 10 unilateral) receiving Biomet stock prostheses with a follow-up of 6–83 months. Incisal opening improved from 26 to 34.4 mm. Pain scores decreased from 7.9 to 3.8, diet improved from 6.8 to 3.5, and quality of life improved from 4 to 2. Four implants required removal.

Advantages of the Biomet system:

1. Off-the-shelf device, ready for immediate use.
2. Metal-on-polyethylene articulation; the gold standard in orthopedics.
3. Patient-fitted devices are available outside the USA.
4. Osseointegration of the mandibular component occurs.
5. No presurgical preparation required.

Disadvantages of the Biomet System:

1. Requires recontouring of the fossa and perhaps the ramus to achieve fit of the stock components.
2. No osseointegration of the fossa component.

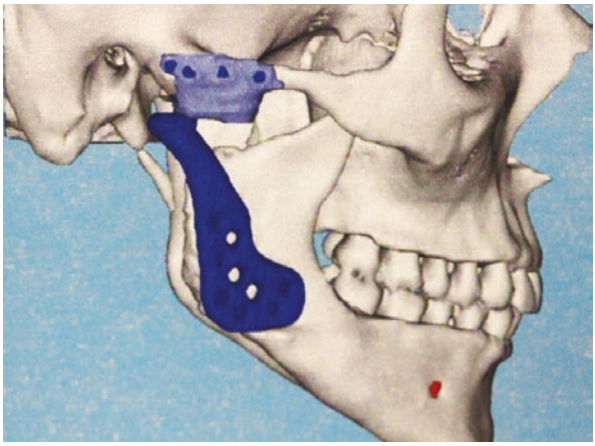

Fig. 8.11 Since the fossa component has no posterior stop, a complication can include posterior displacement of the mandibular component relative to the fossa

3. No posterior stop on the fossa component, which limits ability to advance the mandible and vertically lengthen the ramus and increases risk for posterior dislocation of the mandibular component (Fig. 8.11).
4. Stock prosthesis not indicated for patients who have significantly altered TMJ and mandibular anatomy.

8.15 TMJ Concepts Total Joint Prostheses System

The TMJ Concepts patient-fitted devices were originally developed in 1989 by Techmedica (Camarillo, CA, USA) and manufactured until July 1993 when the US Food and Drug Administration (FDA) halted production of all TMJ devices developed after 1976 [29]. In 1996, the FDA permitted the new owners, TMJ Concepts (Ventura, CA, USA), to manufacture the device under the 510 K provision and granted full approval of these Class III devices in 1999. The TMJ Concepts devices are computer-assisted designed/computer-assisted manufactured (CAD/CAM) devices, designed and manufactured to fit the specific anatomical, functional, and esthetic requirements of each specific patient. The fossa component is made of a titanium shell with a mesh covering all surfaces and ultrahigh molecular weight polyethylene attached to the undersurface for articulation with the condylar component. The mesh on the titanium shell that is patient-fitted to the patient's fossa and lateral rim of the fossa anatomy allows for osseointegration of the bone into the superior aspect of the fossa component and provides a method to attach the polyethylene to the metal base of the fossa component. The ramus component is constructed of titanium alloy, and the condylar head is composed of chromium cobalt alloy. This provides a metal-on-polyethylene articulation, which is the gold standard in orthopedics (Fig. 8.12). The screws are composed of titanium alloy and are 2 mm in

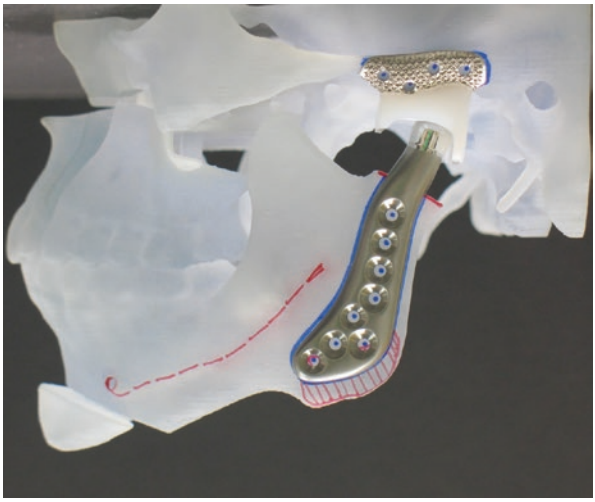

Fig. 8.12 The TMJ Concepts prosthesis is a custom-fitted device. The fossa component is composed of pure titanium shell fitted to the fossa with the shell covered in a titanium mesh. The mesh allows osteointegration of the bone in the fossa with the prosthesis. The mesh also provides a method to attach the polyethylene articular portion. The mandibular strut is made of titanium alloy, and the condylar head is chromium cobalt alloy. This prothesis is mounted on a 3D stereolithic model constructed with virtual surgical planning to place the maxilla and mandible into their new and final position along with a genioplasty

diameter. The fossa component is stabilized with four bone screws, and the mandibular component is usually designed to accommodate eight to nine bicortical bone screws. The fossa component is designed with a posterior stop that keeps the condyle of the mandibular component into a stable home base position.

There are numerous published research studies evaluating the outcomes using TMJ Concepts prostheses. Only a few of the studies will be presented herein. Mercuri et al. [30] published a multicenter study in 1995 presenting the outcomes of 215 patients (202 females, 13 males) with 363 total joint prostheses placed. The average age of the patients was 40.9 years with a mean follow-up of 48 months. The study revealed a 58% decrease in pain, a 51% increase in jaw function, a 55% increase in dietary consistency, and a 27% increase in maximum incisal opening. The greater the number of previous TMJ surgeries, the less favorable the outcomes.

Wolford et al. [31] published a 5-year follow-up study in 2003 that involved 38 patients (37 females) with 68 total joint prostheses placed at the average age of 36 years. Follow-up averaged 73.5 months. The number of previous TMJ surgeries was an average of 2.9. Three groups of patients were evaluated: group 1, 0–1 previous surgeries; group 2, two or more previous surgeries; and group 3, patients with previous Proplast Teflon or Silastic implants prior to placement of the total joint prostheses. In all three groups, the incisal opening improved, and the pain levels decreased, with the best pain outcome for group 1 and the worse with group 2 that had two more previous TMJ surgeries. Jaw function improved in all three groups.

Coleta et al. [32] performed a stability study with bilateral TMJ Concepts total joint prostheses used to reconstruct the TMJs and advance the mandible in 47 females that required counterclockwise rotation of the maxillomandibular complex. Pogonion advanced a mean of 18.4 mm and AP relapse was −0.1 mm. Occlusal plane was rotated counterclockwise with a decrease in angulation of −14.9°, and the relapse was 0.6°. Maxillary incisors advanced 5.6 mm with a relapse of −0.4 mm. The oropharyngeal airway increased an average of 4.9 mm. This study demonstrated the significant stability of the maxillomandibular complex undergoing counterclockwise rotations with the use of the TMJ Concepts total joint prostheses used to reconstruct the TMJs and advance the mandible (Figs. 8.13, 8.14, and 8.15).

Pinto et al. [33] evaluated the same 47 female patients receiving total joint prostheses and counterclockwise rotation of the maxillomandibular complex. There was a statistically significant improvement in facial pain, headaches, TMJ pain, jaw function, diet, disability, and incisal opening. There was a decrease in excursion movements. Fewer previous surgeries resulted in better outcomes in all parameters.

Wolford et al. [34] published a prospective cohort study evaluating 56 patients using Techmedica/TMJ Concepts patient-fitted TMJ TJR devices from 1989 to 1993. Median follow-up was 21 years. Mean age at surgery was 38.6 years. Median number of previous TMJ surgeries was 3. Presurgery and longest follow-up data comparison demonstrated statistically significant improvement for maximum incisal opening, TMJ pain, jaw function, and diet. At longest follow-up, 48 patients (86%) reported improved quality of life, 6 patients (11%) remained the same, and 2 patients (4%) were worse. Increased number of previous surgeries resulted in lower levels of improvement for TMJ pain and maximum incisal opening.

Numerous studies have been published by Wolford et al. [20, 21, 31–43], Mercuri et al. [30, 44–54], and others [55, 56] in reference to outcome data using TMJ

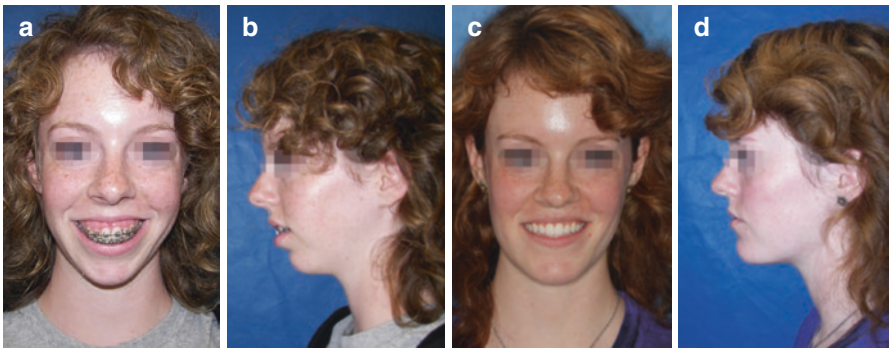

Fig. 8.13 (**a**) A 16-year-old female with bilateral TMJ adolescent internal condylar resorption (AICR) with non-salvageable discs and significant condylar resorption coupled with anterior maxillary vertical hyperplasia. (**b**) Shows the profile illustrating the retruded maxilla and mandible. (**c**) Is a 2-year follow-up that included bilateral TMJ reconstruction and mandibular advancement with the TMJ Concepts total joint prosthesis coupled with superior repositioning of the maxilla and a genioplasty. (**d**) Demonstrates the improvement in the profile

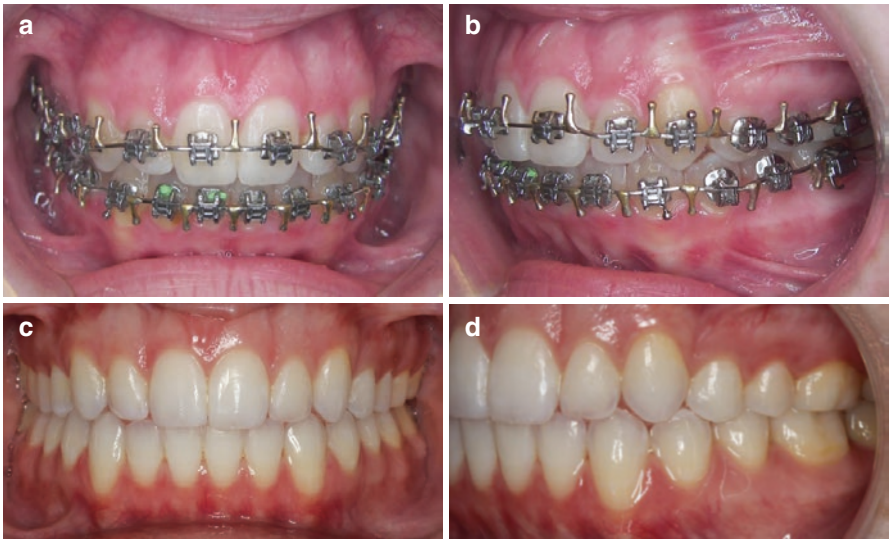

Fig. 8.14 (**a, b**) Demonstrates the presurgical occlusion. The patient has been in orthodontics for an extended time period enabling the orthodontist to keep the occlusion reasonably aligned. (**c, d**) shows the 2-year follow-up occlusal relationship

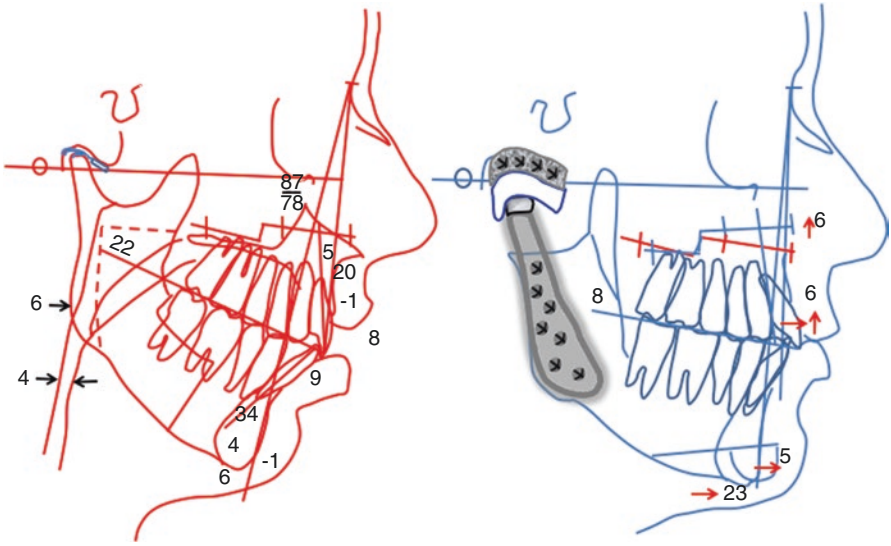

Fig. 8.15 (**a**) Lateral cephalometric analysis shows the maxillary vertical hyperplasia but AP hypoplasia of the maxilla and mandible and the high occlusal plane angle facial morphology. (**b**) The prediction tracing illustrates the counterclockwise rotation of the mandible using TMJ Concepts total joint prostheses as well as maxillary osteotomies to move the anterior maxilla upward in a counterclockwise direction. Genioplasty was performed to augment the chin and finalize the profile change

Concepts total joint prostheses. A summary of these publications have produced the following facts in reference to the TMJ Concepts total joint prostheses:

1. TMJ Concepts prostheses are superior to autogenous tissues for end-stage TMJ reconstruction relative to subjective and objective outcomes.
2. After two previous TMJ surgeries, autogenous tissues have a high failure rate, whereas patient-fitted total joint prostheses have a high success rate.
3. No donor site morbidity.
4. Increased number of previous TMJ surgeries produces a lower level of improvement related to pain and function outcomes compared to patients with 0–1 previous TMJ surgeries.
5. Failed TMJ alloplastic reconstruction (i.e., P/T, Silastic, metal-on-metal articulation, etc.) can create a foreign-body giant cell reaction and/or metallosis, best treated by joint debridement and reconstruction with patient-fitted total joint prostheses.
6. Fat grafts packed around the articulating area of the prostheses improve outcomes relative to decreased pain, improved jaw function, and decreased requirement for repeat surgery.
7. Osseointegration of the TMJ Concepts fossa and mandibular components occurs and is important for long-term stability.
8. Posterior stop on the fossa component is important to stabilize the joint, jaw position, and occlusion.
9. Concomitant orthognathic surgery can be performed at the same time as the TMJs are reconstructed.
10. 20-year follow-up study [34] demonstrated improvements in pain, jaw function, diet, incisal opening, and quality of life.

Advantages of the TMJ Concepts system:

1. Patient-fitted device for the patient's specific anatomical and functional requirements.
2. Metal-on-polyethylene articulation; the gold standard in orthopedics.
3. Surgeon has input for device design.
4. The fossa and mandibular components osseointegrate.
5. Posterior stop on the fossa essential for predictable control of the occlusion and facilitates concomitant orthognathic surgery.
6. A 3D stereolithic model is produced to aid in surgical preparation as well as the design and manufacturing of the devices.
7. Orthognathic surgery can be performed concomitant with the TMJ reconstruction. Enables the correction of minor to severe dentofacial deformities.
8. Large resections of the mandible for tumor removal can be reconstructed.

The disadvantages of this device are:

1. Requires presurgical planning and 3D stereolithic model preparation.

2. Manufacturing of the device takes 12 weeks.
3. May require two-stage surgery for removal and reconstruction of failed metallic TMJ prostheses (i.e., Christensen or nexus devices).
4. Alterations to fossa and ramus performed on the 3D model must be accurately duplicated on the patient.

8.16 Comparative Studies for Autogenous Versus Alloplastic Condylar Replacement

There are few published studies evaluating outcomes for condylar replacement comparing autogenous versus alloplastic reconstruction. Henry and Wolford [35] compared autogenous tissues versus Techmedica (currently manufactured by TMJ Concepts) total joint prostheses in patients who had failed Vitek Proplast/Teflon inter-positional implants or Vitek/Kent total joint prostheses. There were 107 patients in this study with a mean follow-up of 4 years. The following autogenous graft systems were used, and the percentage of success is in parentheses:

1. Costochondral grafts (12%)
2. Sternoclavicular grafts (21%)
3. Dermal grafts (8%)
4. Temporofascial grafts (13%)
5. Temporofascial grafts in conjunction with sagittal split osteotomies (31%)
6. Auricular cartilage (25%)
7. Techmedica total joint prostheses (86%)

These multiply operated patients who had previously failed alloplastic implants demonstrated extremely poor outcomes with the use of autogenous tissues where the success rate ranged from 12 to 31%. The Techmedica total joint prostheses had a relatively high success rate (86%).

Frietas et al. [57] evaluated 12 patients with 24 operated joints. Six patients received costochondral grafts or sternoclavicular grafts, and six patients received TMJ Concepts total joint prostheses. The follow-up ranged from 48 to 58 months. The total joint prostheses provided statistically significant better objective and subjective outcomes, decreased the operating room time, and produced significantly better skeletal and occlusal stability particularly when the maxilla and mandible were advanced.

Wolford et al. [58] evaluated 13 patients with TMJ ankylosis from the age of 5 to 15 years. Four patients received costochondral grafts, six sternoclavicular grafts, and three total joint prostheses with a follow-up of 2–13 years. Seven of the 13 patients had fat grafts packed around the reconstructed TMJs. Of the four costochondral grafts, three grafts demonstrated excessive growth. None of these grafts had fat placed around and all four re-ankylosed. Four patients received sternoclavicular grafts and had fat grafts packed around the articulating area of the grafts. There was no re-ankylosis in this group, and they had good jaw function, although decreased translation ability. Two of the sternoclavicular grafts did not receive fat grafts and both re-ankylosed. With the sternoclavicular grafts, any that had

significant mandibular advancement also experienced some relapse as the grafts remodel some under increased loading to the joints that occurs with mandibular advancement. The three patients that received the total joint prostheses had fat packed around the prostheses. There was no re-ankylosis nor mandibular relapse. The incisal opening presurgery ranged from 2 to 29 mm, and post surgery ranged from 35 to 52 mm, demonstrating good outcomes with the total joint prostheses. The use of fat grafts packed around the articulation area of the autogenous sternoclavicular grafts and around the total joint prostheses prevented re-ankylosis of the TMJs.

Saeed et al. [59] evaluated 49 patients receiving 66 costochondral grafts and 50 patients with 68 total joint prostheses using the Christensen system with metal-on-metal articulation. Mean follow-up ranged from 43 to 49 months, and mean age was 38 years. The authors reported complications in 27 patients receiving costochondral grafts and 34 patients that received the total joint prostheses. However, the authors reported 26 of 49 patients (53%) required reoperation in the costochondral graft group, whereas only 6 of 50 patients (12%) receiving the total joint prostheses required reoperation by the end of the study period. The total joint prostheses provided better subjective and objective outcomes. The authors' recommendations from this study were that total joint prostheses are recommended in cases of ankylosis, multiply operated joints, and previously failed alloplastic implants.

These comparative studies demonstrate the following:

1. Total joint prostheses provide better outcomes relative to pain, function, stability, and esthetics compared to autogenous grafts.
2. Total joint prostheses eliminate the requirement for bone graft harvest, but it is recommended that fat be harvested and packed around the functioning area of the prostheses.
3. With the use of total joint prostheses, concomitant TMJ and orthognathic surgery can be performed at the same operation with highly predictable outcomes relative to stability, function, esthetics, and decrease in pain.
4. Total joint prostheses work better in poorly vascularized tissues and multiply operated TMJs as do vascularized grafts, compared to free autogenous grafts.
5. Patient-fitted total joint prostheses do require presurgical preparation that is more extensive than autogenous tissues or off-the-shelf total joint prostheses, but the surgery is significantly easier and surgery time shortened because of less surgical requirements compared to fitting the off-the-shelf devices.
6. For ankylosis cases, packing fat grafts around the articular area of the autogenous grafts or alloplastic total joint prostheses decreases the risk of heterotopic bone formation and re-ankylosis.

8.17 Prosthesis Longevity

The longevity of a prosthesis for any joint is dependent on materials, design, stability, and functional loading. When the Techmedica patient-fitted CAD/CAM TMJ prosthesis was first introduced, the only guide for joint replacement device

longevity was based on the orthopedic literature since this prosthesis was composed of the same materials considered as the gold standard in orthopedics [60, 61]. However, orthopedic stability studies could not be applied since hip prostheses were stabilized and fixated by different methods including wedging and bone cements. A big issue contributing to hip prosthesis failure involves functional loading that is based on design, materials, articulation, size of articulating components, and body weight. This results in a functional load that can range from 3.5 to 6 times the body weight [62]. Theoretically, the functional load delivered to the hip articulation in a 180-pound individual would be between 630 and 1080 pounds. For running and jumping the load maybe ten times the body weight or 1800 pounds. It is difficult to determine the functional load for the TMJ prosthesis. For the average individual, the biting forces generated at the molars are approximately 60 pounds and for the incisors 35 pounds [63]. Many of the patients requiring TMJ TJR may have significantly lower biting forces creating even lower functional loads. This may explain the longevity of the TMJ Concepts patient-fitted CAD/CAM TMJ prostheses since none of the patients in The Wolford et al. 20-year study [34] required replacement because of wear issues.

8.18 Fat Grafts

Wolford and Karras [64] introduced the use of fat grafts around the articulating area of the total joint prostheses. Earlier experiences demonstrated significant scar tissue formation as well as reactive bone around the articulating areas of the prostheses often creating pain as well as limited jaw function and requiring reoperation for debridement. The theory for using fat grafts is as follows: (1) eliminates dead space, (2) prevents blood clot formation around the total joint prostheses articulating area, (3) inhibits bone growth and fibrosis, (4) decreases pain, and (5) improves joint function.

The Wolford and Karras study [64] evaluated two groups of patients. Group 1 consisted of 15 patients (13 females and 2 males) and 22 joints (7 bilateral, 8 unilateral) that received fat grafts around the prostheses. Group 2 included 20 patients (18 females and 2 males) and 33 joints with 17 bilateral and 3 unilateral. For group 1, no additional surgery was required post surgery when the fat grafts were placed concomitantly with the total joint prostheses. In group 2 that did not receive fat grafts at the initial surgery, 35% of the patients required reoperation for heterotopic bone and/or fibrosis.

Wolford and Morales [20] reported on 115 patients receiving total joint prostheses, with all patients receiving placement of autogenous fat grafts around the articulating area of the prostheses. Christensen and TMJ Concepts prostheses were involved in this study with 88 patients receiving bilateral total joint prostheses and 27 received unilateral total joint prostheses for a total of 203 TMJs reconstructed. There were two groups divided as follows: group 1 received Christensen devices ($n = 42$ patients, 76 joints), and group 2 consisted of TMJ Concepts total joint prostheses ($n = 73$ patients, 127 joints). Of the patients who received Christensen prostheses, 25 of the 76 (33%) required removal because of severe pain due to device failure (fossa fracture) or severe

metallosis and metal hypersensitivity. Despite the problems leading to prosthesis removal, none of the patients demonstrated significant fibrosis or heterotopic bone formation around the prostheses. Four of the 127 (3%) TMJ Concepts prostheses were removed from 2 patients because of severe pain due to severe metal hypersensitivity. One patient maintained the fat grafts around her prostheses, and the second patient developed fibrotic tissues around the prostheses, but no heterotopic bone was noted. Ten patients (8.7%) developed morbidity at the fat graft donor site post surgery. Two obese patients developed abdominal cysts superficial to the rectus abdominis muscles that required surgical removal, and eight patients developed seroma formation requiring aspiration. The results of this study support the efficacy of autologous fat grafts in TMJ total joint prosthetic reconstruction. A statistically significant improvement for both groups was found regarding MIO and patient's perception of jaw function. The removal of 29 prostheses over a follow-up period of 12–65 months was due to problems other than fat graft-related complications.

The most common donor site for fat harvesting is the abdomen, where there is usually abundant or at least adequate fat for most cases. The most common approaches the author uses include the suprapubic incision, the umbilical or transnaval incision, or approach through a preexisting scar (e.g., C-section, hysterectomy, appendectomy, abdominoplasty). However, the fat can be harvested from almost any fat source including buttock, thigh, buccal fat pad, breast, etc. Following fat harvest, good hemostasis of the donor site is required and a pressure dressing applied along with an abdominal binder (for abdominal donor site) for 3–4 days post surgery to prevent hematoma or seroma formation. If adequate hemostasis cannot be achieved, then a drain with negative pressure may be indicated for a few days.

Autogenous tissue grafts have been advocated by some surgeons for TMJ reconstruction [1]. However, some of these aforementioned TMJ conditions can have an adverse effect on the viability of autogenous tissue grafts as well as the physiological impact on the grafts, resulting in a significant incidence of graft failure. The potential risks and complications provide additional concerns when considering and utilizing autogenous tissues. Therefore, TMJ reconstruction with total joint prostheses should be a primary consideration when TMJ condylar replacement is required. TMJ alloplastic replacement usually provides a more predictable outcome for patients with any of the end-stage TMJ conditions.

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9 Complications in Total Temporomandibular Joint Reconstruction

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Surgeons undertaking TMJ surgery of any kind are aware of all the usual postsurgical issues and complications associated with surgical approach and access to the joint, such as scar, bleeding, swelling, injury to facial nerve branches, and pain. Good surgical technique can mitigate the risk of unpleasant scar, excessive bleeding, and injury to the facial nerve. Perioperative steroid administration to minimize surgical edema is as useful in TMJ surgery as it is in orthognathic surgery, and postoperative pain is managed in the same way as for other reconstructive surgeries. This chapter will cover the types of complications or findings that arise specifically from total joint reconstruction and will provide guidance for the surgical team ranging from how to mitigate the risk of these events to how to treat complications should they arise.

9.1 Most Common Complications Requiring Postoperative Intervention

The four complications that most commonly result in the need for a postoperative intervention of some kind (manipulation of the joint, revision surgery, or re-do surgery) are: dislocation, infection, hardware failure, and hardware design error.

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9.1.1 Dislocation

The placement of a prosthetic joint requires the detachment of the muscles of mastication, which increases the risk of the condylar component dislocating. The masseter muscle is detached from the mandible in order to install the mandibular component of the total joint prosthesis. The lateral pterygoid muscle is detached by the removal of the native condylar head, and the temporalis muscle insertion at the coronoid process is eliminated if a coronoidectomy is done. Joint dislocation risk is highest in the first 48 h following total joint reconstruction (TJR), especially in bilateral cases. Frequently, the problem is noted while the surgical team is still in the operating room and the patient is in the process of emerging from anesthesia. Other times, the patient is noted to have a new, significant malocclusion on postoperative day 1 or 2 (Fig. 9.1). The TMJ Concepts prosthesis displacement usually occurs when the condylar component displaces anterior to the fossa component, and less commonly laterally or medially. The Biomet prosthesis displacement, typically occurring when the condylar component displaces posterior to the fossa component, is related to the absence of a posterior stop. Displacement of the prosthetic condylar head occurs much less commonly laterally, medially, and anteriorly (Fig. 9.1).

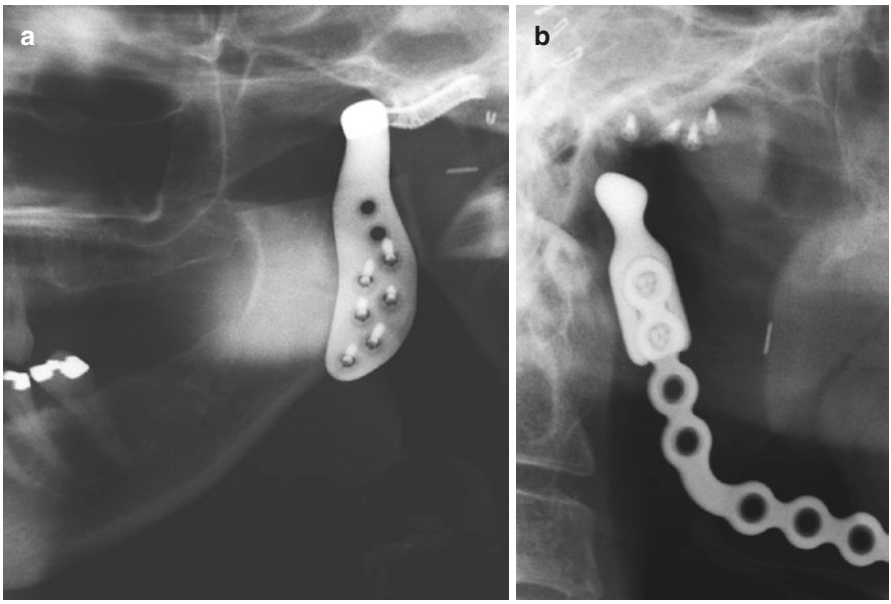

Fig. 9.1 (**a**) The mandibular component of the TMJ Concepts custom prosthesis is dislocated anterior to the prosthetic fossa on postoperative day 2. The titanium mesh supporting the polyethylene fossa (not visible) is seen on x-ray. (**b**) The patient required temporary stabilization of the mandible following jaw resection. The head of a temporary condylar prosthesis articulating against a Biomet polyethylene fossa (not visible on x-ray) is shifted posterior to the fossa component. Only the screws fixating the polyethylene fossa are visible but the condylar head is more posterior than the posterior-most screw, which is not how the mandibular prosthesis was originally positioned

Preoperative considerations: Patients with a significant history of presurgical dislocation from joint hypermobility may require a custom fossa prosthesis that is angled down more steeply at the anterior aspect, to corral the prosthetic joint and prevent postoperative anterior dislocation.

Prevention: While placing the mandibular component in position, aim to position the condylar head toward the posterior aspect of the fossa. This gives the prosthetic joint head a little extra room to "translate" forward if the patient opens wide postoperatively. Because most dislocations occur within the first 48 h, and often within the first few minutes of recovery from general anesthesia, maintenance of maxillomandibular fixation for at least 2 days is advised. Lighter guiding elastics may be employed for several more days or weeks, especially if patient has difficulty finding his/her occlusion or if both joints were replaced. Elastics will provide assistance for the mandible and improved comfort for the patient until the masseter muscle can attach on the surgical side, which may take several weeks following surgery. One may consider leaving the coronoid process in place if the patient had good preoperative mandibular opening. If only the TMJ prosthesis is placed with no concomitant orthognathic surgery requiring counterclockwise rotation or significant advancement, the coronoid and temporalis muscle can remain attached. Leaving the temporalis attachment intact at the coronoid process might help decrease risk of postoperative dislocation, however this may come at the risk of a more limited postoperative opening due to the pull of a strong temporalis muscle. If the surgical plan does call for significant counterclockwise rotation of the maxillomandibular complex, a custom-fitted TMJ Concepts prosthesis with a posterior stop in the fossa component will afford a decreased risk for posterior condylar displacement.

For patients who may require resection of the ramus and the placement of an extended TMJ total joint prosthesis, the anterior displacement risk is very high as the pterygoid-masseteric sling will not be stable to vertically support the mandibular component in the fossa. In this situation when using a custom prosthesis, a preplanned hole can be placed through the head of the mandibular component to support an artificial "ligament" to stabilize the condyle in the fossa. A double-armed #5 braided polyester suture is placed through the hole in the condyle and each end passed through the posterior flange of the fossa component and tied behind the posterior flange of the fossa component. This thick, nonresorbable suture has excellent tensile strength and increased knot security due to the braiding.

Maxillomandibular fixation via screws, temporary anchorage devices (TADs), or hybrid arch bars can be screwed into the maxillary and mandibular alveolar bone, instead of traditional arch bars. Orthodontic appliances or arch bars and elastics can extrude or displace teeth due to the attachment to dental units and vertical tension created from the elastics.

Treatment: If anterior displacement occurs and identified early, manual manipulation with a downward and posterior movement similar to repositioning a displaced natural condyle will usually be effective in reduction. If out of place for more than a couple days, then for patient comfort, general anesthesia or IV sedation may be necessary to reposition a prosthetic joint should it become dislocated. Repositioning will require a significant downward and posterior vector on the mandible, due to the

presence of the fossa's anterior lip of polyethylene for both custom and stock prostheses. Long-term anterior displacement may result in foreshortening of the pterygomasseteric sling restricting manual manipulation and may require surgery to detach the pterygo-masseteric and temporalis musculature in order to disengage the condylar component from its anterior and superior displacement. If posterior displacement occurs in stock prosthesis cases due to lack of a posterior lip of polyethylene, especially when the patient's occlusion has a large centric relation-centric occlusion (CR-CO) slide, the patient might respond to weeks of training with guiding elastics to draw the mandible forward. If not, it may ultimately become necessary to replace the stock joints with custom joints.

9.1.2 Infection

The diagnosis of prosthetic joint infection may be challenging because the signs and symptoms can be intermittent or very subtle and infection workup is hampered by significant imaging limitations or negative laboratory findings. Infection may end up being the diagnosis of exclusion, and long delays in reaching that determination are common. Once an infection is identified, it must be vigorously treated. Much of what our specialty knows about joint prostheses infection comes from the orthopedic literature and research relevant to hip and knee joint replacement. The incidence of infection for hip or knee arthroplasty is estimated to be in the range of 0.9–2.5% [1–3], with the range due in part to whether superficial surgical site infections are considered along with deep prosthetic joint infections. Published data on the infection rate for TMJ total joint prostheses is limited. McKenzie reported an infection rate of 4.5% in a series of 178 joints [4], while Wolford reported an infection rate of 1.6% in a series of 579 joints [5]. Thus the overall incidence of infection for TMJ total joint prostheses for these two studies combined is 2.2% (17 infections in 757 prosthetic joints). Another study published data from a survey of TMJ surgeons. The reported infection rate was 1.51% overall, with most infections appearing within the first 6 months of joint replacement [6]. Most of the infected prostheses in this survey required removal.

As trends go, more microorganisms that may be responsible for periprosthetic joint infections have become resistant to antibiotics, and patients who are candidates for TMJ prosthetic joint replacement may present with more comorbidities than ever before. As a result, it is important to recognize the various patient-specific factors, surgery-specific factors, and postoperative-related factors that can increase the risk of infection [7–10]. Based largely upon the orthopedic literature and the author's experience, the risk factors are discussed below.

Perioperative Considerations: Some of the risk factors can be positively modified or eliminated, to improve the odds of a successful surgical outcome.

Patient-specific risk factors

- Obesity BMI ≥ 35 kg/m^2
- Diabetes
- Cardiovascular disease

- Older age
- Genetic predisposition
- History of multiple invasive joint operations at the same site
- History of infection at surgical site
- Immunosuppression secondary to medications and chronic diseases (e.g., chronic renal disease, hemodialysis, or organ transplantation, cancer treatment, cirrhosis)
- Malnutrition
- Poor body hygiene
- Rheumatoid arthritis and treatment
- Anticoagulants
- Infection at remote site (e.g., skin, urinary, digestive, respiratory, and dental infection)
- Bacterial colonization (urinary tract, nares)
- Smoking
- Alcoholism
- Intravenous drug use
- Socioeconomic status (associated with many of the comorbidities listed above)

Surgery-specific risk factors
- Duration of surgery
- Suboptimal antimicrobial prophylaxis
- Blood transfusion
- Operating room traffic or number of persons within the operating room
- Cross-contamination from the oral cavity, ear, or hair

Postoperative-related risk factors
- Wound or incision factors (e.g., wound dehiscence or necrosis, hematoma, superficial infection)
- Presence of a surgical drain
- Atrial fibrillation, myocardial infarction, urinary tract infection
- Prolonged hospital stay
- *Staphylococcus aureus* bacteremia

9.1.2.1 Diagnosis

In 2013, the Musculoskeletal Infection Society published revised criteria for periprosthetic joint infections (PJI). These criteria have been widely adopted by the orthopedic community although it is also acknowledged that PJI may exist without meeting these criteria, especially in the case of less virulent organisms. The PJI diagnosis requires a positive finding for one of the major criteria or a positive finding for three out of five of the minor criteria [11, 12]. Although these criteria apply to orthopedic joint infections, we may be able to apply much of the information to TMJ prostheses infections.

Major criteria (one of two criteria must exist)
- Two positive periprosthetic cultures with phenotypically identical organisms
- Sinus tract communicating with the joint

Or,

Minor criteria (three of five criteria must exist)
- Elevated serum C-reactive protein (CRP) ≥ 10 mg/L *and* erythrocyte sedimentation rate (ESR) ≥ 30 mm/h
  - Comment: A positive result in CRP and ESR is nonspecific to joint infection. Multiple conditions can elevate CRP and ESR. In addition, CRP may be normal in patients with chronic and low-grade prosthetic orthopedic joint infection [13].
- Elevated synovial fluid white blood cell (WBC) count ≥3000 *or* ++ change on leukocyte esterase test strip
  - Comment: Synovial WBC count may be altered by inflammatory conditions or immunocompromised. Leukocyte esterase test strip results are often affected by blood and debris in the sample and cannot be interpreted.
- Elevated synovial fluid polymorphonuclear neutrophil (PMN) percentage ≥80%
- Positive histological analysis of periprosthetic tissue >5 neutrophils per high-power field in five high-power fields
- A single positive culture

Causative organisms associated with orthopedic prosthetic joint infection are staphylococcal species (e.g., *S. aureus* and especially MRSA in the United States), and coagulase-negative staphylococci (e.g., *S. epidermidis*, *S. haemolyticus*, *S. hominis*, *S. warneri*) are estimated to cause at least half of the prosthetic joint infections [9, 14]. The coagulase-negative staphylococci can also be a culture contaminant, which complicates culture interpretation. It has been noted that early PJI infections that appear within the first 3 months are usually *S. aureus*. In contrast, infections appearing after 3 months tend to be coagulase-negative staphylococci [15]. Negative cultures, despite clinical evidence for infection, may be encountered when prior antibiotic therapy has been instituted. Among the bacteria cultured in TMJ joint prostheses infections, the most common culprits appear to be *Staphylococcus aureus*, MRSA, coagulase-negative staphylococci, *Pseudomonas aeruginosa*, alpha-hemolytic streptococcus, *Serratia*, *Peptostreptococcus*, and *Propionibacterium acnes* [4–6, 16].

Propionibacterium acnes, a low-virulence anaerobic Gram-positive bacillus, has emerged as a leading cause of PJI in shoulder prosthesis infections and can be encountered in TMJ prostheses infections as well. To rule-in or rule-out a *P acnes* infection, the culture should be held by the lab for two weeks. This pathogen has been shown to preferentially colonize the skin above the shoulder, as opposed to the skin around the knee or hip, and may be in higher numbers in males than females [17].

Recently, the diagnosis of PJI has markedly improved through the use of biomarkers. Of the synovial fluid biomarkers that have been studied, alpha-defensin was found

to be the best candidate for the development of an immunoassay test [18] commercially available as the Synovasure Alpha-Defensin test (Zimmer Inc., Warsaw, IN, USA). Alpha-defensin is an antimicrobial peptide released by neutrophils in response to pathogens; it can cause depolarization of the bacterial cell membrane resulting in bacterial cell death [19, 20]. Due to its high sensitivity (97–100%) and specificity (95–100%), ease of use, quick results, and resistance to influence by antibiotics, metallosis, and systemic inflammatory disease, alpha-defensin is an excellent biomarker for PJI [21–25]. The test has not yet been validated to diagnose infection in a native joint or to confirm the presence or absence of infection prior to reimplantation. In addition, its use in the diagnosis of TMJ prosthesis infection has yet to be established and may be hampered by the difficulty in collecting scant synovial fluid.

9.1.2.2 Prevention

A significant risk for infection in TMJ total joint reconstruction cases comes from the ear, followed by poor attention to sterile technique to keep oral, nasal, and hair/scalp bacteria from entering the wound. The following preventative measures are recommended for all total joint cases, based on clinical experience and literature review:

1. Address patient-specific risk factors above, as part of the patient selection criteria, and optimize those factors that can be improved.
2. Reduce OR traffic to a minimum by posting warning signs on the OR door and limiting entry/exit to the OR through one door. Position the patient and instrument table away from the door in use for entry and exit.
3. Administer preoperative antibiotic dose within 1 h of incision. A cephalosporin combined with a beta-lactamase inhibitor is a good choice in non-allergic patients. A typical regimen is ampicillin-sulbactam (Pfizer, New York City, NY, USA), 3 grams IV as a single dose within 60 minutes prior to surgical incision, with intraoperative re-dosing every 2 h up to 3 times, then change to 1.5 g or 3 g IV every 6 hours. For penicillin-allergic patients, clindamycin or vancomycin is recommended. Strictly follow antibiotic re-dosing guidelines, especially in long cases.
4. In bilateral joint cases when the mandibular position will not be changed, place the prosthetic joint on one side, and close the wound completely prior to addressing the contralateral side. When the mandibular position will be altered, carry out the bilateral surgical dissection and joint resection, and then implant the prosthesis on one side and close the wound fully, followed by implantation of the second prosthesis and wound closure on the contralateral side.
5. Avoid shaving the patient's facial hair, or shave facial hair >24 h in advance to avoid small nicks or cuts that can introduce skin contaminants.
6. Patient should shower and shampoo with a chlorhexidine gluconate (CHG) bath product the day prior to surgery.
7. Prior to draping the patient, gently irrigate the ear canal on the surgical side for 5 min using povidone-iodine solution with a syringe and blunt tip catheter (Fig. 9.2 left), or use a chlorhexidine swab to clean the ear canal.

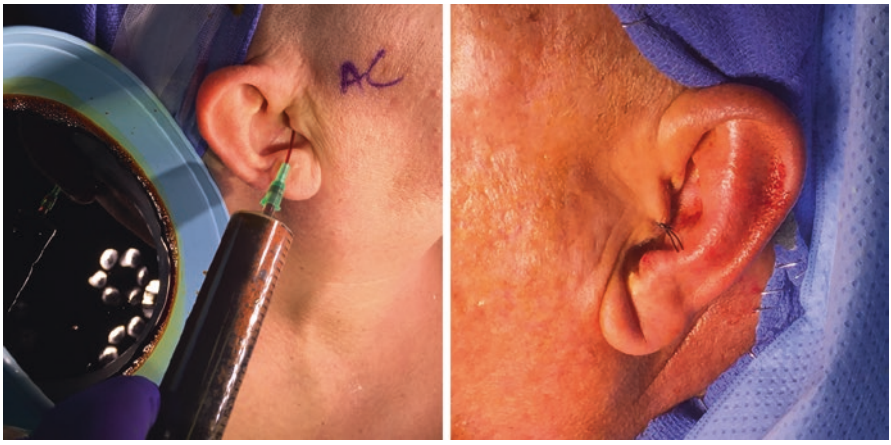

Fig. 9.2 Left: The ear canal is irrigated directly with povidone-iodine to reduce risk of infection from skin contaminants. Right: The tragus is closed with a single suture to prevent Xeroform gauze packing from falling into the wound and potentially contaminating the surgical field

8. Place a small Xeroform (Medtronic, Minneapolis, MN, USA) gauze strip within the external auditory canal, mark the preauricular or endaural incision with a sterile marking pen, and suture the tragus closed with a mattress suture to prevent the Xeroform gauze from falling out (Fig. 9.2 right). When the tragus is sutured closed, it may slightly distort the skin and tragal cartilage and make it more difficult to mark the incision.
9. Keep hair away from the preauricular wound by parting the hair or trimming it with a clipper, but shaving the head is to be avoided due to the possibility of introducing bacteria through small nicks and cuts.
10. Liberal use of sterile towels, paper drapes, clear adhesive drapes, and clear adhesive dressings over the face, neck, and mouth.
11. When placing the patient into maxillomandibular fixation prior to implantation of the prosthesis, designate one surgeon as the "dirty" surgeon and that individual re-scrubs and gowns before rejoining the case. The intraoral instrumentation is kept completely separate, and suction and light handles are changed if they were contaminated with intraoral flora.
12. Do not open prosthetic components until the moment of implantation. If components are opened prematurely, store them in antibiotic-containing solution.
13. Use irrigation with antibiotic throughout the case or after implantation of the prosthesis, prior to closure. Common regimens are vancomycin 1 g per one liter of sterile saline, or Bacitracin 50,000 units per one liter of sterile saline.
14. Close the incision in several well-defined layers.
15. Avoid the use of drains. Drains are often mishandled postoperatively, and introduction of bacteria deep into the wound is possible. It is best to employ meticulous control of bleeding through the use of vessel ties and clips, Bovie, or bipolar cautery.

16. Apply a pressure dressing for 1–2 days to prevent hematoma.
17. Remove the indwelling Foley catheter early to minimize the development of a urinary tract infection.
18. Postoperative antibiotic regimen is intravenous while the patient is in the hospital. Following discharge, an oral antibiotic regimen is recommended for 7 days, although there is not strong evidence for this practice. The antibiotic selected should cover the skin, ear, and oral flora.
19. Patient education: Upon discharge, patients should be educated regarding hand hygiene, incision care, shaving, showering, and hair washing. Incisions should not be handled by the patient except to apply a thin layer of an antibiotic ointment with clean hands or disposable gloves. Shaving in the area of the incision should be avoided. Unless strict care is taken, showering and hair washing tends to soak the incision sites. A lightly moistened washcloth can be used for cleaning the head and neck areas, including the hair.
20. Following total joint replacement of the TMJ, the use of prophylactic antibiotics prior to invasive dental procedures is not supported by data. However, it is an option to use it for at least 2 years postimplantation. The tips of the screws of the mandibular component of the prosthesis lie within the pterygomandibular space and may come into contact with oral flora through the introduction of the needle used for inferior alveolar blocks. Thus, in addition to invasive dental procedures that may release blood-borne pathogens, any dental procedure that requires an inferior alveolar block on the surgical side should stimulate the need for standard orthopedic-style oral antibiotic prophylaxis.

9.1.2.3 Treatment

TMJ prosthesis infections arising acutely within the first few days to weeks following surgery are often superficial and have been managed with retention of the prosthesis in many patients via a technique described by Wolford et al. [5] that includes IV antibiotics via a peripherally inserted central catheter (PICC line), surgical debridement, scrubbing of the prosthesis in situ, and placement of irrigating catheters and drains. Patients with chronic PJI were successfully treated with removal of the prosthesis, and placement of an acrylic spacer and irrigating catheters/drains (Stage I surgery), followed by reconstruction with a new prosthesis several months after the infected prosthesis, was removed (Stage II surgery). As with the acute infection cohort, the chronically infected patients also received a PICC line for outpatient antibiotic therapy for 4–6 weeks. After removing infected prostheses and placing antibiotic-impregnated bone cement as a spacer, Mercuri reported that he was able to salvage the original custom mandibular prosthesis after 3 months by passivating the surface of the prosthesis, re-sterilizing it, and reimplanting it against a new custom fossa [26]. The polyethylene component of the fossa prosthesis cannot be re-sterilized. In the series of eight PJI cases offered by McKenzie, all patients underwent removal of the infected prosthesis without placement of a spacer and a course of IV antibiotics.

Table 9.1 Suggested protocol when total joint prosthesis infection is encountered

Procedure	Comment
Labs: CBC with differential, serum CRP and ESR	Lab testing is likely to be within normal limits in many infection cases
Imaging: CT with contrast, ultrasound to look for possible fluid collection, nuclear medicine scan	Imaging is likely to be negative or equivocal
If fluid collection found, aspirate under sterile conditions and send for anaerobic culture	If possible, use joint aspirate for Synovasure test
Removal of joint prosthesis and placement of antibiotic-impregnated bone cement as spacer, or place silicone orbital implant as a spacer (available in sizes from 12 to 22 mm diameter)	Send tissue, exudate and prosthetic components for culture. Order gram stain, aerobic and anaerobic culture. Ask micro lab to hold cultures for 2 weeks to determine if there is a *P acnes* infection. Send tissue for pathology.
Place in MMF to help patient maintain occlusion	
PICC line for home IV therapy, guided by culture results and infectious disease (ID) consultation	Typical regimen is 6 weeks of home IV therapy
Monitor WBC, CRP, ESR throughout course of treatment	Downward trend should be maintained if values were initially elevated
Discontinue home IV therapy after 6 weeks, and begin oral antibiotic course if advised by ID consultant	
Implantation of new joint no earlier than 3–6 months following explantation of contaminated prosthesis	If custom joint is planned, obtain new CT scan for TMJ concepts

Most patients underwent implantation of new prostheses after complete resolution of the infection [4].

Based on the available literature cited above and clinical experience, the following treatment protocol is recommended for chronic PJI (Table 9.1):

9.1.3 Hardware Failure

Hardware failure may result in an acute change in occlusion and a sudden escalation in pain. Fracture of hardware components is fortunately uncommon, but when it occurs, it is often difficult to visualize on radiographs due to artifact from the metal prosthesis itself and thus may go unrecognized for longer than it should (Fig. 9.3). Screws used in the custom and stock TMJ prostheses are not the locking screw variety often used in mandibular reconstruction plates; if the bone around the screw thread becomes lytic, the screw will loosen quickly, and under function, the situation may cause other screws to loosen as well.

Preoperative considerations: Careful attention should be paid to the preoperative CT scan to look for bony irregularities that may prevent solid seating of the components.

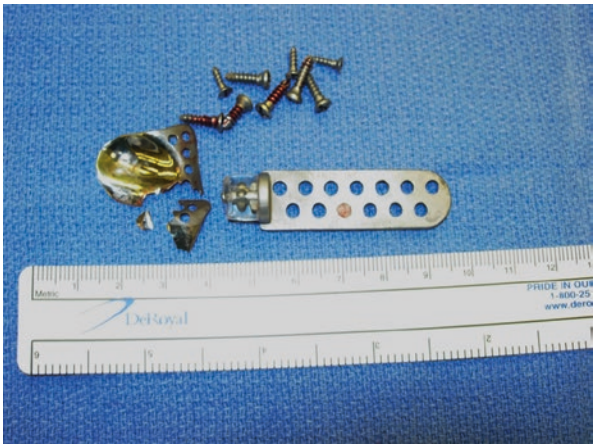

Fig. 9.3 Fracture of the fossa component in a Christensen stock TMJ total joint prosthesis. The patient underwent explantation of the entire prosthesis and eventual reconstruction with a custom prosthesis

Prevention: For custom fossa and mandibular components, bony irregularities must be dispensed with if it is indicated in the TMJ Concepts surgical plan. For cases where a stock prosthesis is being used, take the time to ensure that the underlying bone is as adapted and smoothed as possible to accommodate the prosthetic components without rocking or a significant gap. Regardless of whether a custom or stock prosthesis is used, each fossa component should have four screws, and each mandibular component should have at least six screws. The screws should be tight, but if not, use the emergency screws provided. Despite careful technique, occasionally a gap develops under the mandibular prosthesis between it and the bone, particularly if the screw holes selected are all at the lower end (Fig. 9.4). In theory, this will recreate an unsupported lever arm that could lead to prosthesis micromovement under function and ultimately screw failure. In placing the screws, select a lower screw hole first, lightly tighten the screw, and then select an upper screw hole. Drill and tighten an upper screw into place, then return to the lower screw, and tighten it all the way.

Treatment: Mandibular components are so sturdy that they do not fracture, but there is no choice but to remove and replace a fractured fossa component should there be a fracture of the TMJ Concepts titanium mesh supporting the UHDPE fossa. Although such a fracture is extremely rare, it is usually related to the surgeon improperly positioning the fossa component with a residual "rock" in the device. Unlike the mandibular component, which is designed with more than six potential screw sites, if one or more screws loosen at the custom fossa component, one must remove and replace, since the fossa is usually only designed with four screw holes and no less than four are needed to hold it in place.

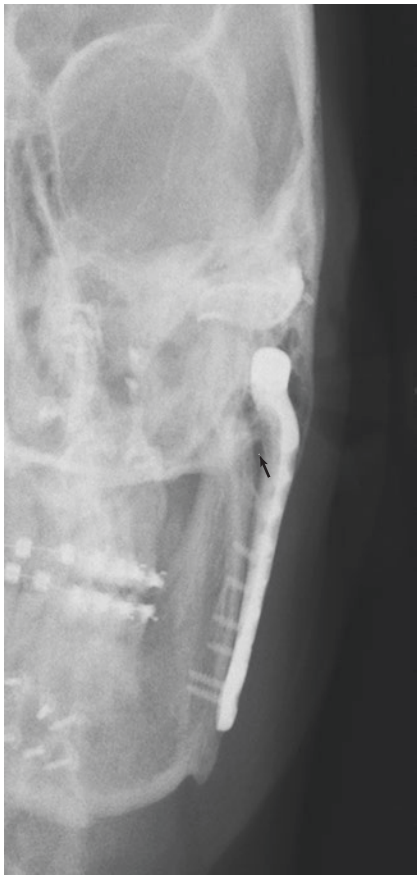

Fig. 9.4 The prosthesis is slightly lifted off the ramus of the mandible in this PA view. This may lead to screw fracture or mobility in the future

9.1.4 Hardware Design Error

A custom TMJ prosthesis has a significant obvious advantage over a stock prosthesis; it fits precisely and often drops into place assuming that soft tissue has been cleared off and bone irregularities/interferences have been removed. However, the accuracy of the prosthesis is only as good as the scan. If the surgeon indicates that the patient's presurgical occlusion is good, a one-piece stereolithic model is planned by TMJ Concepts for prosthesis fabrication, since there is no need to alter good occlusion.

Preoperative considerations: The surgeon *must verify* that the patient reproduced his or her occlusion on the CT scan, because the scan is done without the surgeon present to prompt the patient to put his or her teeth together properly. TMJ Concepts will either physically send the stereolithic model to the surgeon, email 3D reconstruction renderings of the CT scan, or both. Failure to spot that the patient did

not faithfully reproduce their normal occlusion during the CT scan will result in a prosthesis that does not fit properly; specifically the prosthetic joint head will not mate well with the prosthetic fossa, which will result in an obvious malocclusion intraoperatively. Patients with teeth worn flat due to bruxism and those with large centric relation-centric occlusion (CR-CO) shifts are particularly vulnerable to demonstrating one occlusion in the clinic while sitting in the exam chair and a different occlusion in the scanner while laying on the CT scanner bed. The CT technician cannot be relied upon to instruct patients how to bite their teeth together during the CT scan.

Prevention: Rehearse the occlusion with the patient several times prior to obtaining the CT scan. If confidence is low that the patient can distinguish when the teeth are properly touching, then it is very worthwhile to not only provide a custom acrylic splint for the patient to use during the CT scan but also provide TMJ Concepts with stone models of the patient's upper and lower arches and a bite registration. The stone models are scanned and digitally pasted into the CT scan resulting in a very faithful reproduction of the exact occlusion desired (Fig. 9.5).

Treatment: Hardware design errors are very expensive. If a hardware design error is discovered during surgery, the surgeon can abandon the custom prosthesis and place a stock prosthesis instead, which is a very good argument for being familiar with both systems and always having the stock prosthesis system on hand as a backup. Alternatively, a new custom prosthesis can be commissioned. Because hardware design errors are discovered after the native joint is already removed and prosthesis installation is attempted, a temporary spacer is needed (e.g., methyl methacrylate), and a new CT scan can be done with the patient in the ideal occlusion held by solid maxillomandibular fixation.

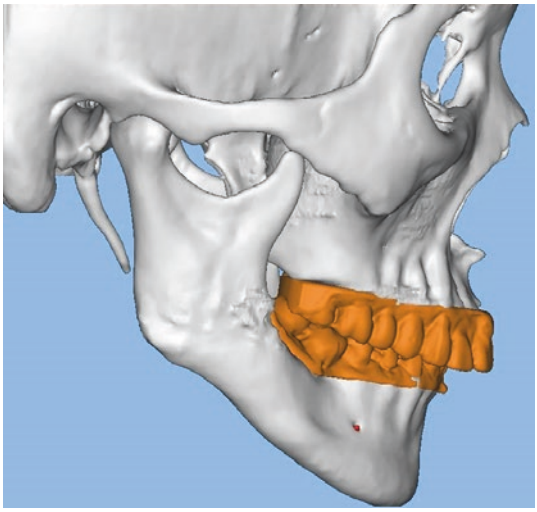

Fig. 9.5 Stone model integration into the CT scan. For patients who have severe dental attrition or who have a large CO-CR slide, a surgical splint made through CAD/CAM methods is strongly advised, even when the plan is to maintain the patient's existing occlusion during unilateral or bilateral total joint replacement

9.1.5 Pain

Pain is a nonspecific finding whose origin may be murky or varied. The etiology may include upregulation of pain receptors, neuroma formation, infection, failed hardware, metallosis, or heterotopic bone formation. Surgeons may be tempted to undertake a surgical exploration of the prosthetic joint if the pain workup is unrevealing, and physical therapy and other modalities are unable to improve the situation. Unexplained postoperative pain is one of the most frustrating problems that a TMJ surgeon can face.

Preoperative considerations: Patients with long-standing TMD chronic pain are unlikely to have sensational pain relief after total joint replacement surgery, even if function is improved. It is wise to have a conversation with the patient to lower expectations about pain relief. The surgical team should line up a chronic pain specialist who can work with the patient perioperatively, as well as a physical therapist, to be a treatment partner in the postoperative period.

Prevention and treatment: Upregulation of pain receptors is hard to prevent even when one practices very careful management of pre- and postoperative opioid consumption. Again, a chronic pain specialist is an ally in the struggle to control perioperative pain. Infection and failed hardware can certainly be responsible for chronic pain and have already been discussed in previous sections.

9.1.5.1 Neuroma Formation

Neuromas of sensory nerves can occur following surgery as a result of nerve trauma. The proliferation of unorganized nerve fascicles within a fibrotic scar can be very painful. If a neuroma of the auriculotemporal nerve is the suspected source of pain, it can be treated surgically through the exploration of the prosthetic joint and careful removal of tissue around the neck and head of the mandibular component. It is logical to blame the auriculotemporal nerve for this condition, as it is the principal sensory nerve of the TMJ. Post-traumatic auriculotemporal neuralgia has been reported as a complication of endaural incision [27]. Prior to committing to surgery, it is worthwhile to try an injection of local anesthesia and steroids at the posterior aspect of the prosthetic condyle to determine if the auriculotemporal neuralgia pain can be ameliorated.

9.1.5.2 Metallosis and Metal Allergy

Metallosis is defined as a tissue reaction to metal corrosion and metal ions released into the bloodstream by the abrasion of metallic components in medical prostheses. The tissue reaction consists of an aseptic fibrosis and necrosis, which leads to loosening of the prosthesis secondary to metal corrosion and release of wear debris. Metal debris within the joint from cast CoCrMo, the alloy found in older hip prostheses, as well as the cast metal-on-metal Christensen TMJ prosthesis (Nexus CMF, Salt Lake City, UT, USA) are in the nanometer range and can activate the host immune response and lead to a foreign body reaction in some patients that results in pain, swelling, osteolysis, and loosening of the metal components. Loose metal prostheses can result in metal fatigue failure and fracture (see Hardware Failure section). Circulating Co

and Cr ions are low when a prosthesis functions well; high blood serum concentrations of Cr or Co suggest significant prosthesis wear in hip prostheses and have been shown to lead to neuropsychiatric deficits in one recent study [28]. In removing the Christensen TMJ prosthesis, the surgeon may see dark metallic tattooing of the surrounding soft tissue or dark fluid at the surgical site, a classic metallosis finding. In the orthopedic gold standard of metal-on-ultra-high-molecular-weight polyethylene (UMWPE) prostheses, the evidence of metallosis is scant or nil.

Allergy to one or more of the elements in the prosthesis alloy should be among the top diagnoses when managing a patient with unexplained postoperative pain, especially if accompanied by lymphadenopathy, swelling, and limited opening. It is estimated that 10–15% of the general population has a metal allergy, and women outnumber men in this condition [29]. One theory is that females become exposed to sensitizing metals at a young age through exposure to cheap metal jewelry on the skin and in pierced ears. Metal sensitivity can either be acute or delayed in presentation, although prosthesis-related reactions are more likely to be delayed reactions. Nickel is the most common metal to cause allergic reactions, and it is found in significant percentages in stainless steel and to a very minor degree in CoCr alloys. Up to 1–3% of the general population has an allergy to Cr or Co, which is found in all TMJ prostheses on the market [30].

When metal hypersensitivity occurs, or metallosis, from a metal-on-metal prosthesis, removal of the prosthesis and replacement with a titanium-on-UHMWPE prosthesis are recommended. Fortunately, the Biomet TMJ prosthesis product line does offer a Ti (Ti-6Al-4V) prosthesis that has a Ti alloy coating. This alloy contains no Ni, Cr, or Co and is at least 88% Ti. Titanium has excellent biocompatibility and has high resistance to corrosion; thus it is considered to be relatively inert compared to other metals, and the incidence of reactions to Ti is very low, although not zero [31].

In the preoperative phase, patients should be questioned about possible metal allergy symptoms, including reaction to watches, rings, necklaces, earrings, and other piercings. A referral to an allergist for testing is warranted if there is cause for concern. The author (RS) uses only the titanium alloy Biomet prosthesis if planning a stock joint replacement.

9.1.5.3 Heterotopic Bone

Heterotopic bone formation has been addressed in the previous chapter. The fat graft, taken in whole, not via liposuction, has been shown to inhibit heterotopic bone formation by eliminating dead space, thus preventing blood clot organization around the prosthetic joint head and fossa (Fig. 9.6). The fat graft harvest is very straightforward and should be a standard part of all TMJ total joint replacement surgery. If excessive heterotopic bone is noted, revision surgery is indicated, especially if it is associated with increasing pain and/or interferes with function of the prosthetic joint. Low-grade heterotopic bone formation may be asymptomatic, but typically patients experience pain and limitation of range of motion. The author (RS) noted that in one case, the implanted abdominal fat grew in volume as the patient gained weight. Facial swelling and discomfort brought the patient back to the clinic over 5 years after the total joint prosthesis and fat graft were placed (Fig. 9.7).

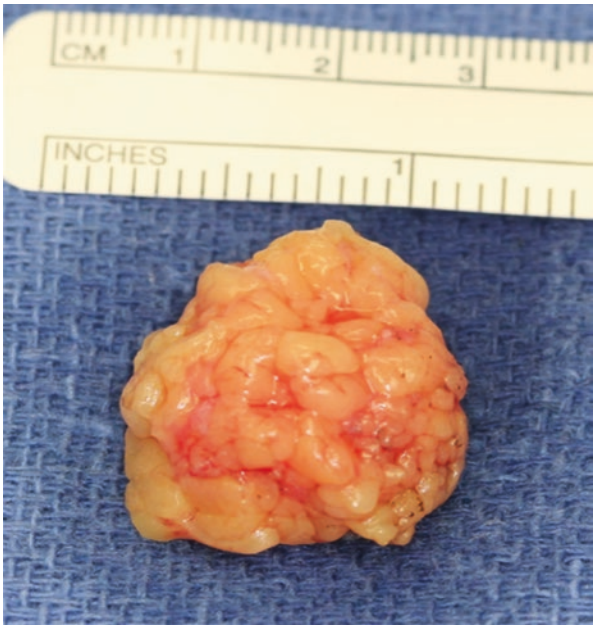

Fig. 9.6 Good-quality abdominal fat is easy to procure and very beneficial for the prevention of heterotopic bone

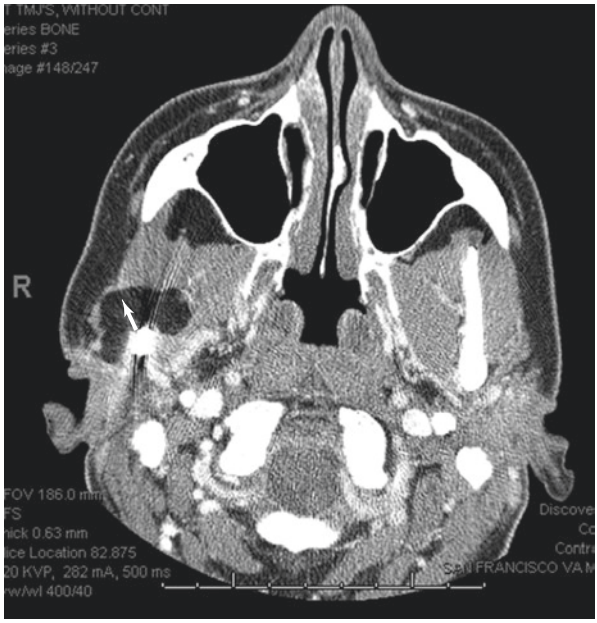

Fig. 9.7 The radiolucency in the area of the right joint represents enlargement of the fat graft placed several years prior to the patient's weight gain. Soft tissue swelling is noted (arrow)

For the patient with significant prosthesis-related pain postsurgically, surgical exploration is not discouraged but is best undertaken if one has narrowed the list of possible etiologies and has a plan for every single one of those possibilities.

The following conditions are included in this chapter because they have been repeatedly observed and are worthy of mention, not only for academic purposes but as part of the informed consent process with the TJR candidate.

9.2 Other Problems and Complications Encountered During and After TMJ Surgery

9.2.1 New or Aggravated Contralateral TMJ Dysfunction

Many TMJ surgical procedures result in a permanent jaw deviation with function, toward the side of the TMJ surgery. This is especially true when the lateral pterygoid muscle is disturbed, as in total joint reconstruction. The question is whether patients with unilateral joint reconstruction are exposed to increased risk of having contralateral TMD symptoms that may or may not result in the need for an intervention. Researchers have studied the masticatory patterns in patients who have had unilateral total joint replacement and have noted the kinematic differences between the prosthetic and natural joints [32, 33]. When a total joint prosthesis is placed, it has no forward translational movement and thus changes the load on the contralateral natural joint and the mechanics on how it moves in function. In addition, the surgical technique for placing the prosthetic joint requires stripping of the masseter muscle and often the temporalis muscle. Postoperatively, the patient naturally uses the intact side for chewing and places high forces on the disc during bruxism. Bekcioglu and colleagues, using finite-element analysis, found that the stress on the contralateral disc increases by over 54% in a unilateral joint replacement model [34]. A subset of patients may begin to experience new or aggravated contralateral TMD symptoms if the native joint cannot tolerate the increased forces. Although Perez's group did not find any adverse effects on the healthy contralateral joint in a group of 61 patients with unilaterally reconstructed joints [13], others' experience is that over several months to 3 years, some patients will return with new or aggravated contralateral complaints requiring interventions ranging from intra-articular steroid injection to joint replacement of the contralateral TMJ in a significant percentage. In a series of 77 consecutive patients who underwent any type of unilateral TMJ surgery and were followed 1–15 years postoperatively, up to 32% required a procedure on the contralateral joint (author's unpublished data). In this series, contralateral procedures ranged from arthrocentesis to total joint replacement. The patients with the highest incidence of contralateral total joint replacement surgery are those who undergo unilateral total joint replacement. More research is clearly needed in this domain to further our understanding of the long-term effects of the biomechanical mismatch that occurs when a natural joint works in concert with a prosthetic joint. The surgeon contemplating

unilateral total joint surgery is advised to warn the patient of the possible activation of contralateral symptoms, especially if there are early changes or symptoms already exist.

9.2.2 Malocclusion

It may be surprising to encounter patients with malocclusion postoperatively because the mandibular component of the TMJ prosthesis is always positioned and fixated with screws while the patient is in tight maxillomandibular fixation (MMF). Nevertheless, occasionally a patient will demonstrate an ipsilateral posterior open bite (Fig. 9.8).

The most common reason for an immediate post surgery posterior open bite results from operator miscalculation or error in positioning the mandibular component or lack of proper placement and stability of the maxilla in double jaw surgery. A simple factor is failure to drill the pilot hole "dead center" in the middle of the screw hole in the mandibular component. Drilling the hole toward the top of the screw hole will shift the mandibular component upward, opening the bite

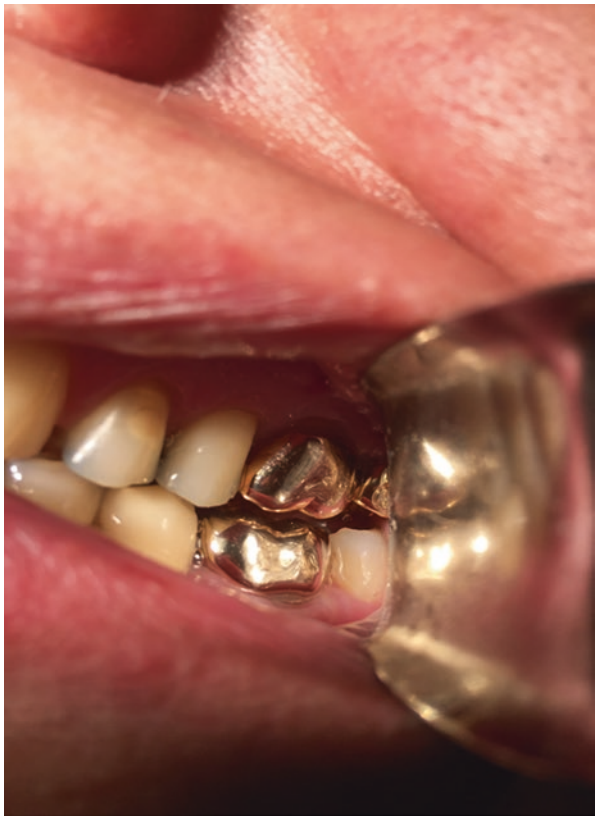

Fig. 9.8 A 1 mm ipsilateral posterior open bite is noted on postoperative day 1, after placing a stock total joint prosthesis

posteriorly. If the mandibular component is not sitting tight against the ramus when the first two screws are placed, the shift of the mandibular component medial-lateral can also cause a shift of the mandibular component creating the posterior open bite. Another reason for a posterior open bite is due to surgical edema or formation of a hematoma. In double jaw surgery, malpositioning of the maxilla can result in a posterior open bite.

The most common cause for an anterior open bite is not seating the mandibular component into the fossa and against the posterior stop in the fossa component. Also, when drilling the pilot hole in the mandibular component, if the pilot hole is drilled against the bottom of the screw hole in the mandibular component, the mandibular component will be displace downward. In double jaw surgery, malpositioning of the maxilla can result in an anterior open bite.

Rather than removing the MMF devices immediately postoperatively or within a few days, consider maintaining the patient in guiding elastics for 1–2 weeks or longer to orthodontically settle the bite into position. If a large anterior or posterior open bite occurs with inability to correct with orthodontic mechanics, then one should consider repositioning the maxilla, performing bilateral sagittal split osteotomies (can be safely done with appropriate surgical protocol in most cases), or repositioning the mandibular component(s).

In other cases, postoperative malocclusion cannot be corrected with guiding elastics. The etiology of the malocclusion may be related to improper intraoperative mandibular positioning during application of MMF. When using the Biomet Microfixation system to implant stock prostheses, especially in bilateral cases, patients with flat or very worn teeth may develop a centric relation-centric occlusion (CR-CO) slide that is not appreciated until the MMF is released. If loosening of the MMF wires occurs while the jaw is manipulated during the screw fixation step of the mandibular prosthesis, or if the mandible is aggressively handled during drilling and screwing, the postoperative result may be an ipsilateral open bite in addition to shifting of the jaw to the contralateral side. The patient may report pain at the contralateral joint due to the torquing of the natural condyle. If this occurs, the prosthesis may need to be repositioned surgically.

The following eight strategies may help prevent postoperative malocclusion:

1. Use of an occlusal splint to help stabilize the mandible, especially when there is significant dental wear or multiple missing teeth.
2. Document the preoperative occlusion with a photo, and post the picture in the operating room for reference.
3. Instead of traditional arch bars with circumdental wiring, consider the use of bone-supported screws or screw-retained anchoring devices. These are less likely to extrude or move teeth if the patient needs to be in postoperative elastic traction for days or weeks.
4. Just prior to fitting and screwing in the TMJ prosthesis, place at least four, tight MMF wires, evenly applied across the arch. Visually verify the occlusion achieved and compared with the preoperative photo, if available.

5. With stock TMJ prosthesis placement, consider interposing a neurosurgical patty between the joint head and the fossa when fixating the mandibular component while the patient is in tight maxillomandibular fixation. This will allow the posterior dentition to act as the vertical stop rather than the prosthetic joint.
6. Do not allow heavy lateral forces to shift the mandible when drilling and screwing down the mandibular prosthetic component. A member of the surgical team should stabilize the jaw during this step.
7. For custom devices, set the condylar head into the fossa against the posterior stop (TMJ Concepts fossa). Set the mandibular component into position on the ramus. Drill the pilot hole "dead center" in the screw hole of the mandibular component. If the pilot hole is not "dead center," then insertion of the screw can produce a slight shift in the occlusion.
8. After placement of two screws (one low and one high) in the mandibular component(s), consider releasing the MMF wires, and check the occlusion prior to placement of the final screws. If bite is off, then remove the screws from the mandibular component, reapply MMF, reposition the mandibular component, and replace the screws. Once this step is completed, then proceed to placing the fat grafts and wound closure. This must be done with great care due to risk of contamination of the surgical field with oral flora.

9.2.3 Preauricular Numbness

Patients should be advised that following open joint surgery, the preauricular skin will be hypoesthetic due to injury of the auriculotemporal nerve. While the affected area frequently shrinks with time, there may be a permanent zone of numbness in front of the ear, which fortunately appears to be of limited consequence except when shaving or applying makeup to the area.

9.2.4 Inferior Alveolar (IA) Nerve Numbness

Three possible etiologies are considered: In the first, screw placement for the mandibular component of the stock prosthesis may inadvertently misdirect a screw toward the nerve, but this will not happen for the custom TMJ Concepts prostheses, which are designed so that the screw holes avoid the IA canal. The second arises from the overzealous use of the mandibular mobilizer or similar device, or a bone tenaculum engaged near the angle of the mandible. The mandibular mobilizer or tenaculum is helpful to exert a downward and forward pull on the mandible while operating at the articular fossa (Fig. 9.9). This movement can stretch the inferior alveolar nerve causing injury. When using the tenaculum, one often finds there is a need to reposition the instrument more superiorly on th ramus than is safe, because it often slips off the narrow bone at the angle of the mandible during traction. This blind maneuver risks damaging the mandibular nerve as it enters the foramen at the lingula.

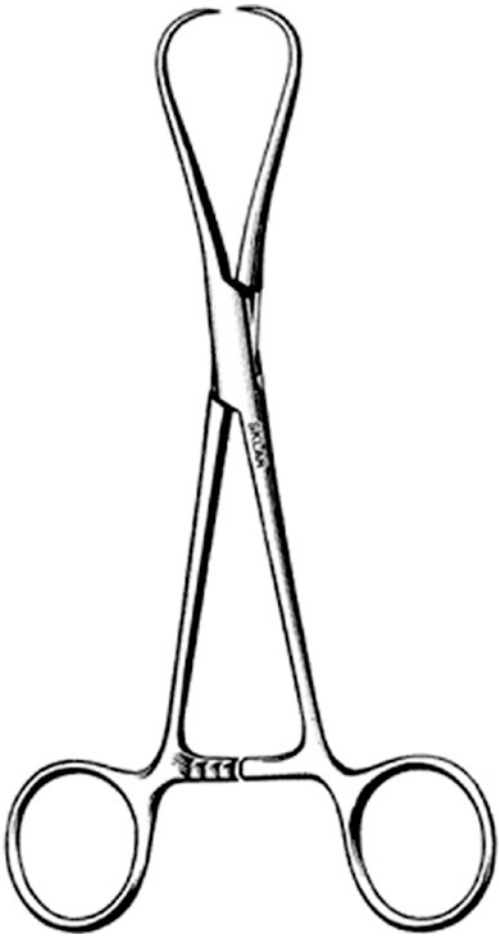

Fig. 9.9 A tenaculum forceps for grasping the mandibular angle and pulling it inferiorly. The sharp tips of the tenaculum may injury the mandibular nerve at the lingula when positioning the instrument to apply downward traction on the mandible

The inferior alveolar nerve may be nicked or severed while creating the gap between the top of the ramus and the articular fossa. The recommended gap is no less than 20 mm, which allows adequate room for the prosthetic fossa and the prosthetic joint head. In cases where the native ramus length is quite short (often due to severe degenerative joint disease), creating the gap needed to accommodate the prosthesis is tricky and more likely to result in encroachment by the saw to the IA nerve. The surgeon needs to pay close attention to how much bone is being removed from the top of the ramus (Fig. 9.10). Measure the bone removal needed in situ, and use a sterile pencil to mark the bone just prior to introducing the saw. The use of a piezoelectric or ultrasonic bone saw may reduce the risk of nerve injury due to its preferential bone cutting action, but careful measurement is still the key to avoidance of injury.

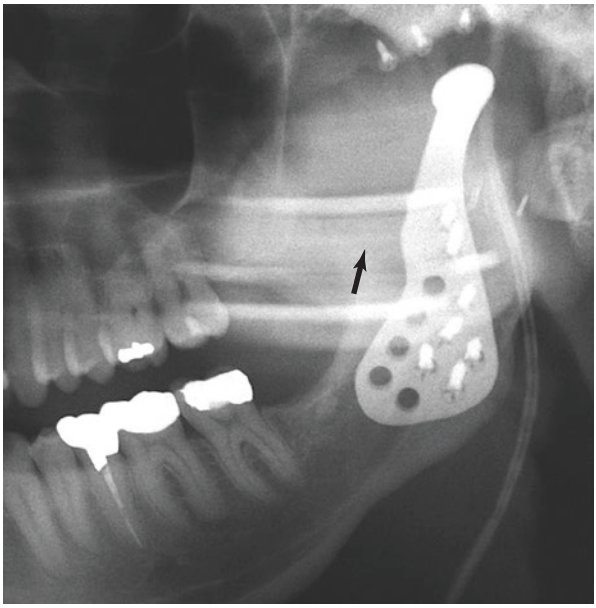

Fig. 9.10 A ramus cut that is too low or at a steep angle many place the inferior alveolar nerve at risk

9.2.5 Bleeding

Experience has shown that problematic bleeding often occurs in patients who have had multiple previous ipsilateral TMJ surgery and in those where the condylar head was previously fractured. Scar development on the medial aspect of the joint head and entrapment of blood vessels is a frequent feature and can result in significant bleeding when the bone is cut and removed. Most arterial bleeding in TMJ arthrotomy arises from the middle meningeal and posterior deep temporal arteries, branches of the internal maxillary artery, or direct injury to the maxillary artery. Venous bleeding is from the retrodiscal tissue and the retromandibular vein. The following top ten strategies to reduce blood loss are recommended:

1. Hypotensive anesthesia technique to keep mean arterial pressure low.
2. Use of piezoelectric or ultrasonic bone saw when osteotomizing the condylar head and the superior portion of the ramus. The BoneScalpel (Misonix, Farmingdale, NY, USA) is an instrument that may significantly reduce total blood loss in TMJ total joint replacement [35] (Fig. 9.11).
3. Neural patties soaked in thrombin pre-prepared and ready to pack into the wound after excision of the condylar head.
4. Gelfoam or Surgicel within the wound.
5. Apply intraoral pressure to bleeding vessels medial to the mandible.
6. Prior to osteotomizing the superior portion of the ramus, open the submandibular incision, and fully dissect down to the inferior border of the mandible first.

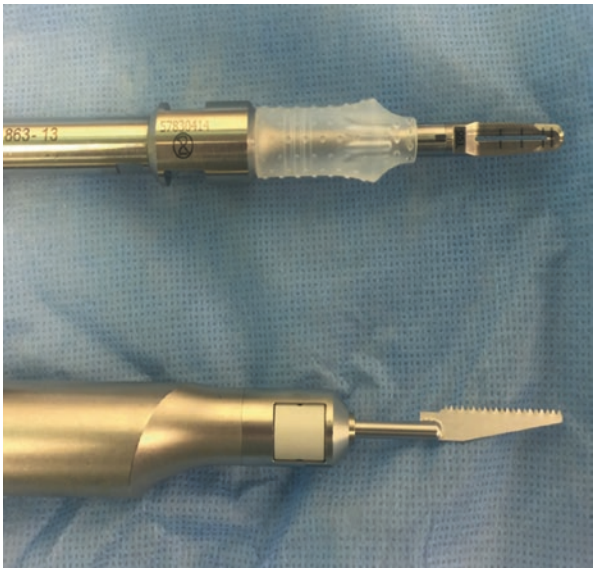

Fig. 9.11 The BoneScalpel (top) versus a reciprocating saw (bottom). The BoneScalpel is a piezoelectric device that preferentially cuts the bone instead of soft tissue. The device has been shown to significantly reduce intraoperative bleeding during TMJ replacement surgery

If uncontrolled arterial bleeding should occur, dissection down to the external carotid artery (ECA) can be rapidly accomplished if the neck incision is already open. Ligation of the ECA is ideally done at a level higher than the bifurcation of the common carotid to control internal maxillary artery hemorrhage, but bleeding control is imperfect. Although technically more difficult, the best results are achieved when ligation is done distal to the origin of the posterior auricular artery branch [36].

7. If bleeding remains uncontrolled, emergent interventional radiology is needed to embolize the bleeding vessel.
8. Control of unnecessary, noxious airway stimulation and blood pressure during emergence from general anesthesia.
9. Pressure dressing for 12–24 h.
10. Surgical drains not advised, due to potential for introduction of bacteria within the wound.

Use of thrombin-containing hemostatic agents such as Floseal (Baxter, US) may be problematic and should be used with caution. The author's (RS) experience with TMJ reconstruction patients who had Floseal placed in the wound prior to closure and who then traveled home on a multi-hour flight is that there was a higher than anticipated risk of VTE in this cohort. As a result, the author no longer uses Floseal on a regular basis, but does utilize postoperative low-molecular-weight heparin starting 1 day after surgery.

9.2.6 Lingual Nerve Numbness

This rare complication may be related to injury to the nerve with removal of the top of the ramus, during the secondary osteotomy needed to create the recommended gap. A piezoelectric bone saw is preferred to prevent inadvertent injury to soft tissues on the medial aspect of the mandible that may contain the lingual nerve. Alternatively, lingual nerve injury may be due to compression of the nerve secondary to bleeding on the lingual aspect of the mandible.

9.2.7 Facial Nerve Injury

Multiple upper and lower division branches of the facial nerve are at risk during TMJ total joint reconstruction surgery, and facial nerve injury appears to be more likely when patients have undergone multiple prior TMJ surgeries. The use of a disposable nerve stimulator or the more sophisticated four-channel nerve monitor such as NIM (Medtronic, Minneapolis, MN, USA) is strongly advised as it provides audible and visual warnings that enable surgeons to identify, confirm, and monitor nerve function to reduce the risk of nerve damage (Fig. 9.12). An eight-channel monitor, if available, is preferable during bilateral TMJ surgery so that leads from one side do not have to be disconnected when the contralateral surgery is being carried out. Often, full facial nerve function is observed while the patient is emerging from general anesthesia, only to progress into weakness as surgical edema develops.

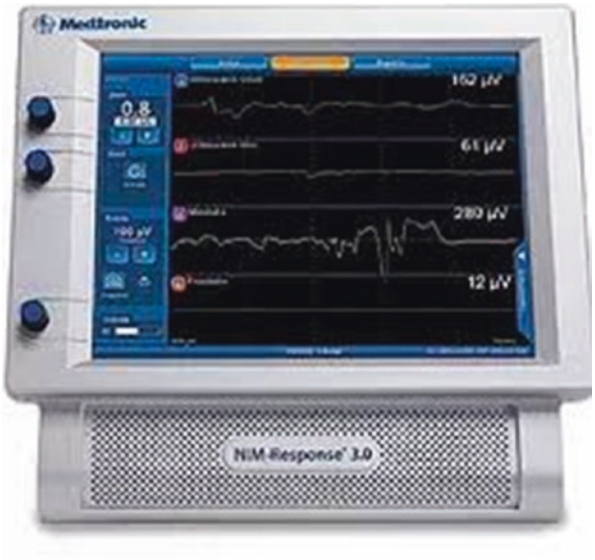

Fig. 9.12 The Medtronic four-channel NIM monitor, for assessing facial nerve function intraoperatively

This is a very common occurrence that patients should be reassured about. Fortunately, many cases of early facial nerve branch weakness resolve given 4–6 months of time.

9.2.8 Gustatory Sweating/Auriculotemporal Nerve Syndrome/ Frey's Syndrome

The auriculotemporal nerve is a branch of the third division of the trigeminal nerve, and it has many branches throughout the preauricular area and temple. Occasionally, post-TMJ surgery patients complain of gustatory sweating and facial flushing on the operated side, which is commonly known as Frey's syndrome. This condition is considered to be very prevalent after parotidectomy. Using Minor's starch-iodine test, the incidence has been reported to nearly 100% in some studies, although clinically symptomatic cases are much fewer [37]. Frey's syndrome can occur after TMJ surgery as well. When damaged parasympathetic postganglionic secretomotor fibers of the auriculotemporal nerve, normally intended for the parotid gland, inappropriately regenerate themselves and connect to the sympathetic receptors of facial sweat glands and vessels, sweating and facial flushing may occur during eating or even when thinking about food. The condition may become evident with a typical latency of 6–18 months after surgery.

Prevention of Frey's syndrome begins with appreciation of the auriculotemporal nerve's branching anatomy. The nerve's parotid branches run off the main trunk and enter the parotid at the superior border of the gland, approximately 8 mm anterior and 8 mm superior to the middle of the tragus [38]. Branches of the auriculotemporal nerve seem to communicate with the buccal and zygomatic branches of the facial nerve, passing on parasympathetic secretomotor fibers [39]. As a result, it should be no surprise that clinical and subclinical Frey's syndrome may arise after TMJ reconstructive surgery given the relationship of the nerve branches within the local anatomy. Surgical techniques for the prevention of Frey's syndrome following parotidectomy have been investigated by various authors, and they include the interposition of biologic and nonbiologic membranes as a barrier between the postganglionic nerve fibers and the target sweat glands and the interposition of various flaps over the parotidectomy bed. Biologic tissues that have been interposed to prevent Frey's syndrome include acellular human dermis (ACD) [40, 41] and free autologous dermal fat grafts [42, 43]. Local flaps include the superficial musculoaponeurotic system (SMAS) flap [44] and sternocleidomastoid (SCM) muscle flap. In the author's (RS) experience, the SMAS flap has the most practical application for the TMJ surgeon. The development of a SMAS flap during access to the TMJ, separate from the overlying skin flap, allows for good surgical repositioning and closure over the parotid at the end of the case. In this way, our group has been able to prevent Frey's syndrome in most patients compared to prior to the implementation of this technique. Supporting this technique variation is the fact that the SMAS flap has been shown to be highly effective in lowering the incidence of Frey's syndrome to around 5% in a study of patients undergoing parotidectomy [45].

The gold standard of Frey's syndrome treatment is botulinum toxin (BTX), which outperforms all other treatments [46]. BTX injection creates a cholinergic block to inhibit saliva production and success rate of averages 98% [47]. One may administer concentrated BTX (40 units/cc) as multiple small doses of 4 units per injection throughout the affected area, using a 30-gauge needle. Treatment is repeated every 12–16 weeks or more as needed, but fortunately, the troublesome symptoms of Frey's syndrome can fade away over time for many patients.

9.2.9 First Bite Syndrome

Postoperative first bite syndrome (FBS) is a rare and interesting complication of cervical and head and neck surgery. It is characterized by severe, sharp, electric-like pain at the affected parotid area upon the first couple of bites of food place into the mouth. Patients often describe an acute and unpleasant squeeze or spasm-like sensation of the parotid. The pain response lasts several seconds and then fades away with subsequent bites of food, just to repeat with the next meal after a period of salivary rest. The syndrome is quite debilitating and can very much have a life-altering effect on the patient's day-to-day life.

FBS has been described following parotidectomy, external carotid artery ligation, carotid endarterectomy, parapharyngeal surgery, infratemporal fossa surgery, bimaxillary osteotomy, and TMJ surgery [48–53]. FBS has occurred as an early symptom of salivary gland malignancy [54], and idiopathic, nonsurgical FBS has also been reported [55]. Although the overall incidence is unknown, it is probably underreported and underappreciated. FBS arises in the weeks to months following surgery. With respect to TMJ reconstruction, our experience has been that it occurs in cases where external carotid artery (ECA) ligation was necessary to control intraoperative bleeding following joint resection. The etiology is thought to be the loss of postganglionic sympathetic innervation of the parotid gland due to surgical disturbance, resulting in over-activation of the salivary myoepithelial cells in response to parasympathetic stimulation, unopposed by sympathetic innervation (Fig. 9.13) [52]. Isolation and ligation of the ECA is one way to disturb the postganglionic sympathetic fibers, which run as a network along the vessel and its branches. In other words, any injury to the sympathetic chain, including ligation of the ECA, increases the risk of development of FBS.

If injury of the postganglionic sympathetic fibers running toward the parotid gland is to blame for FBS, prevention of the syndrome is achieved by avoidance of manipulation or ligation of the ECA. If ligation of the ECA is needed to achieve hemostasis, then the surgeon is alerted to watch for symptoms of FBS developing in the postoperative period. The risk of postoperative FBS is not meant to discourage the surgeon from doing what is necessary to control excessive or catastrophic bleeding intraoperatively.

Diagnosis of FBS is made largely by patient history. In the clinic or office setting, pain can be reproduced by applying lemon juice or lemon glycerine swabs to the mouth to stimulate the flow of saliva. Occasionally, a technetium-99m

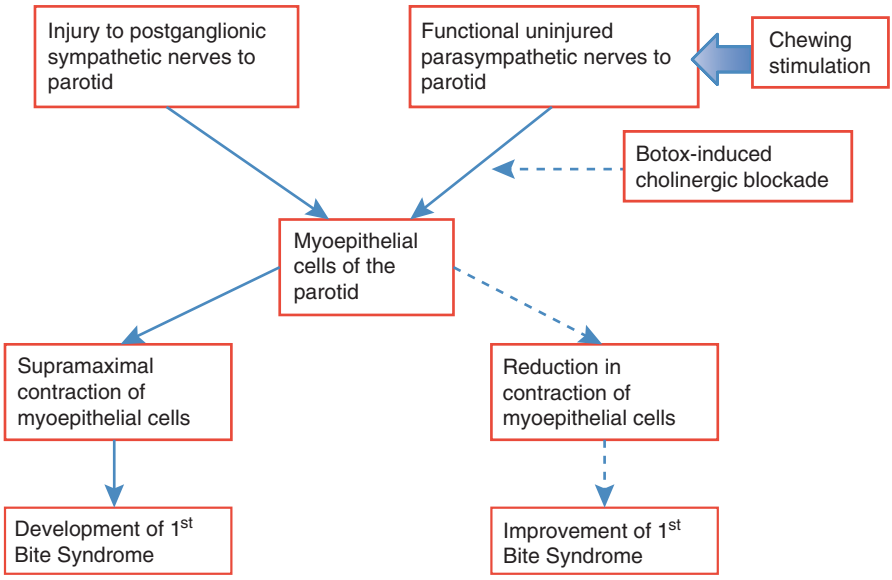

Fig. 9.13 Proposed mechanism of first bite syndrome

pertechnetate nuclear medicine study is ordered to study the affected salivary gland. The clinician may find that uptake of the isotope is within normal range but that stimulation of the gland with lemon will cause pain severe enough to prevent completion of the study. CT and MR imaging is typically negative.

Treatment of FBS is largely unsuccessful. Resolution of the syndrome has been described by Amin and colleagues via laser ablation of the tympanic plexus [53]. Other modalities of treatment that have varied rates of success include NSAIDs, narcotics, amitriptyline, carbamazepine, gabapentin, acupuncture, and Botox (BTX) injections [56–59]. BTX is advocated because it will cause a reduction in parasympathetic innervation to the parotid gland, but mixed results are reported. Ghosh and Mirza report some success with BTX doses up to 50 units into four or more sites within the parotid [60]. In some cases, the syndrome slowly fades away on its own after 4–24 months [61]. In the author's (RS) experience, one case of severe post-total joint replacement FBS could only be resolved with a superficial parotidectomy.

9.2.10 Narrowing of the External Auditory Canal (EAC)

Within the first 1–2 months of the postoperative period, it is common for patients to complain about muffled hearing, inability to clean the ear canal, and/or retention of water within the canal after showering, due to swelling. In addition, hearing aid wearers may not be able to insert the device comfortably or at all. After all surgical edema resolves, some patients may experience long-term narrowing

of the EAC due to scarring, but sometimes the anterior-posterior (A-P) position of the fossa component is to blame. When placing a stock prosthesis, the surgeon should keep in mind to select a fossa prosthesis position so there is no impingement of the ear canal.

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10 Concomitant Custom-Fitted Temporomandibular Joint Reconstruction and Orthognathic Surgery

Rishi Jay Gupta, Steven A. Schendel, and Larry Wolford

Abstract

This chapter presents the diagnostic criteria, treatment planning, and surgical protocols for the application of computer-assisted surgical simulation (CASS) for patients requiring TMJ total joint replacement and orthognathic surgery (C-TJR-OS). The CASS protocol decreases the preoperative workup time and increases the accuracy of model preparation and subsequent surgery.

10.1 Introduction

Patients with temporomandibular joint (TMJ) pathology and coexisting dentofacial deformities can be corrected with concomitant TMJ and orthognathic surgery (C-TMJ-OS). Systematic TMJ and craniofacial analysis utilizing radiographic and clinical findings are critical in the decision-making on whether to proceed with isolated orthognathic surgery or in combination with total joint replacement (TJR). Surgical alterations utilizing C-TMJ-OS can help restore facial esthetics, improve

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airway and mastication function, provide a stable occlusion, and eliminate pain. C-TMJ-OS can be completed in one surgical stage or separated into two surgical stages. The two-stage approach requires the patient to undergo two separate operations (one surgery to correct the TMJ pathology and a second operation to perform the orthognathic surgery) and two general anesthetics, significantly lengthening the overall treatment time and increasing possible risks. Performing C-TMJ-OS in a single operation decreases treatment time, provides better clinical outcomes, but requires careful treatment planning and surgical proficiency in the two surgical areas.

This chapter presents the diagnostic criteria, treatment planning, and surgical protocols for the application of computer-assisted surgical simulation (CASS) for patients requiring TMJ total joint replacement and orthognathic surgery (C-TJR-OS). The CASS protocol decreases the preoperative workup time and increases the accuracy of model preparation and subsequent surgery.

10.2 Indications for C-TJR-OS

Temporomandibular joint (TMJ) disorders or pathology and dentofacial deformities commonly coexist. The TMJ pathology may be the causative factor of the jaw deformity or develop as a result of the jaw deformity, or the two entities may develop independent of each other. The most common TMJ pathologies that can adversely affect jaw position, occlusion, and orthognathic surgical outcome stability include (1) articular disc dislocation, (2) adolescent internal condylar resorption (AICR), (3) osteoarthritis, (4) reactive arthritis, (5) condylar hyperplasia, (6) ankylosis, (7) congenital deformation or absence of the TMJ, (8) tumors, (9) connective tissue and autoimmune diseases, (10) trauma, and (11) other end-stage TMJ pathologies [1–4]. These TMJ conditions can be associated with dentofacial deformities, malocclusion, TMJ pain, headaches, myofascial pain, TMJ and jaw functional impairment, ear symptoms, sleep apnea, etc. Patients with these conditions may benefit from corrective surgical intervention, including TMJ and orthognathic surgery. Some of the aforementioned TMJ pathologies may have the best outcome prognosis using custom-fitted total joint prostheses for TMJ reconstruction. This chapter is designed to improve the surgeon's ability to recognize TMJ conditions that may be best treated with concomitant TMJ total joint prostheses and orthognathic surgery.

Some clinicians choose to ignore the TMJ pathology and symptoms, preferring to perform only orthognathic surgery for these types of cases. However, this treatment philosophy can result in continuation or exacerbation of the presurgical TMJ pathology and adverse outcomes. Although most TMJ patients have associated symptoms, approximately 25% of patients with significant TMJ pathology/disorders may be asymptomatic presurgically. These patients are diagnostically challenging when undergoing orthognathic surgery because the TMJ pathology may not be recognized. Failure to recognize and properly treat the TMJ pathology in symptomatic or asymptomatic patients will commonly result in poor treatment outcomes including potential redevelopment of the skeletal and occlusal deformity by

continued condylar resorption or condylar overdevelopment, initiation of or worsening pain, headaches, and jaw and TMJ dysfunction, as well as other TMJ symptoms [5]. However, there are clinical and imaging factors that can indicate the presence of TMJ pathology in the asymptomatic as well as the symptomatic patient.

Approximately two-thirds of the patients requiring total joint prostheses can benefit from concomitant TMJ and orthognathic surgery for improvement in jaw function, airway and breathing capabilities, improved esthetics, and decreased or elimination of pain.

10.3 Disc Displacement

When determining the presence of TMJ pathology, it is important to appreciate the normal TMJ anatomy (Fig. 10.1). When discs are anteriorly displaced for an extended time period, the discs may become nonreducing, deformed with loss of the intermediate zone and thickening of the posterior and anterior bands (Fig. 10.2). Also, there may be a degenerative process developing in the discs where there is a breakdown of the cartilaginous substance with vascular invasion and degeneration. Displaced discs initiate a cascade of events that lead to TMJ arthritis. When discs are displaced and become nonreducing, the degenerative process of the disc progresses more rapidly as compared to displaced discs that reduce. When discs

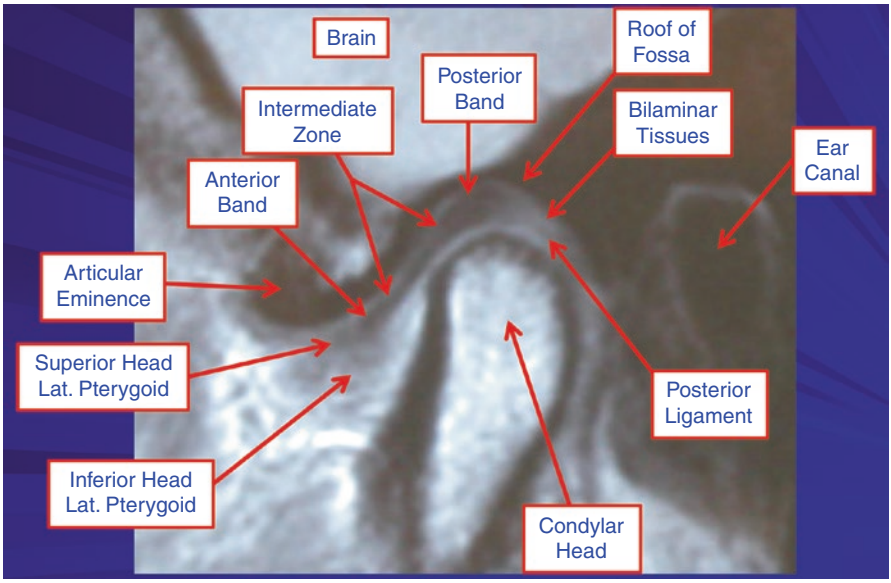

Fig. 10.1 MRI of a normal TMJ in closed position with disc in position. The anatomical landmarks are labeled

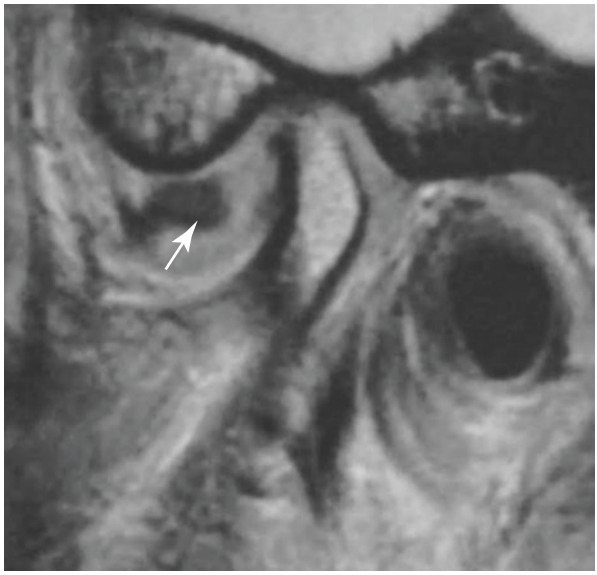

Fig. 10.2 MRI showing arthritic condyle and the articular disc are anteriorly displaced, significantly deformed, degenerated, nonreducing, and non-salvageable

advance to a certain level of deformation and degeneration, they become non-salvageable requiring patient-fitted total joint prostheses to produce the most predictable and high-quality outcomes.

10.4 Adolescent Internal Condylar Resorption (AICR)

Adolescent internal condylar resorption (AICR) is a condition that develops usually during pubertal growth between the ages of 11 and 15 years and predominantly in females (ratio, 8:1 females to males) [1–4, 6]. Clinically, the mandible will be noted to slowly retrude into a Class II occlusal and skeletal relationship with a tendency toward anterior open bite. These patients all have high occlusal plane angle facial morphological profiles. On the MRI, these cases present with a condyle that is slowly becoming smaller in size in all three planes of space and the disc is anteriorly displaced (Fig. 10.3). In some cases, there is significant thinning of the cortical bone on top of the condyle contributing to the inward collapse of the condylar head in this pathological process. The articular discs are anteriorly displaced and may or may not reduce on opening. Commonly, the disc become nonreducing relatively early in the pathological progression. Nonreducing discs will degenerate and deform at a more rapid rate as compared to discs that reduce. AICR stabilization may be achieved with disc repositioning if it is performed within 4 years of the onset of the disc displacement. After around 4 years from the onset of disc displacement, the discs may become non-salvageable, and condyles significantly resorbed with the indicated treatment transitioning to patient-fitted total joint prostheses to repair the TMJs and advance the mandible concomitant with orthognathic surgery.

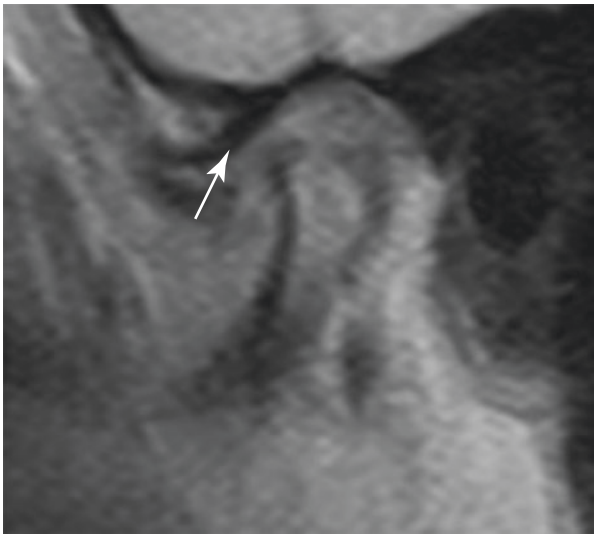

Fig. 10.3 MRI of TMJ demonstrating adolescent internal condylar resorption (AICR) with condylar resorption and an anterior displaced articular disc. These discs can become nonreducing relatively early on in the process. Note the thinness of the cortical bone on the superior surface of the condyle and amorphous tissue surrounding the condyle

10.5 Arthritis

Various types of arthritic pathologies including osteoarthritis, rheumatoid arthritis, and spondyloarthropathies, such as reactive arthritis, may affect the TMJs. These TMJ disorders are discussed in detail in earlier chapters, but a brief review is presented here. Osteoarthritis is the most common type of TMJ arthritis and is characterized by a progressive degeneration of articular disc leading to direct contact of the condyle with the fossa and gradual erosion. Rheumatoid arthritis is an autoimmune disease that may present as an acute onset of bilateral TMJ disease with erosion of the complex. Juvenile rheumatoid arthritis is a progressive Class II malocclusion and apertognathia due to condylar destruction and may lead to ankylosis in late stages. Medical management has decreased the need for surgical intervention [7]. Reactive arthritis is commonly caused by bacterial or viral entities [1–4, 8–11] and may show a localized area of inflammation (synovitis) with erosion of the condyle and/or fossa. It also can present as a more profuse inflammatory process through the bilaminar tissues, capsule, surrounding the disc (Fig. 10.4a), but can progress to destruction of the disc and condylar resorption (Fig. 10.4b). The most common bacteria causing reactive arthritis in the knees and TMJs are *Chlamydia trachomatis* and *Chlamydia pneumoniae* [10–12], as well as *Mycoplasma genitalium* [11]. These are non-culturable, non-motile, obligate intracellular bacteria that stimulate production of pro-inflammatory/pain mediators—TNFα, cytokines, chemokines, substance P, etc.—with subsequent breakdown of the cartilage and bone and generation of pain. Standard antibiotic therapy can be effective for urinary tract, genital, ocular, respiratory, and GI infections involving these bacteria, but are not effective for synovial infections, making it very difficult to eliminate these bacteria from joints including the TMJs [12]. Currently, there are no predictable methods to conservatively treat reactive arthritis involving these particular bacteria. However,

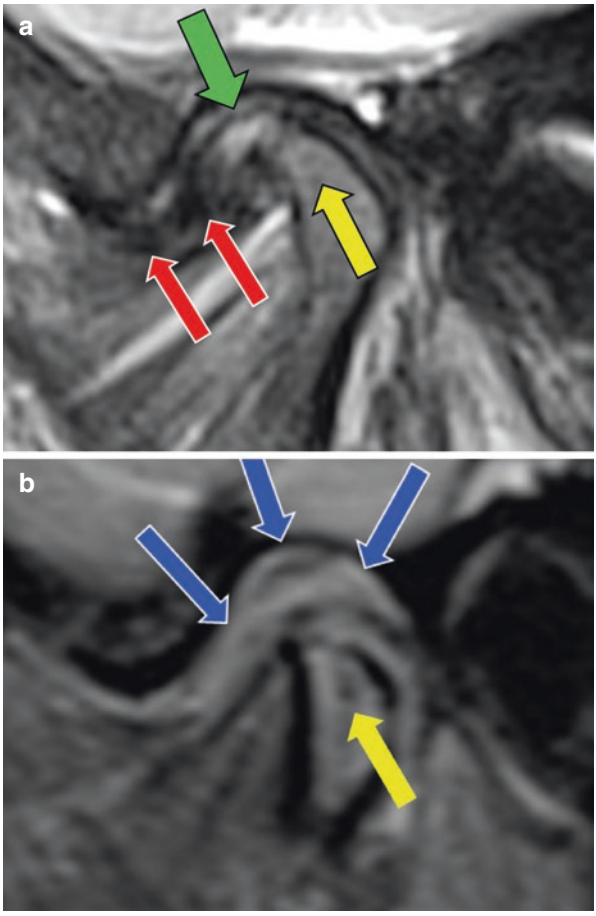

Fig. 10.4 (**a**) T2 MRI of TMJ with relatively early initiation of reactive arthritis. The articular disc is anteriorly displaced (red arrows), and the onset of condylar resorption at anterior aspect of the condyle (yellow arrow) is noted. The synovitis appearing as "gray to white" tissue (green arrow) is surrounding the anterior condyle and superior aspect of the disc. (**b**) MRI of advanced reactive arthritis with the synovitis (blue arrows) filling the fossa, destruction of the articular disc, and condylar resorption (yellow arrow)

when the infection is confined to a small portion of the synovial and bilaminar tissues in the TMJ, debridement may be indicated, but outcomes may be unpredictable. With evidence of arthritic TMJ changes and particularly with destruction of the TMJ tissues, a total joint prosthesis provides the highest predictable outcomes.

10.6 Perforations

Perforations can occur in the TMJ area resulting in bone-on-bone contact. Disc perforations can occur following anterior and/or medial disc displacement. Almost always these perforations are posterior to the posterior band of the articular disc or lateral to the disc, and rarely do perforations occur through the disc itself (Fig. 10.5). Clinically, crepitation will usually be present, and, on the MRI, there will be evidence of bone-on-bone contact, arthritis of the condylar head and/or fossa, as well as anteriorly and/or medially displaced disc. If the disc becomes non-salvageable, a total joint prosthesis may be indicated.

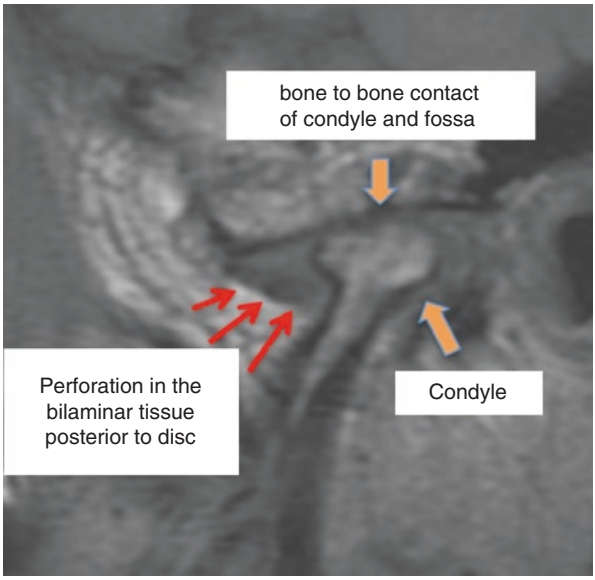

Fig. 10.5 MRI of left arthritic condyle with perforation of the bilaminar tissue posterior to the anteriorly displaced disc. Bone-to-bone contact of the condyle and fossa is observed with crepitation on jaw function

10.7 Connective Tissue/Autoimmune Diseases

The MRI presentation of connective tissue/autoimmune diseases can be pathognomonic. In these conditions, the articular disc oftentimes is in a relatively normal position, but there is progressive condylar resorption, "mushrooming" of the remaining condyle and often resorption of the articular eminence, with slow but progressive destruction of the articular disc that is surrounded by a reactive pannus [13] (Fig. 10.6a–c). This presentation almost always indicates the requirement of total joint prostheses for jaw reconstruction to eliminate the pathologic process in the joint and develop predictable stability [1–4, 13–17]. The use of autogenous tissues in this scenario could result in the disease process attacking autogenous tissues placed into the joint with subsequent failure.

10.8 Trauma

Traumatic injuries to the jaws may develop facial deformities, particularly those that involve the TMJs with unilateral or bilateral condylar or subcondylar fractures that are inadequately reduced. Patients may present with (1) mandible retruded or deviated toward the affected side, if unilateral, (2) pain and jaw dysfunction, (3) deficient growth on the affected side(s) in growing patients, (4) Class II skeletal and occlusal relationships, and (5) premature contact of the occlusion on the affected side(s) and open bite (Fig. 10.25a–c). Imaging features could include (1) evidence

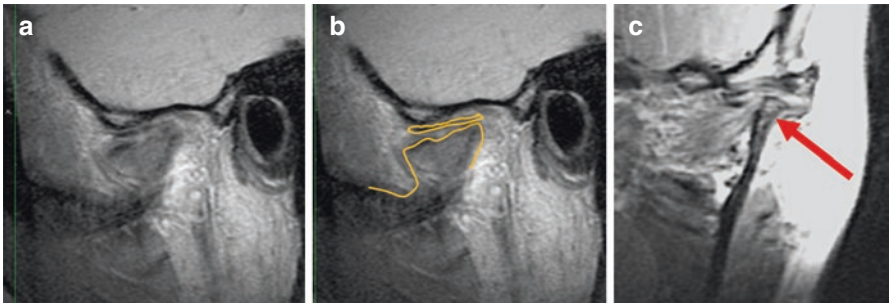

Fig. 10.6 (**a**) MRI of TMJ with juvenile idiopathic arthritis (JIA). The sagittal view demonstrates that the disc is commonly in position but surrounded by a reactive pannus (gray tissue around the degenerated disc and condyle) that destroys the disc, condyle, and articular eminence. The remaining condyle has a "mushroom" appearance. (**b**) The condyle and disc are outlined in orange. (**c**) Coronal view showing the extreme narrowness of the residual condyle

of previous condylar, mandibular, or midfacial fractures; (2) the condyle, when fractured, may be malpositioned downward, forward, and medial to the fossa; and (3) decreased vertical ramus/condyle length. MRI aids in showing the disc position and condition. At the initial presentation of the trauma, the options for treating subcondylar fractures are open reduction, closed reduction, or no treatment. The amount of displacement and the condition of the fracture(s) affect the treatment needed to fix the problem. When identified early, fractures may be best treated by open reduction for significantly displaced segments or closed reduction for minimally displaced segments to achieve a symmetric face and stable occlusion. If the condyle has healed in a minimally to moderately displaced position and the articular disc is salvageable, then orthognathic surgery could realign the jaw structures in the proper orientation. If the condyle is severely deformed and non-salvageable, then the most predictable reconstruction of the TMJ and repositioning of the mandible are using patient-fitted total joint prostheses (TMJ Concepts system) and fat grafts (see Figs. 10.21a–c and 10.22a–d). Other treatment options for TMJ reconstruction include rib grafts and sternoclavicular grafts.

10.9 Ankylosis

Temporomandibular joint (TMJ) heterotopic bone refers to calcifications that develop in and around areas of the joint that are normally void of the bone. The development of heterotopic bone within the confines of a joint or in the surrounding area can cause joint dysfunction, pain, and progression to ankylosis.

Temporomandibular joint ankylosis is a condition where the condyle is fused to the fossa by bony or fibrotic tissues creating a debilitating, painful condition that can interfere with jaw function, mastication, speech, oral hygiene, growth and development, breathing, and normal life activities (Fig. 10.7). There are numerous surgical techniques that have been proposed to manage heterotopic bone and TMJ ankylosis

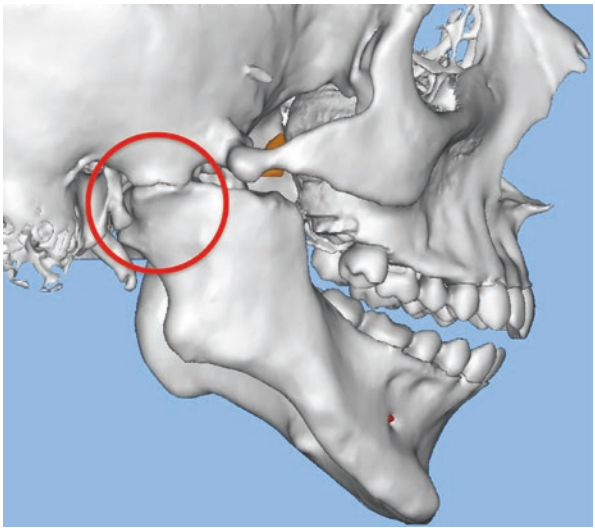

Fig. 10.7 Bony ankylosis of the right TMJ is noted creating severe limitation of jaw function and opening

with varying outcomes reported. The most common complications following the treatment of ankylosis are limited jaw function, pain, and re-ankylosis [18, 19].

The formation of TMJ heterotopic bone and ankylosis is most commonly caused from trauma but can also be related to inflammation or bone growth stimulation related to various TMJ pathologies such as infection, reactive arthritis, osteoarthritis, inflammatory conditions, connective tissue/autoimmune diseases (e.g., juvenile idiopathic arthritis, rheumatoid arthritis, psoriatic arthritis, ankylosing spondylitis, scleroderma, etc.), endocrine and metabolic disorders, multiply operated joints, foreign-body giant-cell reaction, repeated injections of medications into the TMJ (i.e., steroids), as well as unsuccessful previous TMJ surgeries including failed TMJ autogenous grafts and alloplastic implants. In the initial phases, heterotopic bone may be asymptomatic. However, with further progression, the excess bone can create pain, decrease range of motion, and lead to ankylosis (Fig. 10.7). A variable amount of fibrosis and reactive tissue are normally associated with heterotopic bone, thereby worsening the adverse effects.

Bleeding into a joint by trauma or a surgical procedure, the presence of dead space following extensive TMJ debridement, or reconstruction with autogenous bone or total joint prosthesis can lead to blood clot formation in the joint area, with subsequent organization. Pluripotent cells can then migrate into the area and differentiate into fibroblasts and osteoblasts, leading to deposition of collagen and then the bone. This results in the potential development of heterotopic bone and ankylosis. In excessively fibrotic joints, the tissue vascularity decreases with resultant decrease in oxygen tension in the surrounding tissue, which can lead to the transformation of fibrous tissue into the cartilage and bone with potential for ankylosis. Temporomandibular joint ankylosis can be even more devastating in growing

patients resulting in a profound dentofacial deformity in addition to jaw dysfunction and malocclusion [20]. Effective and predictable treatment of ankylosis includes TMJ reconstruction with total joint prostheses and fat grafting [19].

10.10 Craniofacial Anomalies/Obstructive Sleep Apnea

Patients may require C-TJR-OS when treating temporomandibular joint disorders in combination with other factors such as A-P hypoplasia of the maxilla and mandible, craniofacial anomalies, decreased oropharyngeal airway, and sleep apnea issues. Patients with TMJ pathologies, particularly those with condylar resorption, may experience progressively worsening breathing and sleep apnea issues due to progressive mandibular retrusion and posterior mandibular vertical collapse. Craniofacial patients, such as Treacher Collins syndrome, Pierre Robin sequence, and hemifacial microsomia, often present with hypoplastic condyle and mandible which lead to functional (mastication and breathing) disorders. Treatment options that have been applied to these patients' conditions include distraction osteogenesis, costochondral reconstruction, early-stage orthognathic surgery, or TMJ total joint prostheses. When these techniques are used on growing patients, secondary procedures commonly are required following growth completion. Once the patients have completed growth, definitive treatment can be implemented that may involve alloplastic TMJ reconstruction with orthognathic surgery.

Patients with sleep apnea symptoms may require further diagnostic workup including polysomnography and drug-induced sleep endoscopy. Many patients diagnosed with sleep apnea also have TMJ issues that need to be addressed at the same time or before the orthognathic surgery is performed to provide a stable and predictable outcome. Advancing the maxillary and mandibular complex with simultaneous counterclockwise rotation improves facial balance and significantly opens the oropharyngeal airway [21–26]. Double-jaw surgery with counterclockwise rotation of the maxillomandibular complex will increase the oropharyngeal airway of approximately 65–70% for the first 10 mm of mandibular advancement [27–31]. With 10–15 mm of advancement, the oropharyngeal airway continues to open, but at a lesser percentage ranging from 55 to 60% of the mandibular advancement. When the mandible is advanced 15–20 mm, the oropharyngeal airway continues to open but only about 40–45% of the amount of mandibular advancement. Later in this chapter, Cases 1, 2, and 3 illustrate successfully treated patient with TMJ pathology and obstructive sleep apnea utilizing the one-stage concomitant total joint replacement and orthognathic surgery.

10.11 Patient Evaluation

It is important to know the patient's concerns, history, symptoms, and treatment expectations. Although previous publications further detail information on patient evaluation for orthognathic, TMJ, and sleep apnea surgery including clinical,

radiographic, MRI, and dental model analyses [1–4, 32], we will briefly discuss the salient points and provide a general overview. A complete structural craniofacial analysis is carried out to determine the degree to which the individual patient varies from his or her "ideal." This analysis demonstrates all of the maxillofacial deformities and imbalances that require orthodontic and surgical correction. The relative retrusion or protrusion of each facial third in profile and vertical and transverse excess or deficiency of the maxilla and mandible are examined. The anterior facial height is also carefully studied to delineate other skeletal and dental deformities from TMJ pathology resulting in vertical discrepancies. Wolford [33] demonstrated radiographically that the upper anterior face, measured from nasion (Na) to anterior nasal spine (ANS), constitutes 45% of the total anterior facial height and that the lower anterior facial height, measured from ANS to menton (Me), constitutes 55%. Delaire and Schendel [34–36] have confirmed via architectural and structural craniofacial analysis that these percentages represent constants of ideal vertical facial height.

It is imperative for the clinician to realize that patients with TMJ pathology and dentofacial deformities (often with retruded mandible) are sometimes misleading in their clinical presentation because their "natural head position" may posture their head hyperextended, resulting in the lower jaw and chin tipped upward and forward to make the chin appear more prominent and to open the oropharyngeal airway to improve their ability to breathe. If the patients are not evaluated with a properly corrected head position, the amount and degree of maxillary and mandibular retrusion and asymmetry may be missed. Therefore, it is important that the clinician evaluates the patient with the pupillary plane and ear plane parallel to the floor in the frontal view (Fig. 10.8a) and clinical Frankfort horizontal plane (a line from the tragus of the ear through the bony infraorbital rim) parallel to the floor in the profile view (Fig. 10.8b). Obviously there will be some variance in individuals, but this is a basic guide.

10.12 Imaging

Radiographic evaluation is critical in the diagnostic process. Various imaging modalities provide different views of the soft and hard tissues in the craniofacial complex that allows for assessment of pathological conditions and deviation of the bony relationships from the relative normal values. Imaging options include panoramic and cephalometric X-rays, TMJ tomograms, cone beam CT, traditional CT scans, bone scans, and magnetic resonance imaging.

10.12.1 CT Imaging

Three-dimensional (3-D) imaging with CT scan allows for analysis of the TMJ, of the positioning between the maxilla, mandible, and cranial base, and of the oropharyngeal and nasal airways. Cone beam computed tomography (CBCT) provides low-cost and

low-radiation scans when compared to traditional CT scans. Either CBCT or traditional CT scans can be used as part of the diagnostic and planning process. Craniofacial data obtained from cephalometric and CT scan analysis is integrated to determine the treatment plan and simulate the surgical movements using virtual planning. 3-D modeling of the surgical movements, which provides the new position of the jaws and joints, is necessary for manufacture of patient-fitted TMJ total joint prostheses.

10.12.2 MRI Evaluation

Magnetic resonance imaging (MRI) is one of the most important diagnostic tools to evaluate and diagnose and treatment plan for TMJ pathology. MRI evaluates bone and soft tissue structures, TMJ disc position, morphology, mobility, extent of joint degenerative changes, inflammation, the presence of connective tissue/autoimmune diseases, and other pathologies. It aids in the diagnosis of TMJ disorders in patients with "silent joints" that may not make noise or cause pain but have presence of disc displacement and degenerative changes. If the TMJ pathology is not treated in these patients, then the diseased joints may contribute to poor outcomes when only orthognathic surgery is performed.

In general, T-1 MRIs are helpful in identifying disc position and morphology, the presence of alteration in bone and soft tissue structures, and interrelationships of the bony and soft tissue anatomy. T-2 MRIs are more helpful in identifying inflammatory responses in the TMJ, such as effusions, synovitis, etc. 1.5–3.0 T MRI machines are recommended for MRI evaluation of the TMJs. "TMJ coils" are necessary to achieve diagnostic quality images of the TMJs. The basic views that are most helpful in diagnoses include (1) sagittal views in centric relation as well as in maximum opening, (2) coronal views in centric relation, and (3) dynamic views, if available. The MRI imaging can be correlated to cone beam imaging of the TMJs for joint space evaluation and greater interpretation of bony pathology. Figure 10.1 shows a normal TMJ MRI with healthy anatomical structures and relative positioning. Later, this chapter will also discuss examples of TMJ conditions where the MRI provides guidance in determining the appropriate surgical treatment option.

10.12.3 Cephalometric Analysis

The lateral cephalometric analysis can determine the severity of the jaw deformity, dental alignment, and airway dimensions in the anteroposterior vector. Cephalometric analysis is an important assessment for diagnosis and treatment planning for TMJ patients because the most dominant facial type that experiences TMJ pathology is the high occlusal plane angle facial morphology with a retruded maxilla and mandible. Normal cephalometric relationships have been described in detail in previously published papers [3, 32].

One of the primary factors contributing to sleep apnea is a decreased oropharyngeal airway that is commonly seen in TMJ patients, specifically with a history of TMJ condylar resorption. The normal cephalometric A-P dimension from the posterior pharyngeal wall to the soft palate and posterior pharyngeal wall to the base of the tongue is 11 mm, plus or minus 2 mm. In patients who have a retruded maxilla and mandible, this airway may be significantly decreased. The airway size and length increase until age 20, at which time there is a variable period of stability, after which the airway at first decreases slowly in size and then, after age 50, more rapidly [37]. Accompanying these deficiencies is usually a high occlusal plane angle. The normal cephalometric angle of the occlusal plane to the Frankfort horizontal plane is 8°±4°. Cephalometric analysis depicting a significantly increased occlusal plane is commonly seen with a retruded maxilla and mandible (particularly with condylar resorption) and should be addressed in the treatment planning.

10.13 Comprehensive Diagnostic List and Treatment Plan

Following completion of all necessary and required evaluations, a comprehensive diagnostic list can be compiled. A definitive treatment plan can then be established to address these issues and other treatment options that may be available to allow the patient to make an informed decision as to the preferred treatment.

The following triad of factors are commonly encountered in the diagnostic list of TMJ patients: (1) A high occlusal plane angle facial morphology associated with retruded maxilla and mandible with an accompanying decreased oropharyngeal airway, (2) nasal airway obstruction related to hypertrophied turbinates and/or nasal septal deviation or spurring, and (3) TMJ pathology. A recent study evaluated 1234 consecutive patients referred for orthognathic surgery requiring at least maxillary osteotomies [36]. There were 603 patients (49%) with hypertrophied turbinates requiring partial turbinectomies and 278 patients (23%) required nasal septoplasty. For patients requiring partial turbinectomies ($n = 603$), 84% had maxillary hypoplasia, 72% had mandibular hypoplasia, 69% had a high occlusal plane angle, and 49% of the patients required C-TMJ-OS. Furthermore, a female predominance was seen in the data reviewed. Sixty-seven percent of the turbinectomy cases and 73% of concomitant turbinectomy and orthognathic and TMJ surgery cases involved female subjects. A strong correlation has been established between hypertrophied inferior turbinates, hypoplastic maxilla and mandible, and a steep occlusal plane. The findings of this study correlate with other studies evaluating the morphology of mouth breathing and nasally obstructed patients [38–42]. Therefore, patients with the high occlusal plane angle facial morphology with a retruded maxilla and mandible should be assessed for nasal airway obstruction, decreased oropharyngeal airway and sleep apnea, as well as TMJ pathology including asymptomatic patients.

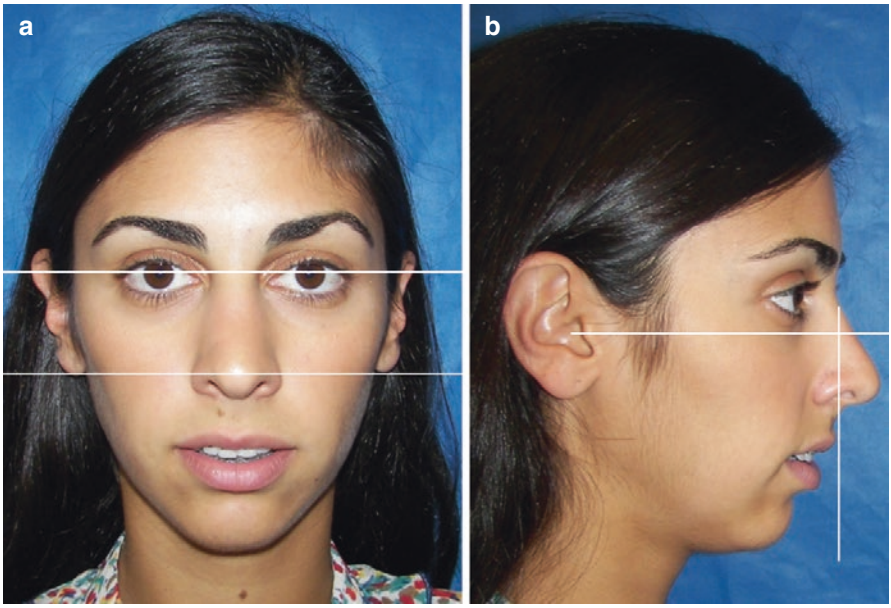

Fig. 10.8 (**a**) Patients should be evaluated in the frontal view with pupillary plane and ear plane relatively parallel to the floor with understanding there are variations in symmetry in this view. (**b**) In profile, patients should be evaluated with clinical Frankfort horizontal plane (a line from the tragus of the ear through the bony inferior orbital rim) parallel to the floor for assessment of A-P and vertical facial balance

10.14 Age for Surgical Intervention

Although there are individual variations, females usually have the majority of their facial growth (98%) complete by the age of 15 years and males by the age of 17–18 years [43]. Predictability of results and limiting corrections of the jaw and TMJ pathology related deformities to one major operation can best be achieved by waiting until growth is relatively complete if only the TMJ total joint prostheses are placed without maxillary surgery, particularly if only a unilateral prosthesis is required. However, there are definite indications for performing surgery during the growing years such as progressive TMJ deterioration, ankylosis, masticatory dysfunction, tumor removal, pain, sleep apnea, etc. Performing surgery during growth may result in the need for additional surgery at a later time to correct a resultant deformity and malocclusion that may develop. Additional surgery is a greater probability with unilateral prosthesis and a normal contralateral TMJ if surgery is performed during the growing years. In addition, some orthognathic surgical procedures, such as maxillary Le Fort 1 osteotomies, have a profound effect on subsequent facial growth and development where maxillary anterior-posterior growth is stopped. However, the vertical alveolar growth of the maxilla and mandible continues contributing to a downward and backward rotation vector of facial growth with

maintenance of occlusion. Therefore, bilateral TMJ patient-fitted total joint prostheses and maxillary osteotomies can be done at an earlier age with predictable results. If repeat orthognathic surgery is required at a later time, the advancement of the mandible with the TMJ total joint prosthesis can be accomplished by one of four surgical options: (1) intraoral mandibular ramus sagittal split osteotomy; (2) extraoral mandibular ramus sagittal split osteotomy; (3) advance the mandible forward relative to the prosthesis by removing the screws from the mandibular component, separate it from the ramus, advance the mandible along the patient-fitted prosthesis, and re-fixate the prosthesis to the mandible with bone screws in its new position (can usually work for only smaller advancements); or (4) replace the mandibular component of the total joint prosthesis with a new longer custom fabricated mandibular component that would be reattached to the mandibular ramus after the mandible is moved into its new position.

Previous publications have described the effects of maxillary and mandibular orthognathic surgery on growth with guidelines for age considerations for surgical intervention [44–46] as well as the effects of TMJ surgery on facial growth [20] and will not be further discussed here. Later in this chapter, Case 2 illustrates successfully treated juvenile idiopathic arthritis (JIA) patient (age 16) utilizing the one-stage concomitant total joint replacement and orthognathic surgery with good functional and esthetic results without requiring secondary procedures [13]. These cases are predictable when performed at age 13 years or older in females and 15 years or older in males. However, the vector of facial growth will change in younger patients to a downward and backward direction.

10.15 High Occlusal Plane Facial Morphology

The common functional and esthetic characteristics of the high occlusal plane facial morphology generally include the following:

1. Increased occlusal plane angulation (occlusal plane greater than 12°).
2. Increased mandibular plane angulation.
3. Anterior vertical maxillary hyperplasia and/or posterior vertical maxillary hypoplasia.
4. Increased vertical height of the anterior mandible and/or decreased vertical height of the posterior mandible.
5. Decreased projection of the chin (anteroposterior microgenia).
6. Anteroposterior and vertical posterior mandibular and maxillary hypoplasia.
7. Decreased angulation of maxillary incisors, although overangulation can occur.
8. Increased angulation of mandibular incisors.
9. Class II malocclusion is common, although Class I and Class III malocclusions also can occur.
10. An anterior open bite may be accompanied by an accentuated curve of Spee in the upper arch.

11. Loss of incisal guidance, loss of canine rise occlusion, and the presence of working and non-working dental interferences in the molar areas may occur in more pronounced cases in which the occlusal plane approaches the slope of the articular eminence.
12. More severe cases may demonstrate moderate to severe sleep apnea symptoms as a result of the tongue base and soft palate displaced posteriorly and constricting the oropharyngeal airway (normal oropharyngeal airway space is 11 ± 2 mm).
13. Nasal airway obstruction related to hypertrophied turbinates and/or septal deviation or spur.
14. TMJ pathology.

10.16 Occlusal Plane Angle

The correction of dentofacial deformities often requires double-jaw surgery to achieve a harmonious result when addressing the function, esthetic, and airway needs. An often ignored but important cephalometric and clinical interrelationship in the diagnosis and treatment planning for the correction of dentofacial deformities is the occlusal plane angulation [32, 47–49]. The occlusal plane angle is formed by the Frankfort horizontal plane and a line tangent to the cusp tips of the lower premolars and the buccal groove of the second molar. The normal value for adults is 8 ± 4°. An increased (high) occlusal plane angle usually is reflected in an increased mandibular plane angle (dolicocephaly), and a decreased (low) occlusal plane angle usually correlates with a decreased mandibular plane angle (brachycephaly). Patients may benefit functionally and esthetically with surgical alteration of the occlusal plane.

10.17 Surgical Decrease of the Occlusal Plane

In the high occlusal plane patients, the indicated surgical correction may include a counterclockwise rotation of the maxillomandibular complex. In open bite cases, the maxillary occlusal plane and the mandibular occlusal plane may be different, and each should be evaluated independently. For illustrative purposes, a Class I case is used with the maxillary incisor edge as the center of rotation for counterclockwise rotation (Fig. 10.9). The anatomical changes that occur include the following: (1) occlusal plane angle decreases; (2) mandibular plane angle decreases; (3) maxillary incisor angulation increases (the same amount that the maxillary occlusal plane decreases); (4) mandibular incisor angulation decreases (the same amount that the mandibular occlusal plane decreases); (5) projection of the chin increases relative to the lower incisor edges; (6) posterior facial height increases; (7) vertical prominence of the mandibular angles increases; (8) maxillary incisor edges move forward relative to the perinasal area; (9) incisal guidance and canine rise occlusion improve, and posterior working and non-working interferences are eliminated; and (10) oropharyngeal airway increases.

The center of rotation affects the esthetic relationship of the jaws with the other facial structures. In the illustrative case (Fig. 10.9), the center of rotation is at the

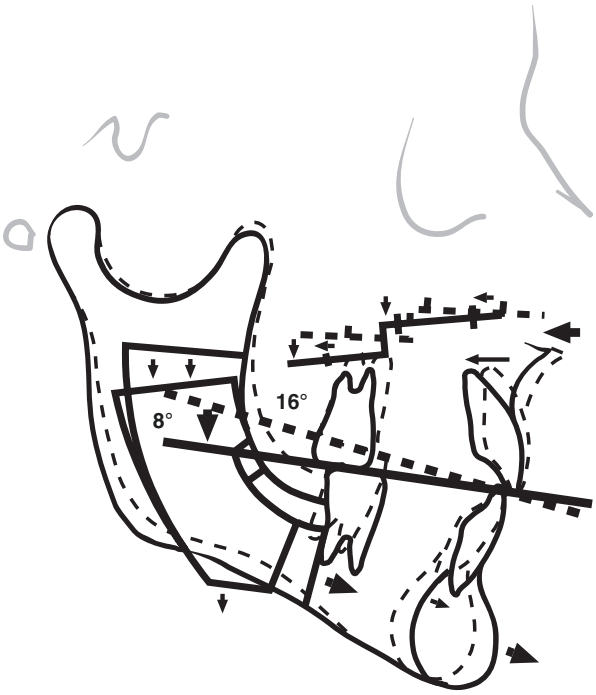

Fig. 10.9 Surgical decrease of the occlusal plane from the dotted line to solid line (counterclockwise rotation) rotates the chin forward, decreased prominence of the perinasal areas, maxillary incisor angulation increases, mandibular incisor angulation decreases, and the oropharyngeal airway increases

maxillary incisor edge. Counterclockwise rotation of the maxillomandibular complex results in the perinasal area, subnasale area, and the nasal tip moving posteriorly, but the mandible and chin come forward. If rotation is around point A or higher, then the perinasal area and the nose are less affected, but the mandible, chin, and maxillary incisor edges come further forward, increasing the anteroposterior support to the upper and lower lip (Fig. 10.10). This demonstrates the significant esthetic difference that the alteration of the occlusal plane can make by rotating at different points of rotation [32, 47–49]. When decreasing the occlusal plane angle and advancing the mandible counterclockwise, the oropharyngeal airway increases approximately 50–70% of the mandibular advancement measured at the genial tubercles for the first 10 mm of forward movement [27–31].

10.18 Concomitant TMJ Total Joint Replacement and Orthognathic Surgery (C-TJR-OS)

Treatment planning for C-TJR-OS cases is based on cephalometric and 3-D analysis, prediction tracing, clinical evaluation, and dental models, which provide the templates for movements of the upper and lower jaws to establish optimal treatment

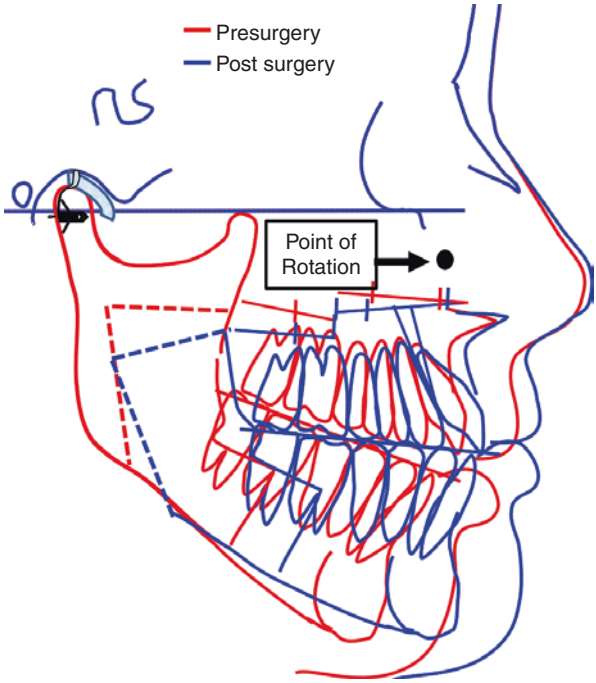

Fig. 10.10 When the point of rotation is moved upward above the maxillary osteotomy level and counterclockwise rotation of the maxillomandibular complex is completed, all structures below that point move forward including the maxilla, mandible, and teeth, with the greatest forward movement at menton

outcome in relation to function, facial harmony, occlusion, and oropharyngeal airway dimensions. For patients who require total joint prostheses, a medical-grade computed tomographic (CT) scan with 1 mm overlapping cuts is recommended of the maxillofacial region that includes the TMJs, maxilla, and mandible. The surgeon has two options for model preparation to aid in the construction of patient-fitted total joint prostheses using the TMJ Concepts system (Ventura, CA). Previously published articles have detailed the traditional protocol technique versus the computer-assisted surgical simulation (CASS) protocol. The CASS technique is also known as virtual surgical planning (VSP) [50, 51]. In this chapter, we will present only the CASS technique.

Over the past decade, CASS technology has been integrated to many maxillofacial surgical applications [52, 53], including dentofacial deformities, congenital deformities, treatment of obstructive sleep apnea, defects after tumor ablation, post-traumatic defects, reconstruction of cranial defects [54], and reconstruction of the TMJ [55]. CASS technology can improve surgical accuracy, provide intermediate and final surgical splints, and decrease the surgeon's time input for presurgical preparation compared with traditional methods of case preparation [50, 51]. C-TJR-OS involves intricate surgical steps that must be judicially planned and executed.

10.19 Protocol for C-TJR-OS Using CASS

To prepare for C-TJR-OS cases using CASS, a medical-grade CT scan is obtained, and the Digital Imaging and Communications in Medicine (DICOM) data is then sent to a VSP company. The CASS technology is utilized by several different VSP companies including 3D Systems (formerly Medical Modeling), ProtoMED, Materialize, and ProPlan. The orthognathic surgery is planned using CASS technology by moving the maxilla and mandible into their final positions in a computer-simulated environment (Fig. 10.11a–c). Using the computer simulation, the

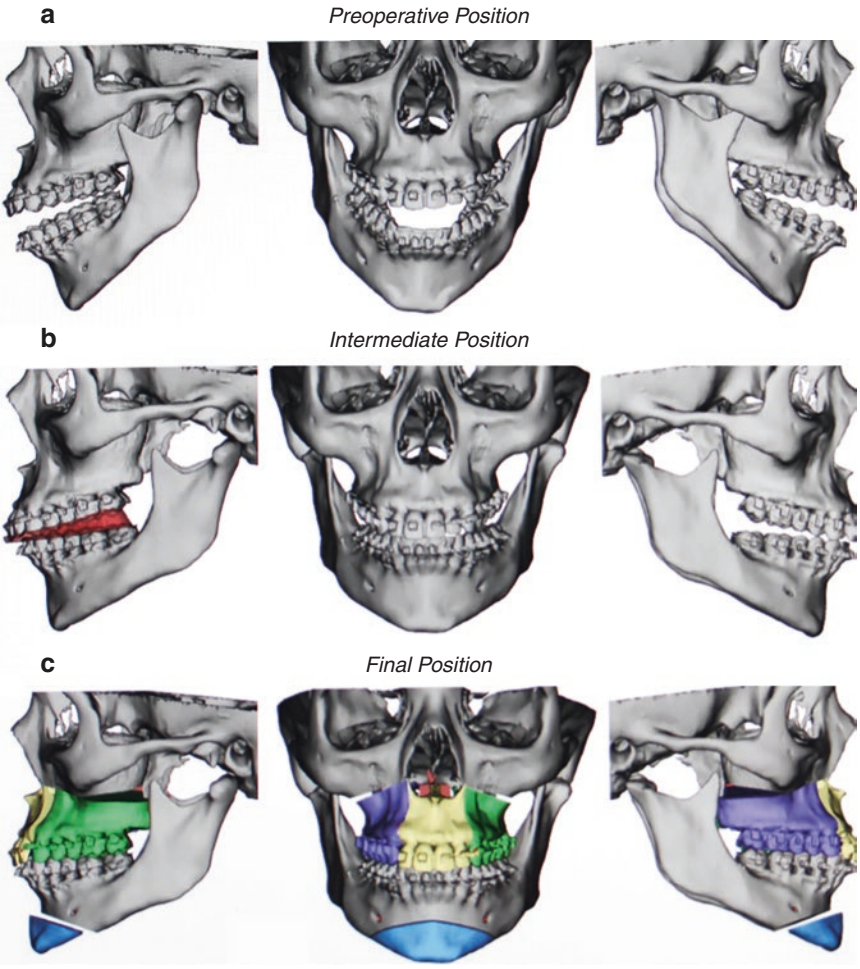

Fig. 10.11 Staged computer-aided surgical simulation (CASS). (**a**) Simulated preoperative position of the maxilla and mandible. (**b**) The maxilla and mandible in the simulated intermediate position, with the maxilla in it's original position, but mandible in it's final position with the mandibular surgery performed first for fabrication of the intermediate splint (red simulated splint). (**c**) The final position of maxilla and mandible, after counterclockwise rotation advancement of the mandible and segmented maxilla, for the production of a palatal splint

anteroposterior and vertical positions, pitch, yaw, and roll are accurately finalized for the maxilla and mandible based on clinical evaluation, dental models, cephalometric analysis, prediction tracing, and computer simulation analysis.

The stereolithic model is produced with the maxilla and mandible in the final position and provided to the surgeon for removal of the condyle and recontouring of the lateral rami and mandibular fossae if indicated. The stereolithic model is sent to TMJ Concepts (Ventura, CA) for the design, blueprint, and wax-up of the prostheses. Using the Internet, the design is sent to the surgeon for approval. Then, the custom-fitted total joint prostheses are manufactured (Fig. 10.12). It takes approximately 12 weeks to manufacture the total joint custom-fitted prostheses.

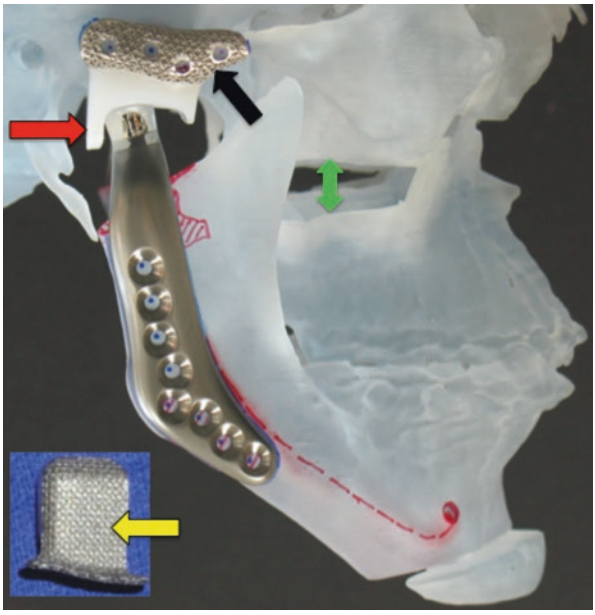

Fig. 10.12 Stereolithic model fabricated after simulated maxillary and mandibular counterclockwise rotation advancement to the final position. Condylectomy and recontouring of the lateral rami and fossae were performed and prostheses manufactured. The basic design of the TMJ Concepts patient-fitted prosthesis is observed. The black arrow points to the mesh framework on the underside of the custom-fitted titanium shell that secures the polyethylene articulating portion of the fossa component. The yellow arrow points to the mesh on the superior surface of the fossa component that allows osseointegration with the fossa bone. The red arrow points to the posterior stop of the fossa, a necessary component for mandibular advancement and stability. The green arrow shows the bony defect in the lateral maxillary wall created from the counterclockwise rotation of the maxilla. These defects require rigid fixation and bone or synthetic bone grafting for stability of the maxilla

Approximately 2 weeks before surgery, final dental models are produced. If single piece maxillary and mandibular surgery without equilibration is planned, then only one set of models is required. Two sets of maxillary and mandibular models are required if the maxilla or mandible is to be segmented or dental equilibrations are required. One of the maxillary models is segmented if indicated, dental equilibration performed, and segments placed in the best occlusion fit with the mandibular dentition. The maxillary segments are then fixed to each other with glue, wax, or other means that the surgeon prefers. The dental models do not require mounting on an articulator. The three or four models (two maxillary and one mandibular or two mandibular models if equilibrations are done) are sent to a VSP company for scanning and simulation into the computer model. Recent advancements in direct intraoral scanning can also be utilized instead of stone casts for VSP planning. Because the authors routinely perform the TMJ reconstruction and mandibular advancement with the TMJ Concepts total joint prosthesis first, the unsegmented maxillary model is simulated into the original maxillary position, and the mandible is maintained in the final position. The intermediate splint is constructed (Fig. 10.13a–d). Then the

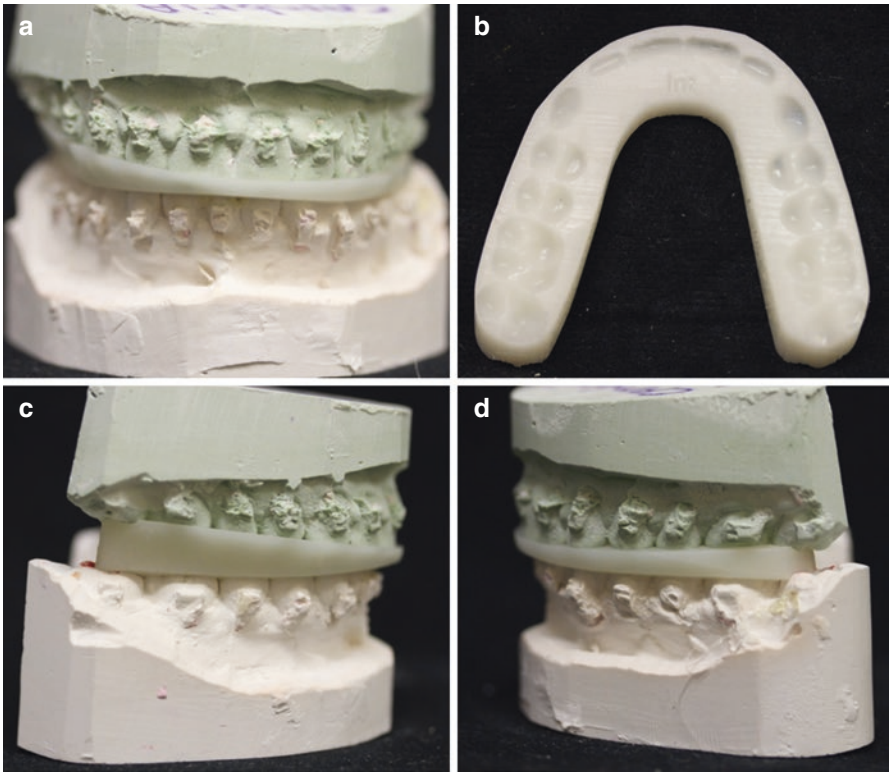

Fig. 10.13 (**a**–**d**) Intermediate splint is printed from the CASS model with the mandible in the final position and the maxilla in the original position

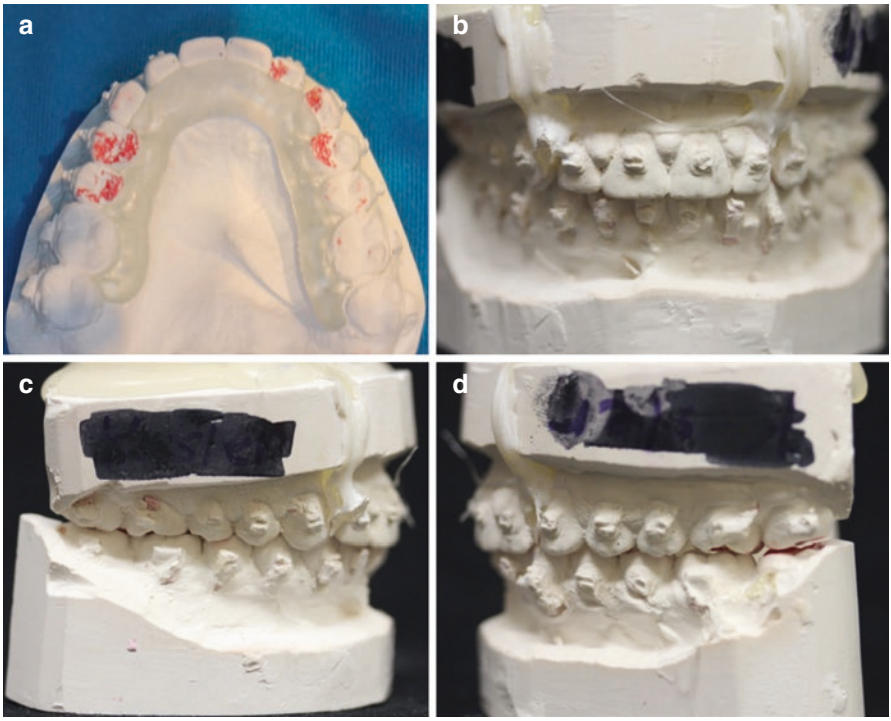

Fig. 10.14 (**a**) The final palatal splint is printed for surgical application. (**b**–**d**) The palatal splint allows the teeth to fit together maximally and can remain in positon for several months if required for stability and the maxillary segments. If the maxilla is not segmented, then the palatal splint may not be required. It is stabilized to the maxillary arch with light gage wires securing it to the first molars and first bicuspids

segmented maxillary model is simulated into the computer model in its final position, with the maxilla and mandible placed into the best occlusal fit, and the final splint is fabricated (Fig. 10.14a–d). The stereolithic model, dental models, splints, and images of the computer-simulated surgery are sent to the surgeon for implementation during surgery.

10.19.1 Step-by-Step Methods

1. CT scan of the entire mandible, maxilla, and TMJs (1 mm overlapping cuts).
2. Dental models/dental scans and CT scan sent to VSP company.
3. Processing of DICOM data to create a computer model in CASS environment by the VSP company.
4. Correction of dentofacial deformity, including final positioning of the maxilla and mandible, with computer-simulated surgery.
5. Stereolithic model constructed with jaws in final position and sent to surgeon for condylectomy and rami and fossae recontouring if indicated.

6. Model sent to TMJ Concepts for prostheses design, blueprint, and wax-up.
7. Surgeon evaluation and approval using the Internet.
8. TMJ prostheses manufactured and sent to hospital for surgical implantation.
9. Two weeks before surgery, acquisition of final dental models (two maxillary, one or two mandibular models if dental equilibrations are required); one maxillary model is segmented and models equilibrated if indicated to maximize the occlusal fit; models sent to the company performing the CASS planning.
10. Models incorporated into computer-simulated surgery for construction of intermediate and final palatal splints.
11. Stereolithic model, dental models, splints, and printouts of computer-simulated surgery sent to surgeon.

Using CASS technology for CTOS cases eliminates the "traditional" steps requiring the surgeon to manually set the mandible into its new final position on the stereolithic model, thus saving time and improving surgical accuracy. Although dental model surgery is necessary only if the maxilla requires segmentation or equilibration, the models do not require mounting on an articulator. This saves considerable time by eliminating the time required to mount the models, prepare the model bases for model surgery, reposition the mandible, construct the intermediate occlusal splint, and make the final palatal splint. With CASS technology, the company performing the CASS planning manufactures the splints.

10.19.2 Surgical Sequencing for C-TJR-OS

1. Condylectomy and discectomy.
2. Coronoidectomy (if mandible significantly advanced or lengthened vertically).
3. Detach the masseter and media pterygoid muscles from the ramus.
4. Modify rami and fossae if indicated from the stereolithic model preparation.
5. Mobilize the mandible.
6. Maxillomandibular fixation with intermediate surgical splint.
7. Placement of total joint prostheses.
8. Bilateral TMJ fat grafts harvested from the abdomen or buttock.
9. Maxillary osteotomies and mobilization.
10. Turbinectomies, septoplasty, etc.
11. Maxillary segmentation and application of the palatal splint if indicated.
12. Maxillary rigid fixation and bone grafting.
13. Adjunctive procedures such as genioplasty, rhinoplasty, UPPP, facial augmentation, etc.

The TMJ Concepts prostheses use design principles and materials that are proven highly successful and are the gold standard in orthopedic joint reconstruction for hip and knee replacements. The prosthesis consists of a fossa component with a commercially pure titanium framework covered with a mesh and an

ultra-high-molecular-weight polyethylene functional component fused to the mesh on the bottom side of the framework. The fossa component is attached to the lateral rim of the fossa with four 2-mm-diameter screws. The mandibular component is composed of a titanium alloy shaft with a cobalt-chromium alloy head with the prosthesis secured to the mandibular ramus with seven to nine 2-mm-diameter bicortical screws. The fossa and mandibular components osseointegrate with the fossa and ramus, respectively.

10.20 Surgical Procedure

1. After surgical prepping including the face, neck, mouth, ears, ear canals, nose, endotracheal tube, and abdomen, the abdomen and the face and neck are draped, and the mouth and nose are isolated by application of a Tegaderm film dressing (Fig. 10.15a), and the ear canal is gently packed with cotton or Xeroform.
2. The TMJs are approached through an endaural (Fig. 10.16) or preauricular incision to perform the condylectomy, discectomy, joint debridement, and coronoidectomy (Fig. 10.17a) (when the mandible is significantly advanced or vertically lengthened). The condylectomy and debridement of the joint are performed first, and then the coronoidectomy is preformed through the endaural incision using a reciprocating saw cutting from the anterior aspect of the coronoid and coursing horizontally across the ramus 5 mm inferior to the sigmoid

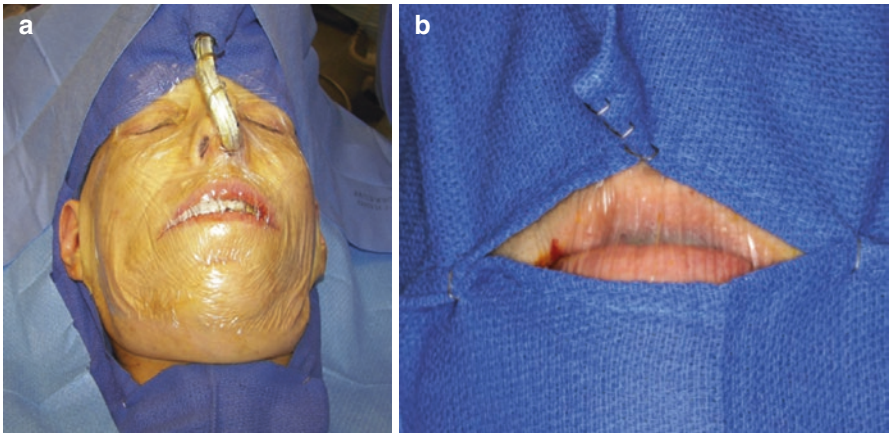

Fig. 10.15 (**a**) After preparation of the face, neck, ears, and oral cavity, a Tegaderm film dressing, 6 × 8 in., is applied to seal off the oral cavity and nasal airway from the surgical field. (**b**) Following mobilization of the mandible and preparation to enter the oral cavity to place the intermediate splint, sterile towels are draped around the mouth to prevent contamination of the extraoral surgical sites. The Tegaderm dressing is cut to provide access to the oral cavity for placement of the intermediate splint and maxillomandibular fixation. Following application of the splint and intermaxillary fixation, as well as removal of the towels, a new Tegaderm dressing is placed over the mouth and nose

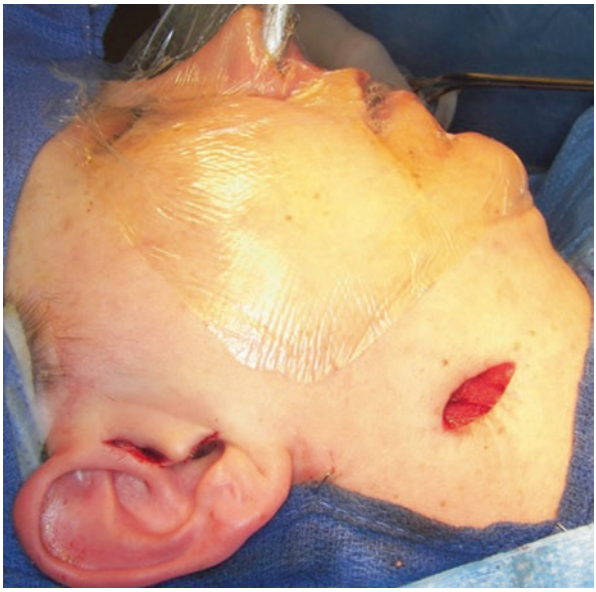

Fig. 10.16 Incisions for placing the total joint prostheses include an endaural (shown) or preauricular incision as well as a submandibular incision

notch. Using a medial retractor or packing Surgicel or Gelfoam medial to the coronoid will protect the vessels and other soft tissue structures while the cut is made. The coronoidectomy may also be performed after the submandibular approach to the ramus to allow for access to the external carotid artery for urgent ligation in case uncontrollable bleeding is encountered from the maxillary artery and branches. The bone from the condylectomies and coronoidectomies is saved for use in grafting the bone defects that may be associated with the maxillary osteotomies.

Risks associated with this part of the surgery include facial nerve injury and bleeding as the facial nerve branches and maxillary artery and branches are in close proximity. Facial nerve involvement can be minimized by understanding the anatomy, employ small incisions, use of a nerve stimulator when appropriate, careful surgery, and avoid heavy-handed inferior retraction toward earlobe as this can cause damage to the main branch of the nerve. Bleeding may be prevented by using retractors that surround the medial side of the condyle and neck at the time of the condylectomy. Traditionally, reciprocating saw is used for the condylectomy and coronoidectomy. Packing Surgicel or Gelfoam around the medial side of the condylar neck and medial to the ramus, sigmoid notch area, and coronoid will help prevent encountering the major vessels in the area by placing a physical barrier between the bone cuts and the vessels. Using Piezo technology can also be of benefit. For example, the use of the ultrasonic BoneScalpel in TMJ reconstruction results in less blood loss when compared to surgeries employing the use of the conventional reciprocating saw (Fig. 10.17b, c) for completing osteotomies and is now being used more widely in TMJ and orthognathic surgery [56].

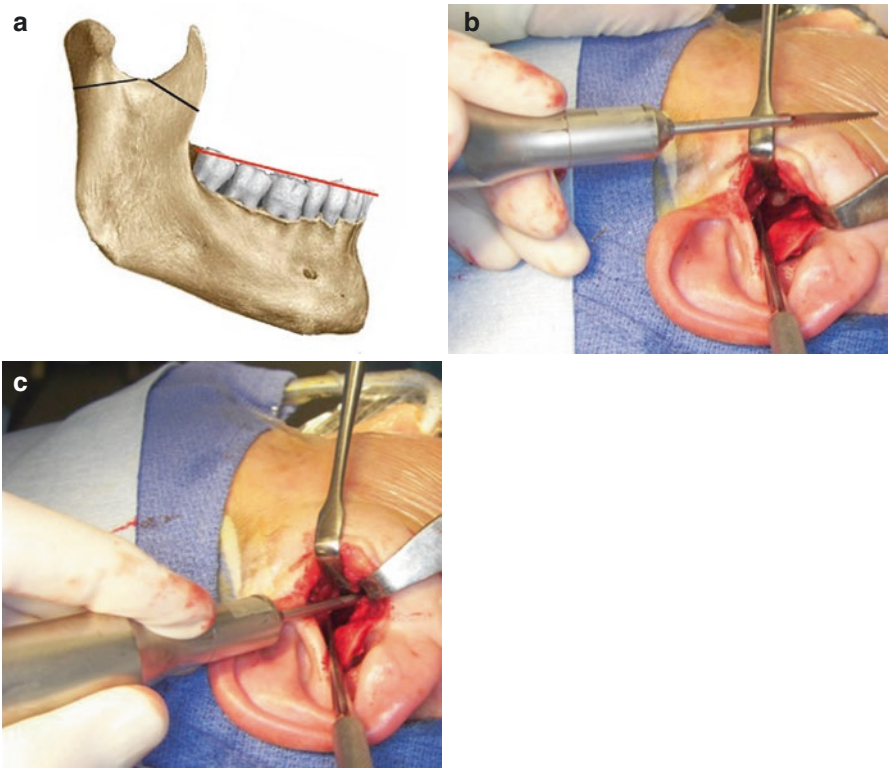

Fig. 10.17 The condylectomy is performed and joint debrided. (**a**) A coronoidectomy is indicated if the ramus is to be significantly lengthened vertically or advanced. (**b**, **c**) The coronoidectomy is performed through the endaural incision with a reciprocating saw and removed. The bone can be used to graft the maxillary osteotomy bony defects

Next, the fossa is debrided and recontoured if indicated according to the preparation on the stereolithic model. Generally, 20 mm of space is required between the fossa and the top of the ramus when the mandible is placed in its new position. Be sure to remove an adequate amount of the bone to accommodate the prosthesis; otherwise there could be interferences that won't allow the prosthesis components to be properly seated.

3. Submandibular incisions (Fig. 10.16) are used to access the ramus to reflect off the masseter and medial pterygoid muscles (if angle significantly advanced or vertically elongated), to recontour the lateral aspect of the ramus if indicated, as well as to mobilize the mandible in a downward and forward direction. Potential risk factors include facial nerve damage and bleeding. The use of a nerve stimulator during dissection to the angle area will help identify the nerve branches and prevent damage. After cutting through the platysma muscle, blunt dissection to the pterygoid-masseteric sling will avoid vascular injury. The lateral

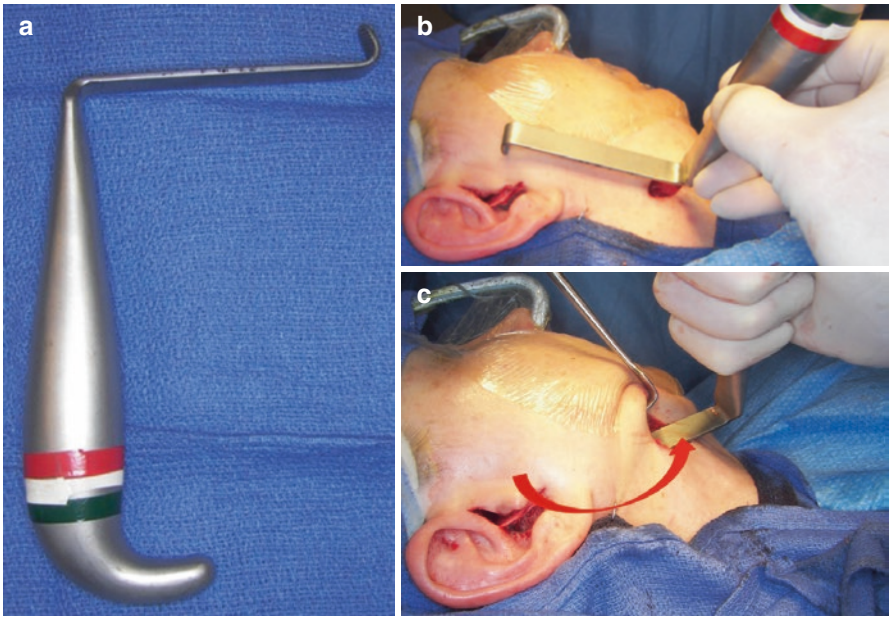

Fig. 10.18 (**a**) The mandibular mobilizer (**b**, **c**) is inserted through the submandibular incision and hooked over the sigmoid notch area and then pulled downward and forward to mobilize the mandible

aspect of the ramus is prepared by duplicating the alterations on the stereolithic model.

4. The mandibular mobilizer device (KLS Martin, Jacksonville, FL) (Fig. 10.18a) is inserted through the submandibular incision and hooked around the sigmoid notch/condyle area and pulled downward and forward to facilitate vertical lengthening and advancement of the mandibular ramus (Fig. 10.18b, c).
5. The oral cavity is isolated by draping with sterile towels and is exposed by cutting through the Tegaderm from commissure to commissure (Fig. 10.15b). If the case includes bilateral total joint prostheses, the intermediate splint is inserted and maxillomandibular fixation applied. If it is a unilateral total joint prosthesis case, then go to Step 6.
6. For unilateral total joint prosthesis, using separate instrumentation, a contralateral mandibular sagittal split osteotomy is performed and the mandible mobilized on that side. The intermediate splint and maxillomandibular fixation are applied. Rigid fixation is placed to secure the mandibular segments and incision closed.
7. The surgeon changes gloves and gown, face is re-prepped if indicated, and the mouth and nose are sealed off once again with a Tegaderm film dressing.
8. The total joint prostheses are inserted and fixed in position, placing the fossa component first and stabilizing with four, 6-mm-length and 2-mm-diameter

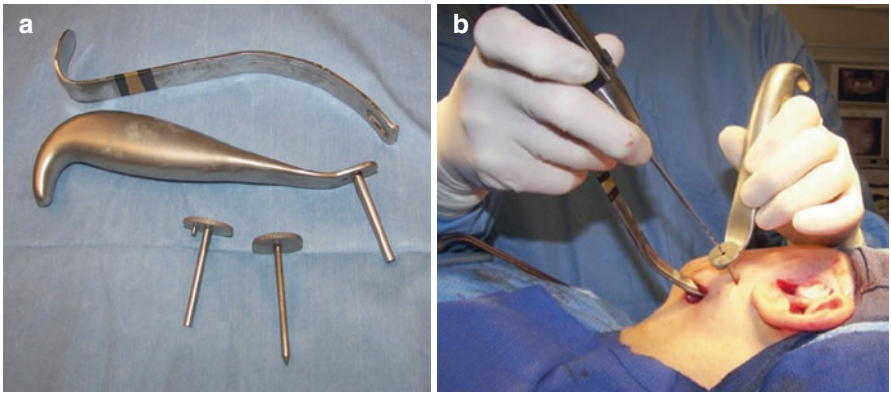

Fig. 10.19 (**a**) A trocar with drill guide and a retractor can be used to provide easy access for placement of screws in the holes at the top of the ramus component of the prostheses. (**b**) The trocar is inserted through a stab incision about 1 cm below the ear lobe. It is aligned to the hole in the prosthesis, hole drilled, and screw inserted through the trocar

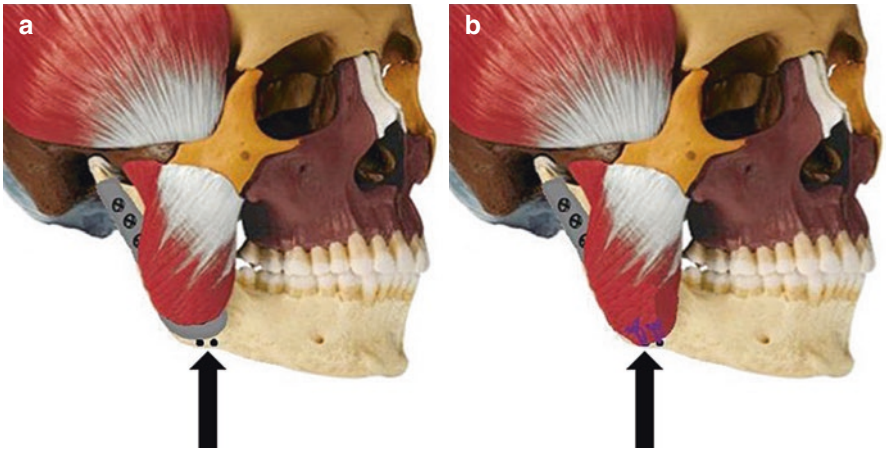

Fig. 10.20 The masseter muscle is reattached to the mandible. (**a**) Three to four holes are drilled at the bottom of the inferior border. (**b**) 2-0 PDS suture is used to secure the masseter muscle to the inferior border with continuous or interrupted sutures

screws. The mandibular component is inserted through the submandibular incision and secured with six bicortical 2-mm-diameter screws. A stab incision can be made about 1 cm below the earlobe and a trocar inserted to place screws in the holes at the top of the prosthesis that are difficult to access from the submandibular incision (Fig. 10.19a, b).

9. The submandibular surgical areas are thoroughly irrigated with saline and then betadine solution. The masseter muscles are reattached to the mandible by placing three to four bicortical holes through the inferior aspect of the mandibular

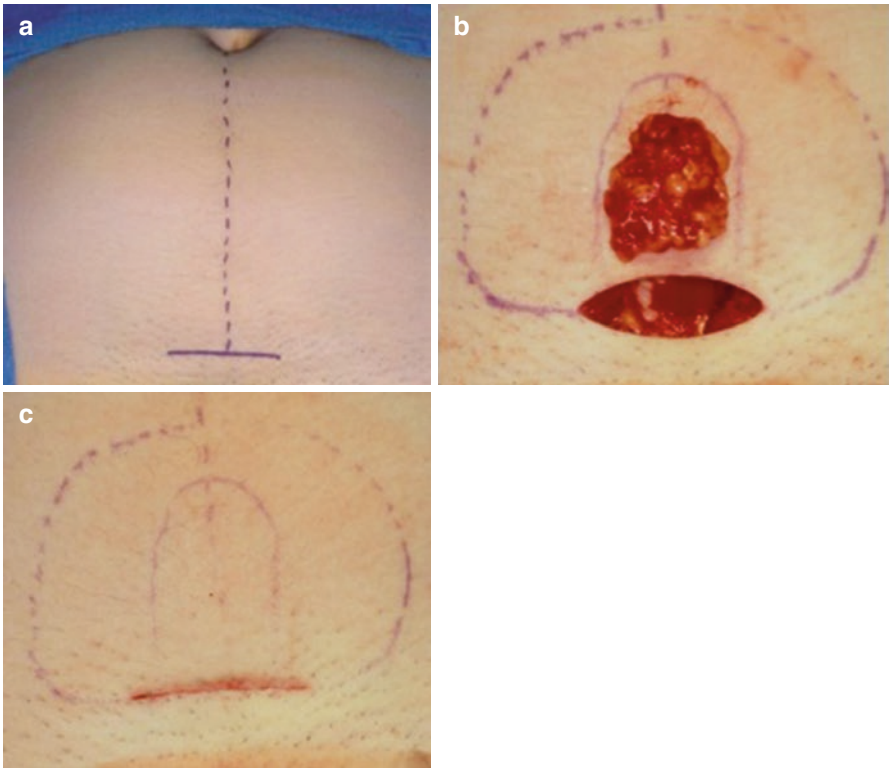

Fig. 10.21 (**a**, **b**) Fat harvested from the suprapubic area of the abdomen for placement around the articulating area of the prostheses. (**c**) Hemostasis obtained and incision closed

angle area where the muscle was originally attached. 2-0 PDS suture is used to tie the masseter muscle to the bone using the transosseous holes (Fig. 10.20a, b). The submandibular incisions are closed in layers.

10. Fat grafts are harvested from the abdomen through incisions in the suprapubic region (Fig. 10.21a–c), previous scar line, umbilical area (Fig. 10.22a–d), or buttock with establishment of good hemostasis and closure of the incisions. A small drain and vacuum bulb can be inserted in the donor area if good hemostasis cannot be achieved.
11. The articulating area of the prosthesis is thoroughly irrigated with saline and then betadine solution through the endaural or preauricular incisions. The fat grafts are packed around the articulating area of the prostheses (Fig. 10.23a–d) and the incisions closed in layers.
12. The oral cavity is then entered, maxillomandibular fixation released, and intermediate splint removed.
13. Maxillary osteotomies are performed and maxilla mobilized. If indicated, intranasal procedures such as turbinectomies and septoplasty are completed.

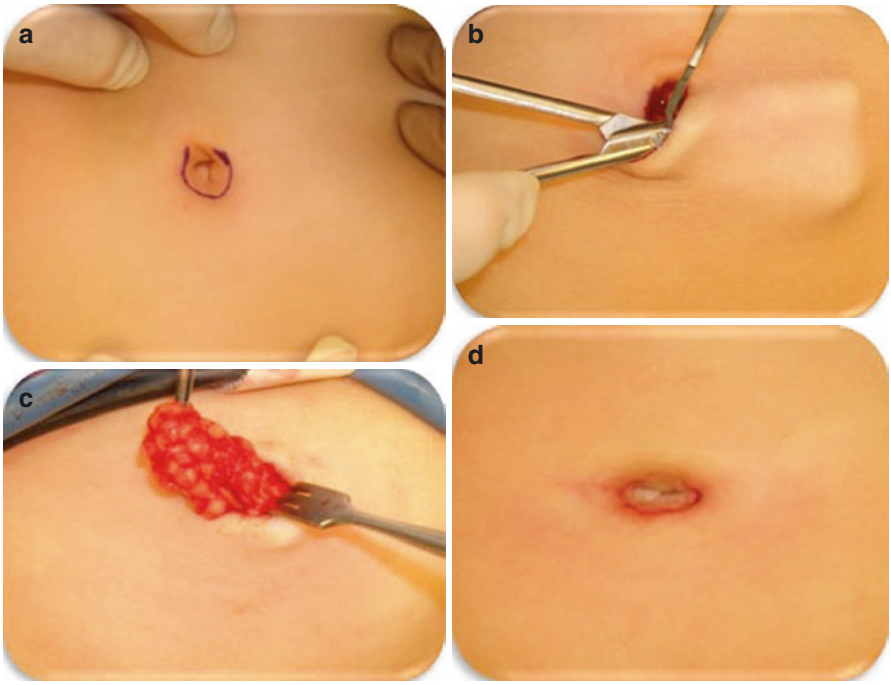

Fig. 10.22 (**a**) Umbilical donor site with incision outlined. This donor site is more commonly used for teenage patients. (**b**) Dissection underway for harvesting of fat. (**c**) Fat graft being delivered. (**d**) The incision is closed

14. The maxilla is segmented, palatal splint inserted, and maxillomandibular fixation applied. The maxilla is rigidly fixated with four bone plates (Fig. 10.24a, b). Bone grafts are positioned at the osteotomy sites if indicated.
15. The alar base cinch suture is placed, and maxillary incision is closed in a V-Y design.
16. Any other adjunctive procedures can be performed such as genioplasty, rhinoplasty, etc. Special care must be taken to prevent communication with the total joint prosthesis implantation site when performing a concomitant genioplasty procedure by ensuring a conservative posterior dissection along the symphysis/body region. Such a communication could increase the risk of infection.
17. The muscles of mastication including the masseter, medial pterygoid, and temporalis muscles are usually detached. As a result, vertical support to the mandible and occlusion using elastics is required postsurgery. Bone screws or temporary anchoring devices (TADs) can be placed in the alveolar bone area to allow for inter-arch stability through the use of elastics. By shifting the constant inter-arch forces from tooth-borne options to these devices, the teeth are not extruded or displaced. The bone screws or TADs are usually necessary for 2–3 weeks postsurgery until the muscles of mastication can reattach and provide adequate vertical support.

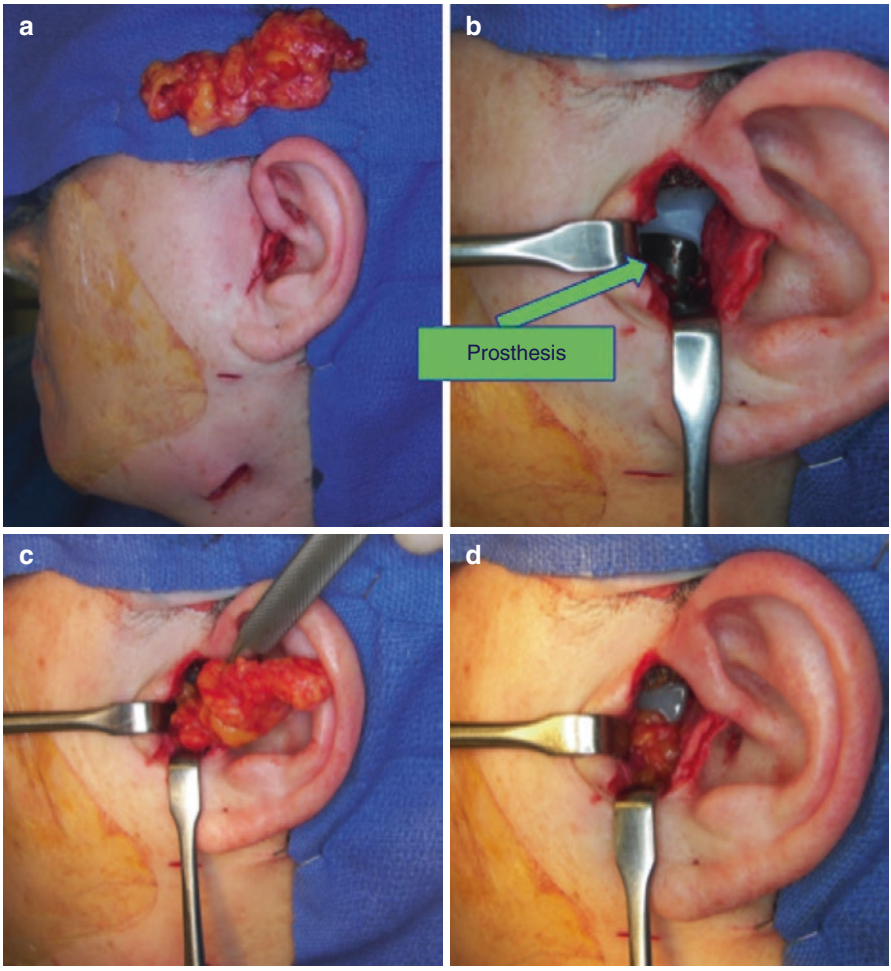

Fig. 10.23 (**a**) Fat harvested from the abdomen for placement around the articulating area of the prostheses. (**b**) Patient-fitted prosthesis is observed via the endaural incision. (**c**) Packing the fat into the joint area. (**d**) Completion of fat packing and ready for incision closure

10.21 Special Considerations

A potential risk to patients receiving TMJ total joint prosthesis is infection. The occurrence rate is less than 5% with greater risk for immunodeficient patients and those on immunosuppressant medications such as rheumatoid patients or others with connective tissue/autoimmune diseases. Bacterial or viral contamination of the prosthesis can occur during surgery or develop at a later time from bacterial seeding through a hematological route or localized bacterial sources. As a result, strict adherence to sterile technique for the procedures performed can help prevent or reduce the chance of infection. A few techniques that the authors utilize to minimize

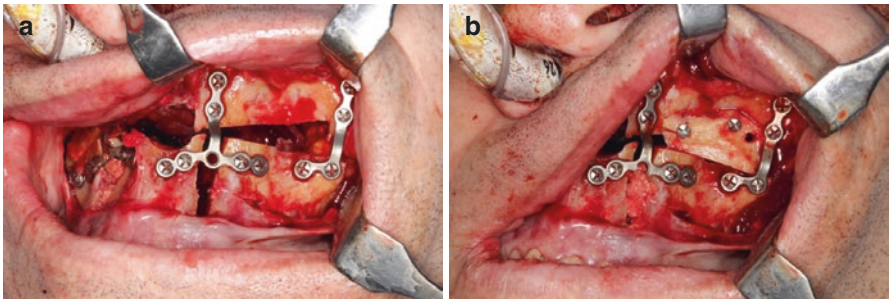

Fig. 10.24 (**a**) Left side maxillary osteotomies completed with bone plate stabilization. Bone defects are obvious. (**b**) Bone grafting completed to provide bone continuity and to enhance healing

infection risk include the placement of Xeroform or cotton ear plugs soaked in betadine in the external auditory canal to isolate contents in the ear from the surgical site, use of antibiotic in the irrigation, and resection of bilateral TMJs first followed by implantation and immediate closure to minimize the exposure time of the prosthesis. Appropriate IV antibiotics are used while in the hospital and then PO antibiotics for an additional 7–10 days after hospital discharge. This patient management scheme should minimize the risk of infection.

Postsurgically, light force vertical elastics are necessary to support the mandible since the muscles of mastication are detached during surgery and may take a few weeks to reattach and provide adequate support to the mandible. Otherwise, postsurgical patient management is the same as routine double-jaw orthognathic surgery [55, 57].

10.22 Utilization of Fat Grafts

Early on in the use of total joint prostheses, a common problem encountered in approximately 35% of the patients was postsurgical fibrosis and heterotopic bone formation around the prostheses causing jaw dysfunction, decreased incisal opening, and pain [58]. In 1992, Wolford developed a technique to place fat grafts (harvested from the abdomen or buttock) around the articulating area of the total joint prosthesis to eliminate the dead space. This prevents blood clot formation in the space around the prosthesis that could provide a matrix for fibrous ingrowth and pluripotent cells migration resulting in the development of heterotopic bone and dense fibrotic tissues. Also, in patients with previous failed alloplastic implants, the fat graft occupies areas around the implant preventing foreign-body giant-cell reaction (FBGCR) and formation of reactive bone. Wolford et al. [58–60] have demonstrated the improved outcomes for patients using fat grafts packed around the prostheses compared to patients that did not receive the fat grafts when evaluating function, pain, and elimination of additional surgical procedures such as joint debridement. Mercuri et al. [61] reported the efficacy of the fat grafts packed around the prostheses in TMJ ankylosis cases.

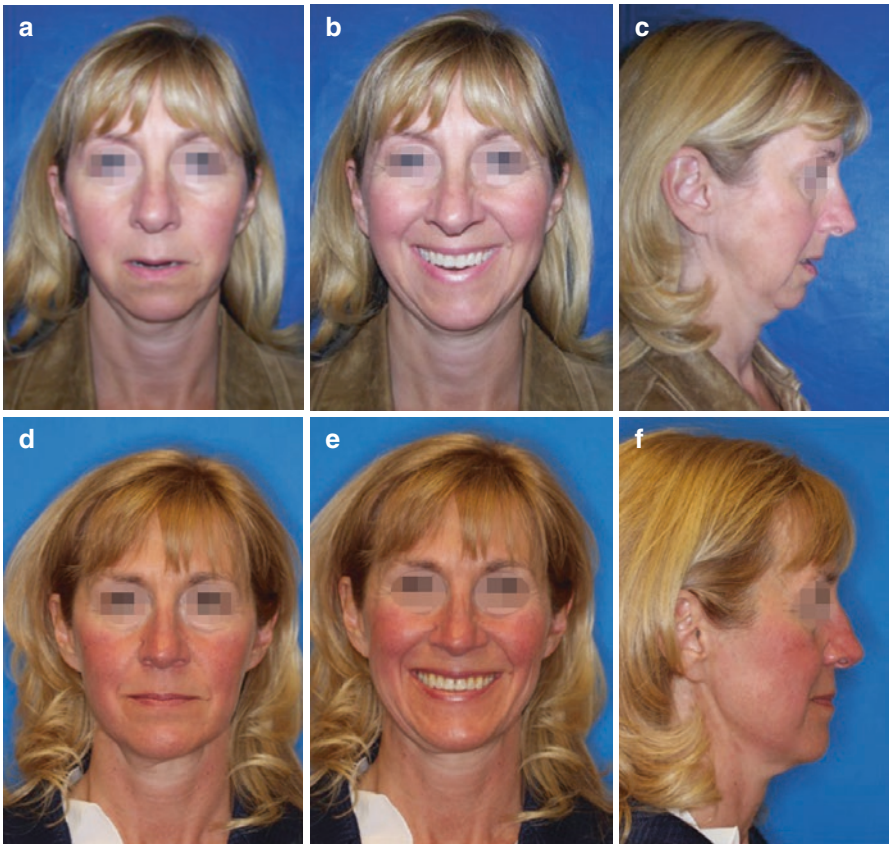

Fig. 10.25 Case 1: (**a**–**c**) presurgery clinical pictures of 48-year-old female with reactive arthritis, maxillary and mandibular hypoplasia, anterior open bite, sleep apnea, and pain. (**d**–**f**) Clinical images at 2 years postsurgery with improved function and facial balance, resolution of sleep apnea, and elimination of pain

10.23 Case Examples Utilizing C-TJR-OS

Case 1: (Figs. 10.25, 10.26, 10.27, and 10.28)
This 48-year-old female sustained trauma to the TMJs at age 28 with subsequent development of bilateral TMJ reactive arthritis with resultant condylar resorption and development of an anterior open bite (Figs. 10.25a–c, 10.26a–c, 10.27a–d and 10.28a). She was in splint therapy for 16 years and underwent most of the nonsurgical management imaginable. She suffered daily headaches at a level of 8 (0 = no pain, 10 = worse pain imaginable), TMJ pain at 5, myofascial pain at 8, jaw function at 8 (0 = normal function, 10 = no jaw movement), diet at 8 (0 = normal diet, 10 = liquids only), and disability at 8 (0 = no disability, 10 = totally disabled). MRI showed severe TMJ arthritis, condylar resorption, and displaced non-salvageable

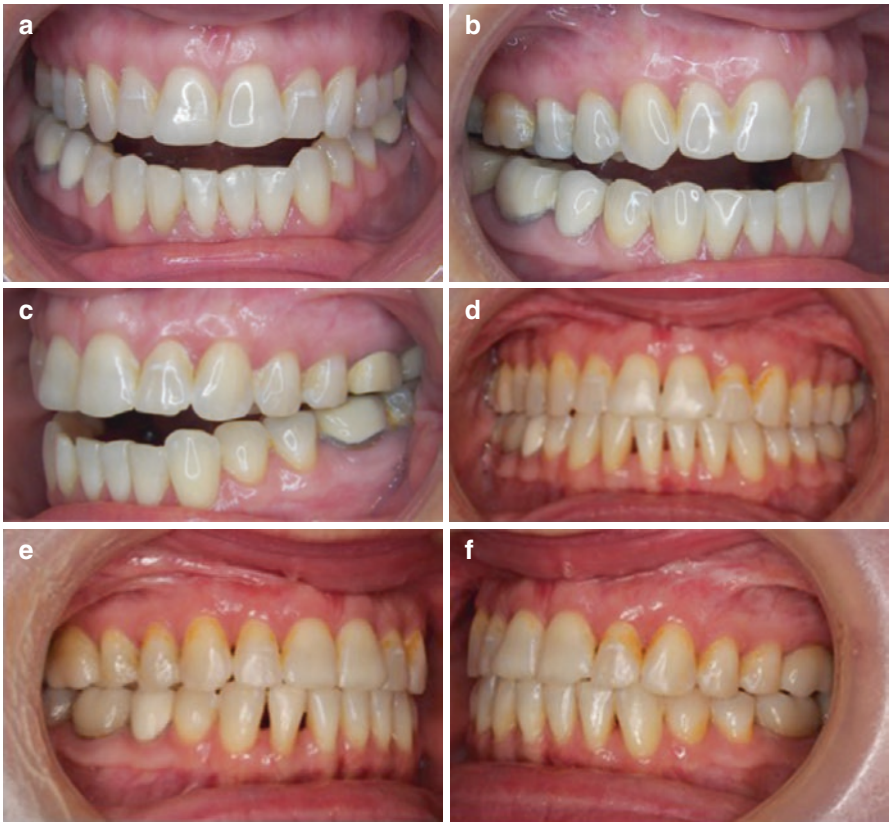

Fig. 10.26 Case 1: (**a**–**c**) presurgery occlusion with a Class II open bite and occlusal contact only on the posterior teeth on the left side. (**d**–**f**) At 2 years postsurgery, the occlusion is stable with a Class I cuspid-molar relationship

discs (Fig. 10.27a–d). She was diagnosed with the following: (1) bilateral TMJ reactive arthritis with condylar resorption, (2) maxillary hypoplasia, (3) mandibular hypoplasia, (4) anterior open bite occluding only on the left posterior teeth, (5) sleep apnea related to decreased oropharyngeal airway, (6) bilateral turbinate hyperplasia causing nasal airway obstruction, and (7) TMJ pain, myofascial pain, and headaches requiring years of narcotic use. The maximal incisal opening with severe pain was 40 mm and without pain was 14 mm.

Her surgery was planned for C-TJR-OS using CASS technology and included the following (Fig. 10.28b): (1) bilateral TMJ reconstruction and counterclockwise rotation of the mandible with TMJ Concepts patient-fitted total joint prostheses; (2) bilateral coronoidectomies; (3) bilateral TMJ fat grafts packed around the articulating area of the prostheses, harvested from the abdomen; (4) multiple maxillary osteotomies for counterclockwise rotation and advancement; and (5) bilateral partial inferior turbinectomies.

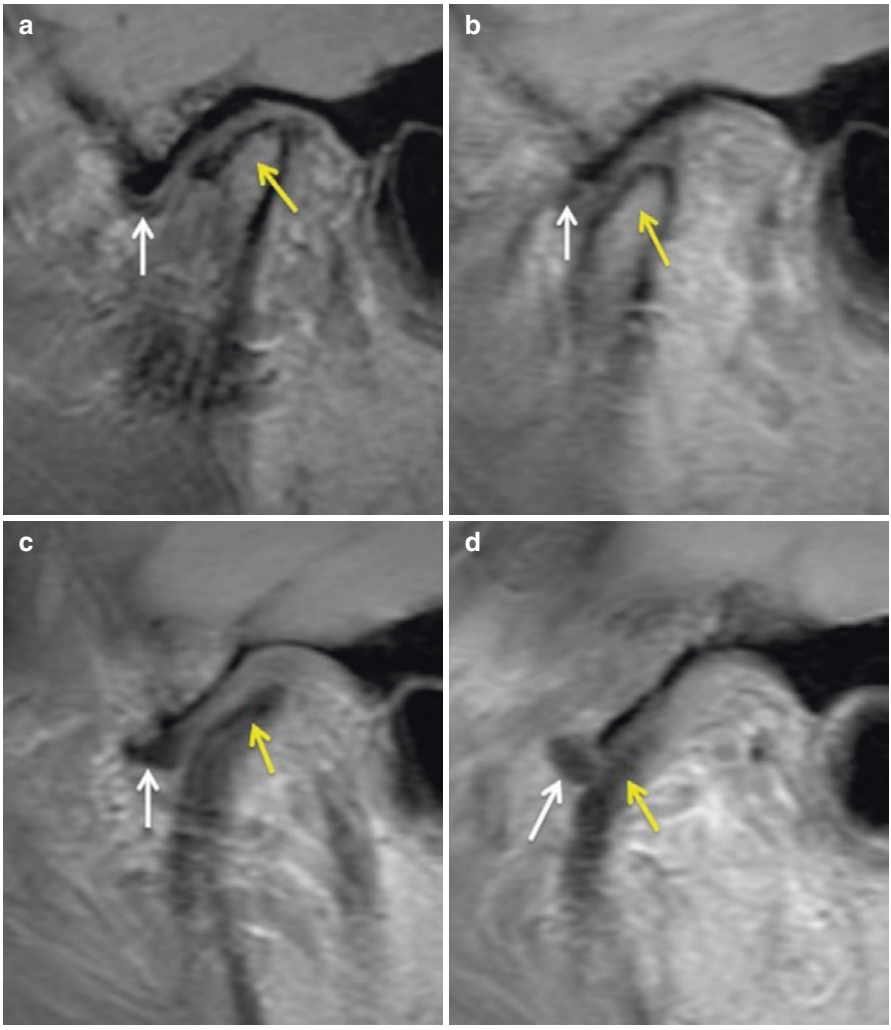

Fig. 10.27 Case 1: presurgery TMJ MRI sagittal images. (**a**) Right TMJ closed and (**b**) open views show severe arthritis of condyle (yellow arrow) and anteriorly displaced disc (white arrow) severely degenerated, nonreducing, and non-salvageable. (**c**) Left TMJ closed and (**d**) open views show severe destruction of the condyle (yellow arrow) with the articular disc (white arrow) severely degenerated, nonreducing, and non-salvageable

At 2 years postsurgery, she reported no myofascial pain, TMJ pain, or headaches with elimination of pain medications. Her incisal opening improved to 46 mm pain-free. She rated her jaw function at 2, diet at 2, and disability at 2. A class I occlusion was obtained, improved facial balance was achieved, and sleep apnea was eliminated (Figs. 10.25d–f and 10.26d–f).

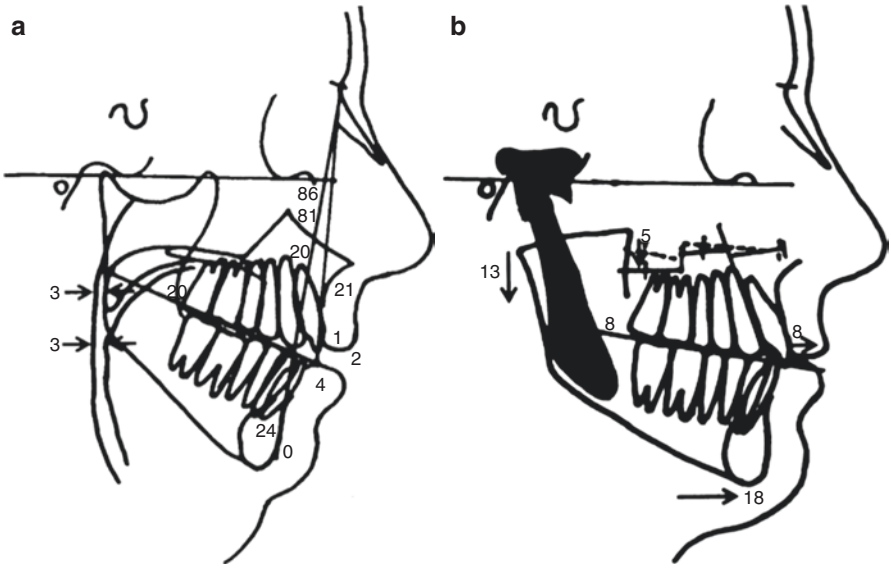

Fig. 10.28 Case 1: (**a**) presurgical cephalometric tracing shows the retruded maxilla and mandible as well as the high occlusal plane angle (21°) and decreased oropharyngeal airway (3 mm). (**b**) The surgical treatment objective demonstrated the planned surgical changes with counterclockwise rotation advancement with the maxillary incisal edges advanced 8 mm, pogonion advanced 18 mm, and the occlusal plane angle decreased 13°

Case 2: (Figs. 10.29 and 10.30)
This 14-year-old female presented with juvenile idiopathic arthritis (JIA) of the TMJs with the onset at approximately 9 years old but first noted clinically at age 11, with progressively worsening facial deformity related to condylar resorption and difficulty breathing (Figs. 10.29a–c, 10.30a–c, 10.31a–d and 10.32a). She had no pain issues, and only other joints affected were the ankles. Her incisal opening was 47 mm and excursions 7 mm to the right and 8 mm to the left. Her diagnosis included the following: (1) bilateral TMJ JIA, (2) maxillary A-P and posterior vertical hypoplasia, (3) mandibular A-P and posterior vertical hypoplasia, (4) Class II occlusion, (5) microgenia, (6) decreased oropharyngeal airway with sleep apnea symptoms, and (7) hypertrophied turbinates creating nasal airway obstruction. The MRI scans (Fig. 10.31a–d) demonstrate the severe destruction of the condyles and resorption of the articular eminences.

Her surgery was planned for C-TJR-OS using CASS technology. Figure 10.11 is a similar CASS workup. Surgery included the following (Fig. 10.32b, the prediction tracing): (1) bilateral TMJ reconstruction and counterclockwise rotation of the mandible with TMJ Concepts patient-fitted total joint prostheses; (2) bilateral coronoidectomies; (3) bilateral TMJ fat grafts packed around the articulating area of the prostheses, harvested from the abdomen; (4) multiple maxillary osteotomies for

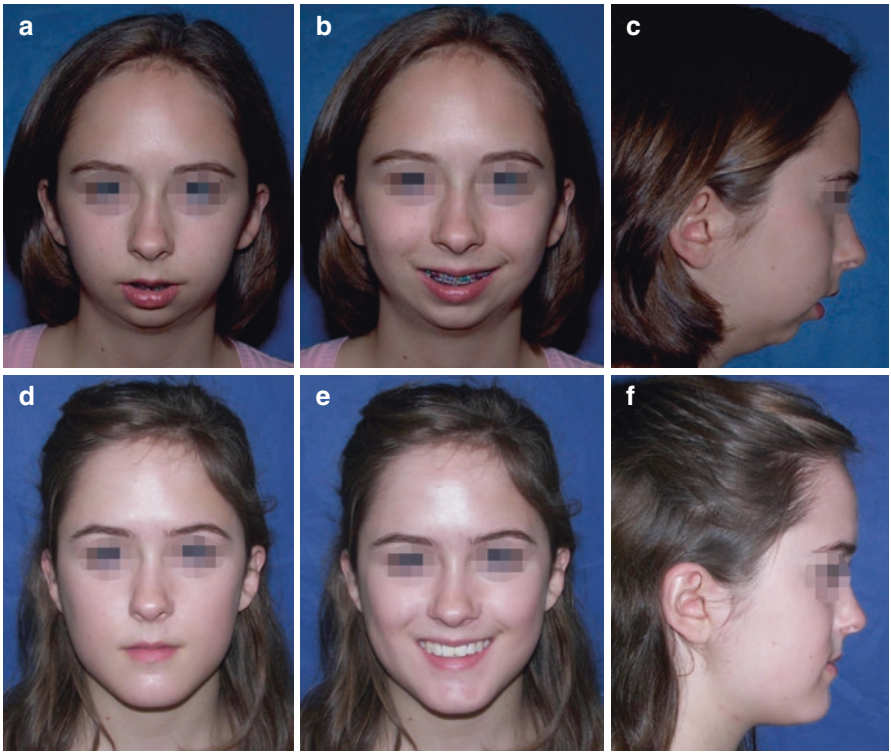

Fig. 10.29 Case 2: (**a**–**c**) a 14-year-old female with JIA and grossly resorbed mandibular condyles, retruded mandible and maxilla, posterior maxillary vertical hypoplasia, high occlusal plane angle facial morphology, decreased oropharyngeal dimension and sleep apnea symptoms, as well as hypertrophied turbinates and difficulty breathing through the nose. (**d**–**f**) The patient is seen at 2 years postsurgery demonstrating significantly improved facial balance and function with a stable occlusion

counterclockwise rotation and advancement; (5) anterior mandibular horizontal osteotomy to augment the chin; and (6) bilateral partial inferior turbinectomies.

At 2 years postsurgery, she remained pain-free, incisal opening at 40 mm but continuing to improve, excursive movements 3 mm to the right and 4 mm to the left, stable Class I occlusion, improved facial balance, good nasal airway, and elimination of sleep apnea symptoms (Figs. 10.29d–f and 10.30d–f).

Case 3: (Figs. 10.33, 10.34, and 10.35)
This 18-year-old male presented with unilateral right TMJ ankylosis and retruded, asymmetric maxilla and mandible (Figs. 10.33a–c, 10.34a–c and 10.35a). Pt reported a traumatic injury to the jaw a few years earlier resulting in a significantly limited incisal opening as well as the jaw deformity. The resultant right TMJ ankylosis stunted the mandibular growth on the right creating the significant facial

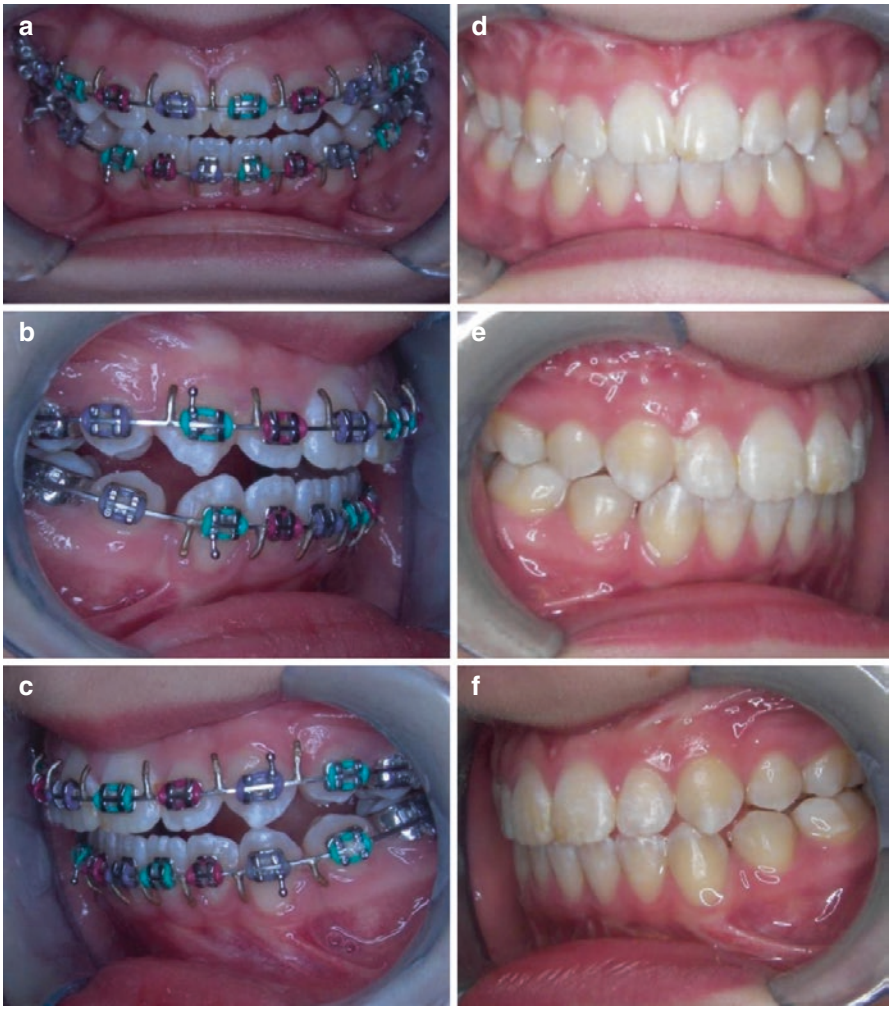

Fig. 10.30 Case 2: (**a**–**c**) the patient has a Class II occlusion presurgery. (**d**–**f**) At 2 years postsurgery, she demonstrates a stable Class I occlusion

asymmetry. He had moderate pain and headaches. CT scan and MRI showed right TMJ bony ankylosis but the left side TMJ anatomy was normal.

The patient was planned for C-TJR-OS using CASS technology. Surgery included the following steps with mandible-first approach (Fig. 10.35b): (1) unilateral right TMJ reconstruction and counterclockwise rotation advancement of the mandible with TMJ Concepts patient-fitted total joint prosthesis; (2) right TMJ fat grafts packed around the articulating area of the prosthesis, harvested from the abdomen; (3) right coronoidectomy; (4) left mandibular ramus sagittal

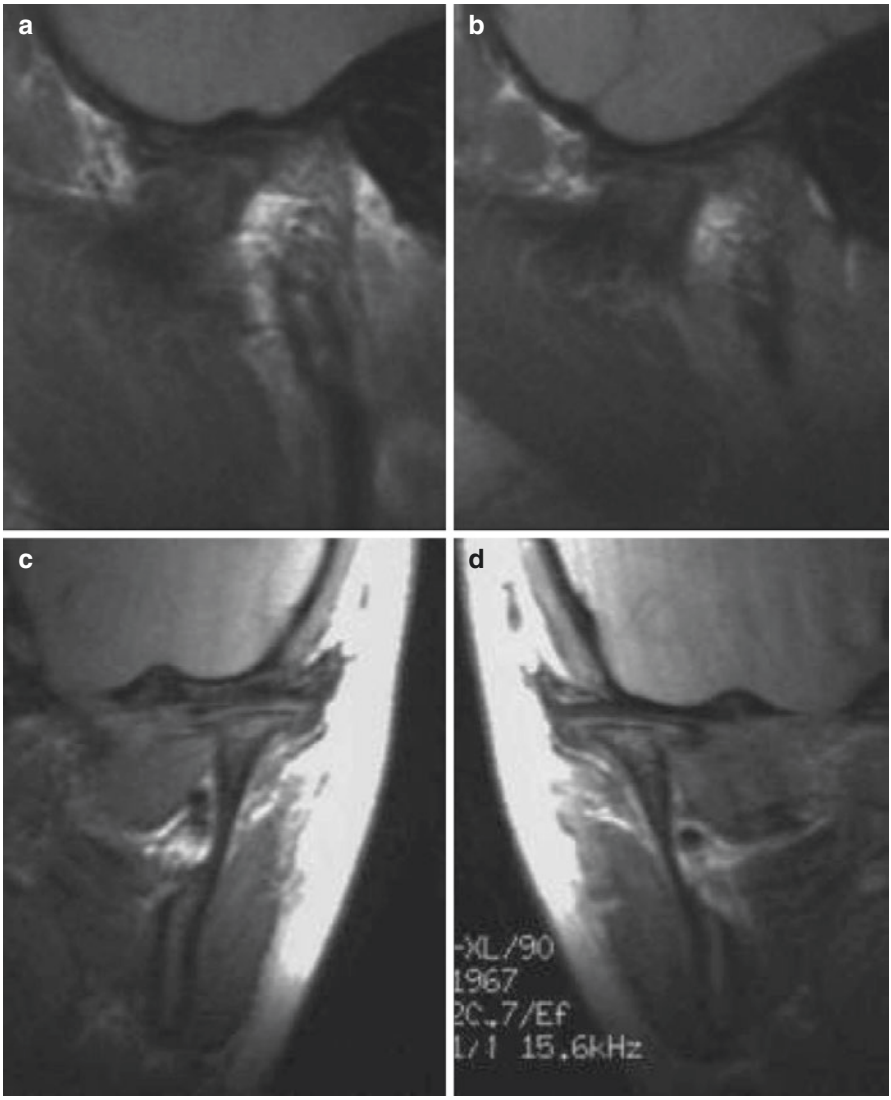

Fig. 10.31 Case 2: MRI scans of the TMJs. (**a**) Left TMJ sagittal view. (**b**) Right TMJ sagittal view showing the destruction of the condyle and articular eminence, common in JIA cases. Notice the "mushrooming" of the remainder of the condylar neck process. (**c**) Left TMJ coronal view. (**d**) Right TMJ coronal view demonstrating the severe narrowing of the condylar neck stump

split osteotomy for advancement; (5) maxillary osteotomies for counterclockwise rotation and advancement; and (6) bilateral partial nasal inferior turbinectomies.

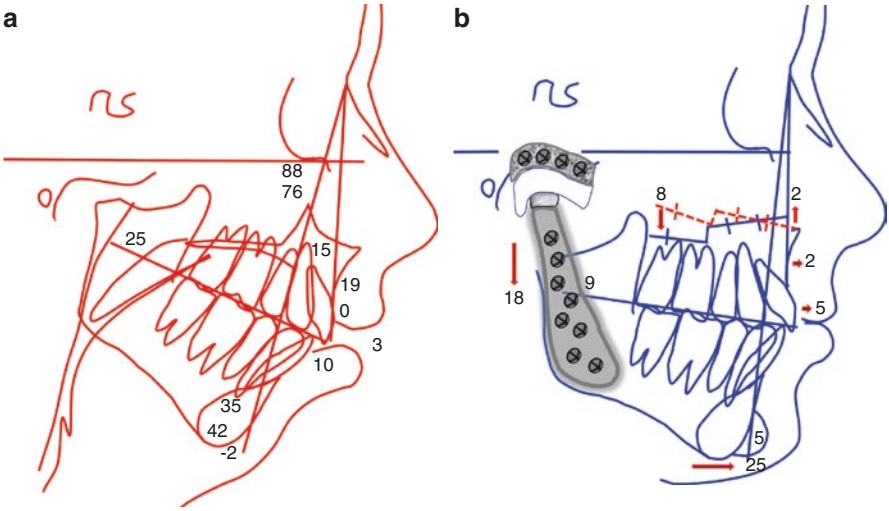

Fig. 10.32 Case 2: (**a**) the cephalometric analysis shows the severe jaw deformity with retruded maxilla-mandible, high occlusal plane angulation, and decreased oropharyngeal airway. (**b**) The prediction tracing demonstrates the counterclockwise rotation of the maxillomandibular complex. The chin is augmented with a bony genioplasty. Maxillary incisors advanced 4 mm, pogonion advanced 28 mm, and the occlusal plane decreased 16°, creating improved function and facial balance

At 1 year postsurgery, the patient was pain-free, with incisal opening at 45 mm, excursive movements 5 mm to the right and 3 mm to the left, and a stable Class I occlusion (Figs. 10.33d–f and 10.34d–f).

Case 4: (Figs. 10.36, 10.37, 10.38, 10.39, 10.40, and 10.41)
This 68-year-old male presented with bilateral degenerative joint disease and anterior disc displacement of the TMJs and moderate obstructive sleep apnea (Fig. 10.36a, b). Pt reported a 7-year history of severe pain, clicking, and popping in bilateral TMJs, worsened with PAP therapy. As a result, pt. had not been compliant with PAP therpay. Pt also stated significant daytime somnolence, fatigue, and restless sleep. Polysomnography showed a respiratory disturbance index (RDI) of 15.7 and lowest O2 of 89%. Drug-induced sleep endoscopy revealed retropalatal and retroglossal airway collapse. CT scan showed bilateral degenerative joint disease, and MRI demonstrated bilateral anterior disc displacement and degenerative changes of the condyle (Fig. 10.37).

Given patient's history of TMJ pathology and moderate OSA with significant pain and sleep apnea symptoms, he was planned for C-TJR-OS using CASS technology. Figure 10.38a–c depicts the CASS workup with final positioning of the maxilla and mandible and final positioning of the bilateral TMJs with TMC Concepts. Surgery included the following steps with mandible-first approach

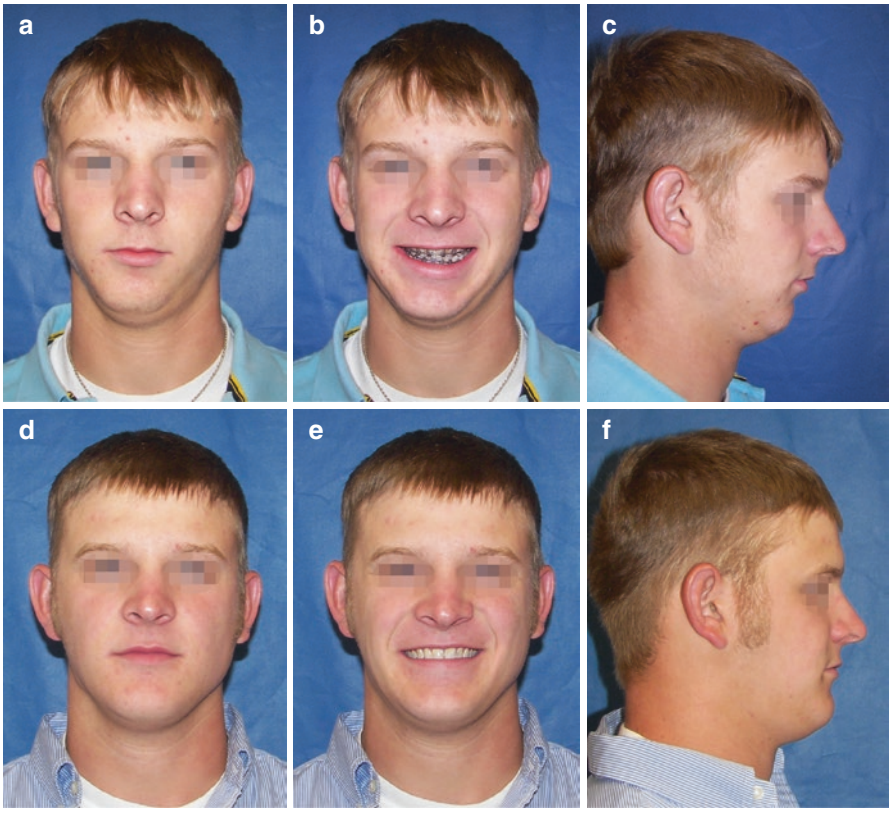

Fig. 10.33 Case 3: (**a**–**c**) an 18-year-old male with unilateral right bony ankylosis. Maxilla and mandible are retruded and asymmetric. (**d**–**f**) The patient had the following procedures: (1) right TMJ reconstruction and mandibular advancement with TMJ Concepts total joint prosthesis, (2) right TMJ fat graft, (3) right coronoidectomy, (4) left mandibular ramus sagittal split osteotomy, (5) segmental maxillary osteotomies, and (6) bilateral partial turbinectomies. The patient is seen 1 year postsurgery pain-free, with incisal opening 48 mm, left excursion 3 mm and right excursion 5 mm, and improved facial balance

(Fig. 10.39a–d): (1) bilateral TMJ reconstruction including coronoidectomies and counterclockwise rotation of the mandible with TMJ Concepts patient-fitted total joint prostheses; (2) bilateral TMJ fat grafts packed around the articulating area of the prostheses, harvested from the abdomen; and (3) multiple maxillary osteotomies for counterclockwise rotation and advancement. Pre- and postoperative lateral cephalometric image depicted the planned movements including counterclockwise rotation of the maxillomandibular complex, TMJ reconstruction, and increase in airway space (Fig. 10.40a, b).

At 1 year postsurgery, he remained pain-free, with incisal opening at 45 mm, excursive movements 3 mm to the right and 3 mm to the left, stable Class I occlusion, and RDI less than five with elimination of sleep apnea symptoms (Fig. 10.41a, b).

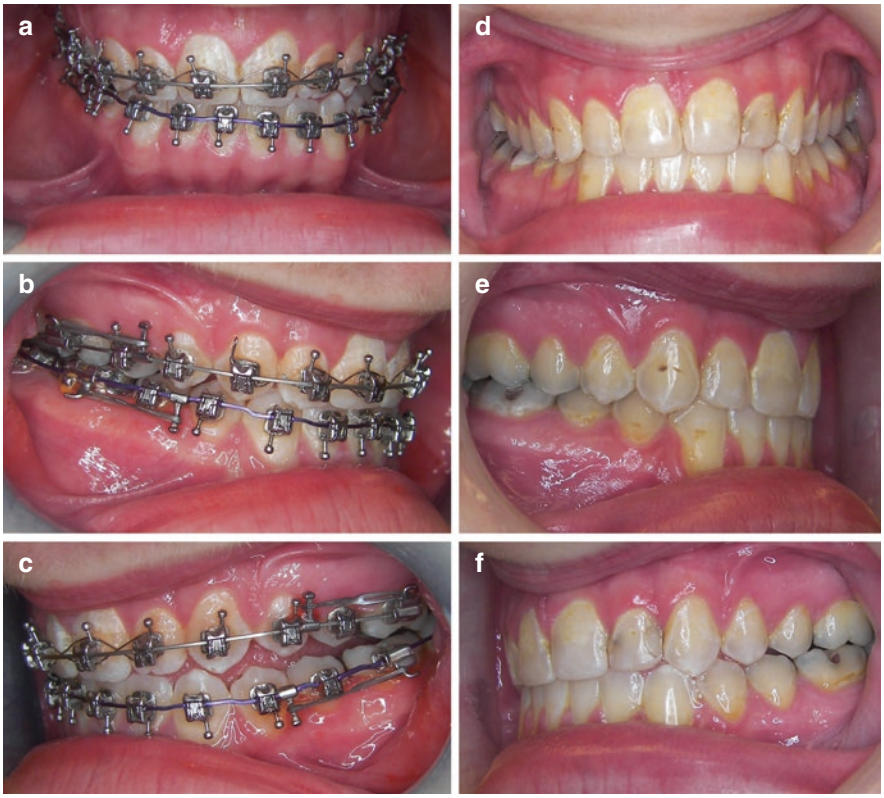

Fig. 10.34 Case 3: (**a**–**c**) presurgery occlusion with a Class I occlusion but left side posterior open bite. (**d**–**f**) Postsurgery occlusion shows a nicely integrated bite relationship

10.24 Treatment Outcomes Utilizing These Treatment Protocols

Various publications over the years have demonstrated good stability and treatment outcomes utilizing the C-TJR-OS protocols. Various modifications to the TJR steps such as minimization of prosthesis exposure, fat graft placement, and use of ultrasonic BoneScalpel handpiece (Fig. 10.42) have reduced infection rates, fibrotic and heterotopic bone formation, and bleeding leading to improved outcomes. These modifications have been applied in the C-TJR-OS protocol leading to less complications and improved results in an already complex surgical procedure.

Dela Coleta et al. [62] evaluated 47 female patients for surgical stability following bilateral TMJ reconstruction using TMJ Concepts patient-fitted TMJ total joint prostheses, TMJ fat grafts, and counterclockwise rotation of the maxillomandibular complex with menton advancing an average of 18.4 mm and the occlusal plane decreasing an average of 14.9°. Average follow-up was 40.6 months. Results demonstrated minor maxillary horizontal changes, while the mandibular measurements

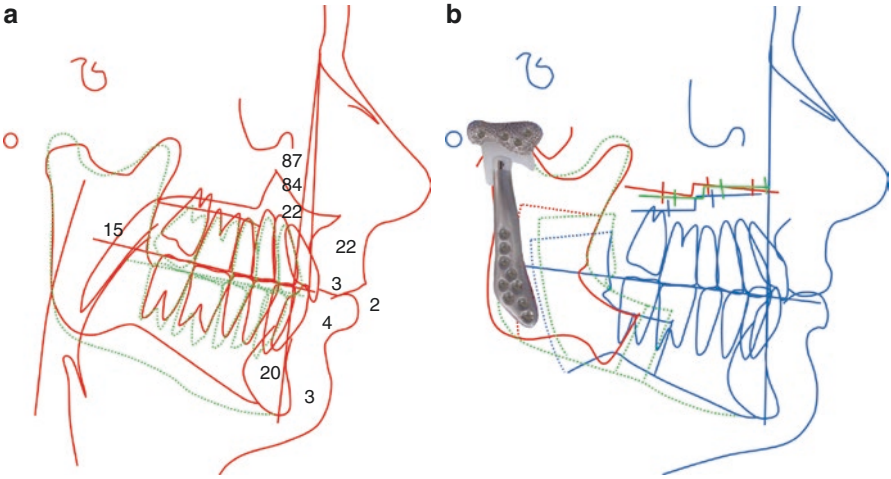

Fig. 10.35 Case 3: (**a**) presurgery lateral cephalogram shows the vertical asymmetry and retruded maxilla and mandible. (**b**) The surgical treatment plan included (1) right TMJ reconstruction and mandibular advancement with TMJ Concepts total joint prosthesis, (2) right TMJ fat graft, (3) right coronoidectomy, (4) left mandibular ramus sagittal split osteotomy, (5) segmental maxillary osteotomies, and (6) Bilateral partial turbinectomies

remained very stable. Pinto et al. [63] evaluated the same 47 female patients relative to pain and dysfunctional outcomes. Patients were divided into two groups based on the number of previous surgeries: Group 1 had zero to one previous surgeries, while Group 2 had two or more previous surgeries. Significant improvements (37–52%) were observed for TMJ pain, headaches, jaw function, diet, and disability. MIO increased 14%. Group 1 patients had better pain and jaw function results than Group 2 patients. For patients who did not receive fat grafts around the prostheses and had previous failure of alloplastic TMJ implants including Proplast-Teflon (PT) and silicone elastomers, more than half required secondary surgery including TMJ debridement for removal of FBGCR, fibrosis, and/or heterotopic bone formation. These two studies demonstrated that end-stage TMJ patients could be treated in one operation with TMJ Concepts patient-fitted TMJ total joint prostheses, fat grafts, and maxillomandibular counterclockwise rotation for correction of an associated dentofacial deformity with good stability and improvement in pain and TMJ function.

Although the life expectancy of this device is unknown, Wolford, Mercuri, et al. [64] recently published a 20-year follow-up study of 56 patients who had received the Techmedica total joint prostheses between 1989 and 1993. There were statistically significant improvements in all parameters including incisal opening, jaw function, TMJ pain and diet, and 85.7% of the patients reporting significant improvement in their quality of life. Furthermore, patients who underwent a greater number of previous TMJ surgeries reported a lower degree of subjective improvement but increased objective findings in regard to mandibular function and improved quality of life. There were no reports of device removal due to material wear or failure.

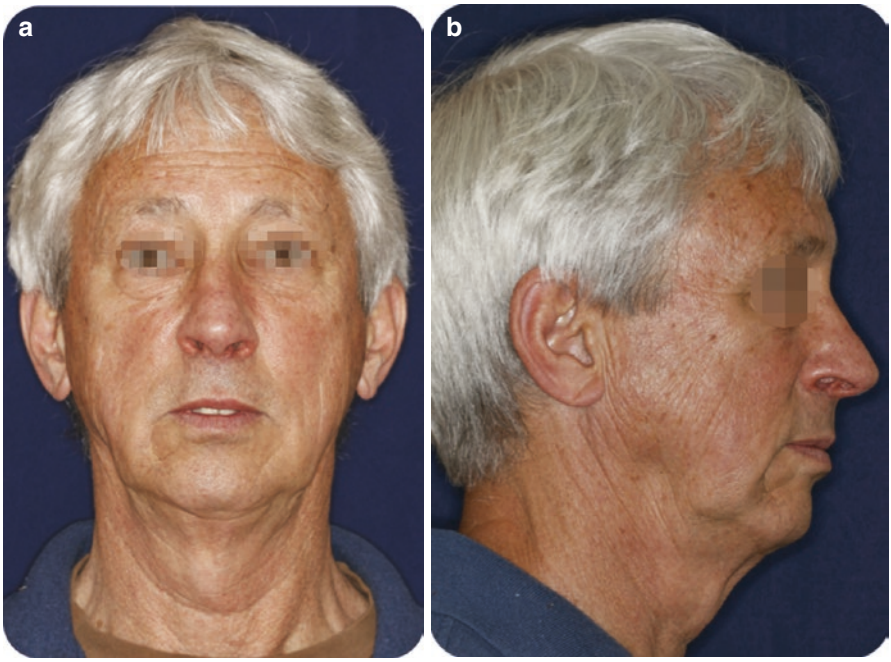

Fig. 10.36 Case 4: (**a**, **b**) a 68-year-old male with bilateral degenerative joint disease and anterior disc displacement of the TMJs and moderate obstructive sleep apnea. Mandible appears retrognathic

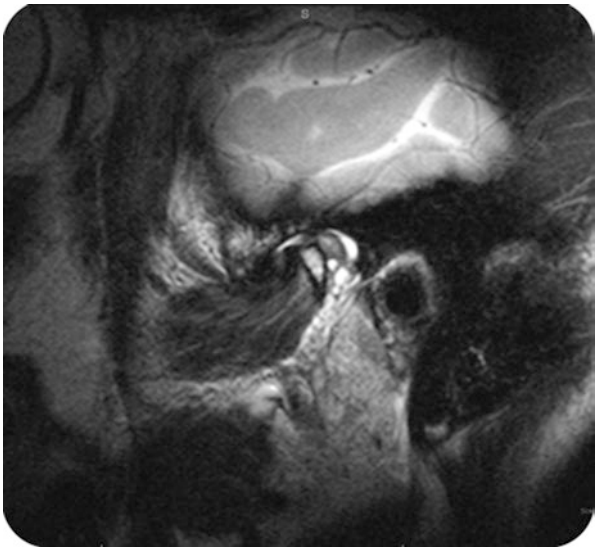

Fig. 10.37 Case 4: MRI of the right TMJ shows anterior disc displacement and condylar remodeling

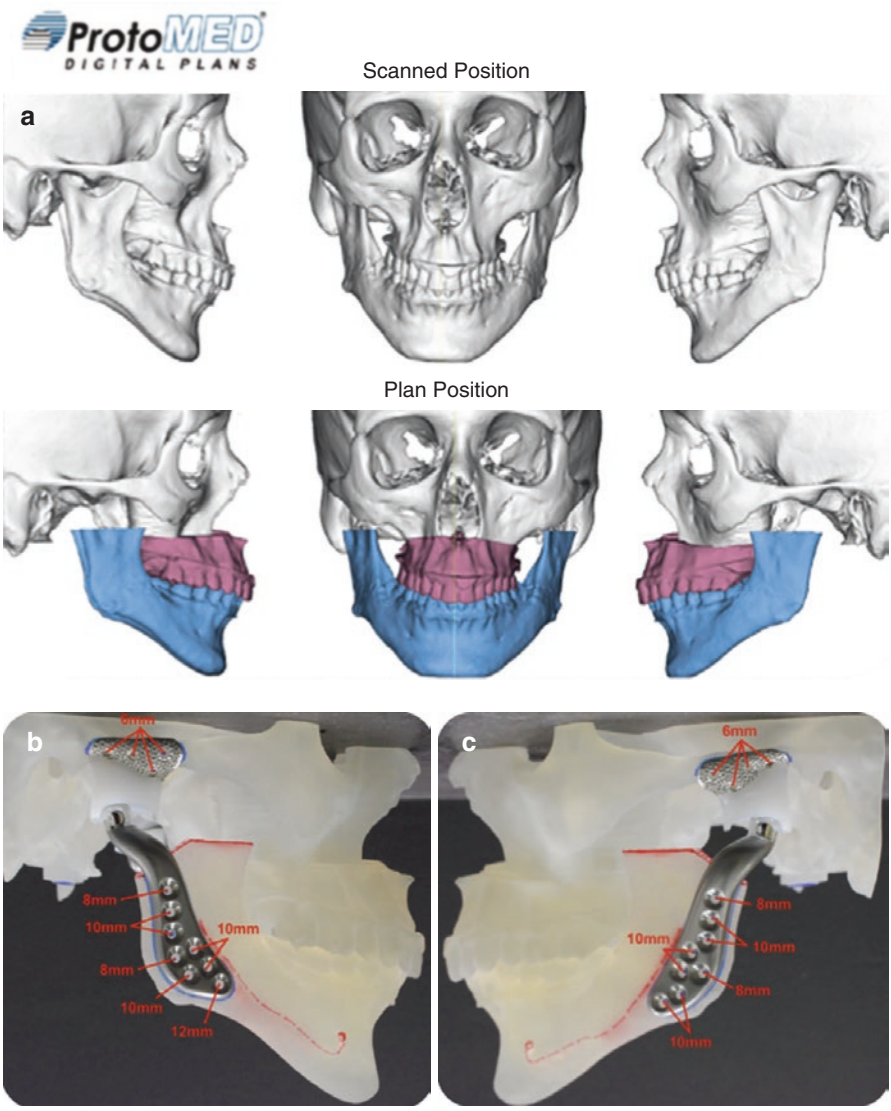

Fig. 10.38 Case 4: (**a**) final positioning of the maxilla and mandible. (**b**) Fabrication of the right TMJ prosthesis in the final position. (**c**) Fabrication of the left TMJ prosthesis in the final position

Wolford et al. [13–17, 62–69], Mercuri et al. [15–17, 70–77], and others [78–81] have published numerous studies in reference to outcome data using TMJ total joint prostheses. A summary of these publications have produced the following facts in reference to the TMJ Concepts total joint prostheses:

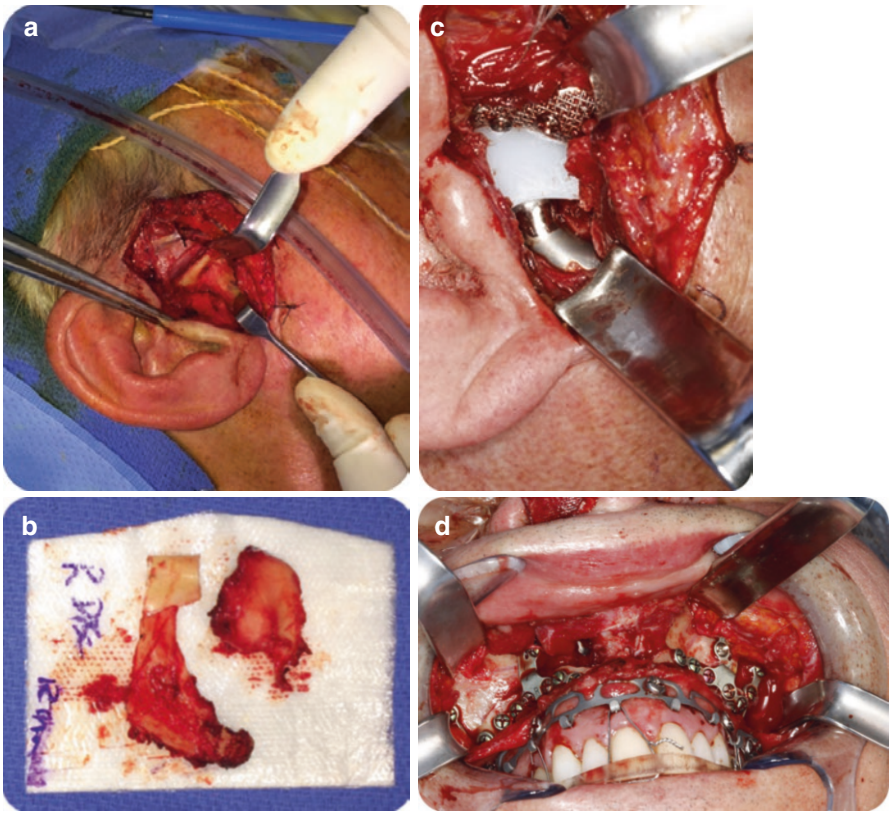

Fig. 10.39 Case 4: (**a**) preauricular approach showing exposure of the right condyle and fossa. (**b**) Image shows the right condyle, coronoid, and disc resected. Condyle and coronoid resected. (**c**) The right condylar and fossa components have been fixated to the ramus and zygomatic arch. (**d**) The maxilla is then advanced and rotated counterclockwise in the final position

1. TMJ Concepts prostheses are superior to autogenous tissues for end-stage TMJ reconstruction relative to subjective and objective outcomes [16, 65, 74, 75, 77].
2. After two previous TMJ surgeries, autogenous tissues have a very high failure rate, whereas patient-fitted total joint prostheses have a high success rate [16, 64, 76, 77].
3. No donor site morbidity.
4. The increased number of previous TMJ surgeries produces a lower level of improvement related to pain and function outcomes compared to patients with zero to one previous TMJ surgery [14–17, 63, 64, 68–77].
5. Failed TMJ alloplastic reconstruction (i.e., PT, Silastic, metal-on-metal articulation, etc.) can create a foreign-body giant-cell reaction and/or metallosis, best treated by joint debridement and reconstruction with patient-fitted total joint prostheses [14–17, 63–66, 69, 73].

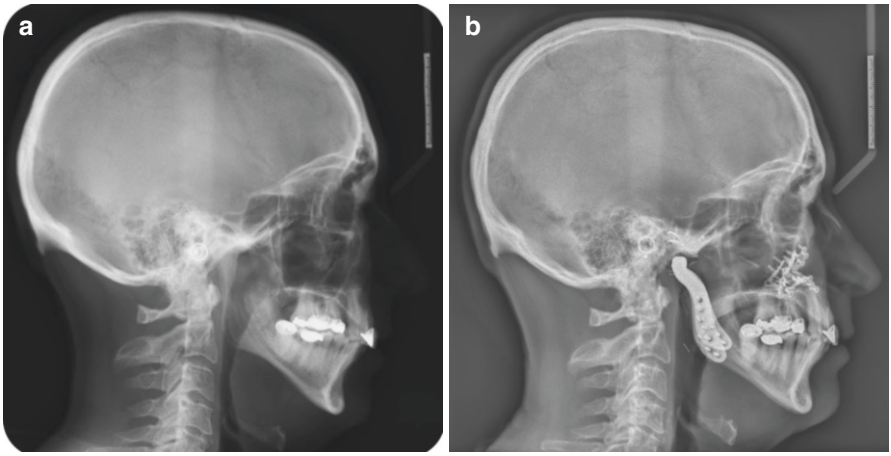

Fig. 10.40 Case 4: (**a**, **b**) pre- and postoperative lateral cephalometric image depicted the planned movements including counterclockwise rotation of the maxillomandibular complex, TMJ reconstruction, decrease in occlusal plane, and increase in airway space

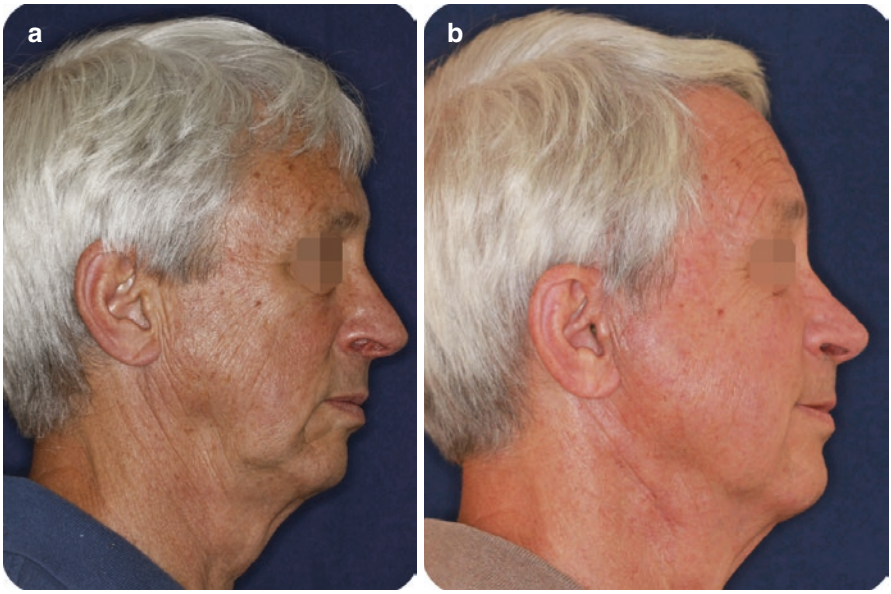

Fig. 10.41 Case 4: (**a**, **b**) pre- and postoperative profile views show significant advancement of the maxillomandibular structures

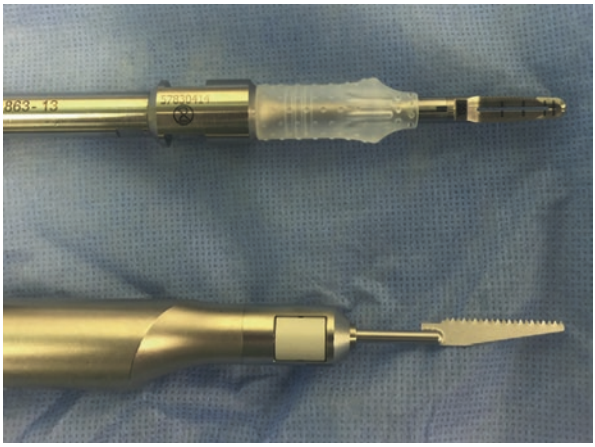

Fig. 10.42 Case 4: a side-by-side comparison of the BoneScalpel to a conventional reciprocating saw. Note the comparable dimensions of the handpiece and cutting surfaces

6. Fat grafts packed around the articulating area of the prostheses improves outcomes relative to decreased pain, improved jaw function, and decreased requirement for repeat surgery [58–61].
7. Using Piezo technology such as ultrasonic BoneScalpel in TMJ reconstruction results in less blood loss when compared to surgeries employing the use of the conventional reciprocating saw [58].
8. Osseointegration of the TMJ Concepts fossa and mandibular components occurs and is important for long-term stability [13–17, 49, 62–65, 67–72].
9. Posterior stop on the fossa component is important to stabilize the joint, jaw position, and occlusion [13, 14, 16, 62, 63, 67, 68].
10. Concomitant orthognathic surgery can be performed at the same time as the TMJs are reconstructed [13, 16, 49, 62, 63, 67, 68].
11. Twenty-year follow-up study demonstrated improvements in pain, jaw function, diet, incisal opening, and quality of life [64].

10.25 Summary

Healthy and stable TMJs are necessary for quality treatment outcomes in orthognathic surgery. If the TMJs are found to have pathological changes, orthognathic surgery results may be unsatisfactory relative to function, esthetics, skeletal and occlusal stability, and pain. The oral and maxillofacial surgeon should be suspicious of possible TMJ problems in the following types of patients: (1) high occlusal plane angle facial morphologies with retruded maxilla and mandible; (2) developing anterior or lateral open bites; (3) progressively worsening occlusal and jaw relationship; (4) facial asymmetry, particularly with progressive worsening; and (5) patients reporting headaches, TMJ pain, myofascial pain, history of clicking and popping of

the TMJs, and/or ear symptoms. The surgeon should not ignore these symptoms, and patients presenting with one or more of these symptoms should be evaluated for possible TMJ pathology. An MRI of the TMJs can aide in identification of the specific TMJ pathology. Failure to recognize and treat these conditions can result in significant relapse, increased pain, and a greater complexity of subsequent treatment.

During the past 30 years, major advancements have been made in TMJ diagnostics and the development of surgical procedures to treat and rehabilitate the pathological, dysfunctional, and painful TMJ. Research has clearly demonstrated that TMJ and orthognathic surgery can be safely and predictably performed at the same operation, but it does necessitate the correct diagnosis, formulation of a comprehensive treatment plan, and requirement of the surgeon to have expertise in both TMJ and orthognathic surgery. The surgical procedures can be separated into two or more surgical stages, but the TMJ surgery should be done first. Combined TMJ and orthognathic surgery requires a thorough analysis of facial soft tissue features, hard tissue shape and relative relationships, and TMJ pathological condition with physical examination and radiographic studies. Adherence to the general surgical principles as outlined above will maximize restoration of harmony among the osseous, dental, muscular, and cutaneous elements of the face and TMJ. As a result, coexisting TMJ pathology and dentofacial deformities treated concomitantly will provide patients with a youthful appearance, functional improvements, and overall satisfaction.

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Considering the TMJ in Mandibular Reconstruction: Ablation/ORN/Trauma

11

Baber Khatib, Allen Cheng, and Eric Dierks

Abstract

When mandibular defects occur following tumor ablation, trauma, infection, or necrosis, anatomical reconstruction becomes necessary to restore proper form and function. Prior to any mandibular rehabilitation, involving resection of the TMJ or not, the function of the stomatognathic apparatus, including the teeth, muscles, and the temporomandibular joint, needs to be taken into consideration for an optimal surgical result. For obvious reasons, this is especially important with disarticulation of the TMJ in oncologic, necrotic, infective, and traumatic settings, which inherently have unique management challenges and reconstructive nuances. In this chapter, we review the various TMJ reconstructive options and their applications in the settings of resection defects that result from tumor ablation, trauma, infections, and necrosis.

11.1 Introduction

When mandibular defects occur following tumor ablation, trauma, infection, or necrosis, anatomical reconstruction becomes necessary to restore proper form and function. Prior to any mandibular rehabilitation, involving resection of the TMJ or not, the function of the stomatognathic apparatus, including the teeth, muscles, and the temporomandibular joint, needs to be taken into consideration for an optimal surgical result. For obvious reasons, this is especially important with disarticulation

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of the TMJ in oncologic, necrotic, infective, and traumatic settings which inherently have unique management challenges and reconstructive nuances.

Historically, the options for TMJ reconstruction in these settings have been varied with no standardized guidelines. Although the literature is replete with reports of partial and total reconstruction for the management of internal derangement or degenerative joint disease, it is extremely limited in the aforementioned areas.

In this chapter, we review the various TMJ reconstructive options and their applications in the settings of resection defects that result from tumor ablation, trauma, infections, and necrosis.

11.2 Trauma

Gunshot wounds (GSWs) to the craniofacial region result in devastating functional disabilities and esthetic deformities, which are further magnified by the associated psychological trauma. Although most GSWs involve injuries to extremities, most self-inflicted GSWs are to the head and neck [1–3]. In 2014, Shackford et al. published an 11-year, multicenter retrospective review of GSW injuries to the face. Of the 720 patients, 85% of the patients who survived past 48 h underwent surgical reconstruction, the mandible being involved in 40% of these. Patients with mandibular trauma required an average of 1.7 operations. This was consistent with Taher's review of 1135 facial gunshot injuries requiring an average of 1.5 operations [4, 5].

Reconstruction in the setting of high-velocity GSWs (>1200 fps, military/hunting weapons) is challenging as high-velocity bullets produce tremendous soft and hard tissue defects from both immediate damage and progressive tissue die-back phenomenon. Low-velocity bullets (<1200 fps) may not cause the same composite defects, rarely result in a significant die-back phenomenon, but can result in comminution. Early nonvascularized bone grafts, prosthetic reconstruction, and open surgery are at increased risk of infection and hardware exposure. On the other hand, closed reduction can result in soft tissue contracture potentially limiting joint mobility and increasing the risk of ankyloses. Traditionally, external fixation was used in this setting to prevent further devascularization of the bone secondary to periosteal stripping and to temporarily maintain large bony defects without soft tissue retraction until definitive repair. GSWs involving the TMJ are unique in that foreign debris within the joint space is an indication to open the joint [6]; however, periosteal stripping of the condyle/ramus unit for rigid fixation in this setting may increase the potential for resorption of the condylar head due to its limited blood supply. Although external fixation has been largely replaced with rigid internal fixation, it is still a useful adjunct in the armamentarium for treatment of complex GSWs to the mandible.

For those cases in which the soft tissue and condylar defects are amenable to primary repair, local flaps and/or nonvascularized bone grafts, aided by virtual surgical planning, can be carried out in the early posttraumatic period. For instance, in grossly comminuted fractures or continuity defects, the contralateral mandible can be digitally mirrored to the injured side to approximate the mandible's pre-traumatic

form. This can then be used to create a custom TMJ alloplastic prosthesis to restore form and reasonable function.

In grossly comminuted fractures with large avulsed soft tissue defects, repair with nonvascularized tissue (e.g., costochondral graft) or a joint prosthesis alone may not suffice. In these situations, microvascular free flap reconstruction has become a mainstay. Microvascular free flap reconstruction provides simultaneous reconstruction of both the soft and hard tissue defects. It is possible to simultaneously reconstruct composite defects of the TMJ with a soft tissue flap and alloplastic joint; however the risk of infection of the joint may be higher in this setting. One could stage the reconstruction by placing soft tissue first and then return to the operating room for eventual alloplastic joint reconstruction, but this extends the patient's malocclusion, requires a second operation, and increases the risk for scarring and contracture. Total reconstruction of the temporomandibular joint with a vascularized fibula free flap using a skin paddle is a common solution in this setting. Other microvascular options for reconstruction include the deep circumflex iliac artery, osteocutaneous radial forearm, vascularized metatarsal or metatarsal-phalangeal joint, and costochondral flaps, which have their specific indications but are used much less frequently in the authors' practice [7].

The composite defects caused by gunshot injuries to the mandible are similar to those defects caused by ablative tumor surgery or necrotizing infection. Many of the principles and techniques used in the reconstruction of post-ablative defects involving the condyle due to resection can be applied to gunshot injuries to these structures (Fig. 11.1).

11.3 Infection

Osteomyelitis and necrotizing infections involving the condyle are rare. There are less than 20 reported cases of condylar osteomyelitis in the English literature even though the mandible is the most common facial bone affected [8]. The erosive and destructive nature of advanced infection can result in loss of the condyle and malocclusion. These patients are typically reconstructed in a secondary fashion with the primary treatment involving source control and antibiotics. However, surgical resection to healthy bleeding bone has been employed for those patients who are nonresponsive to antibiotic therapy. Reconstruction is done with a prosthetic joint, typically in a delayed fashion, to minimize further bacterial seeding of the joint. A consideration for microvascular reconstruction in this setting seems prudent as the defect can be immediately reconstructed at the time of resection. For those infections that have a necrotizing soft tissue component, similar to avulsive GSW defects, options for reconstruction include osteocutaneous microvascular reconstruction versus vascularized soft tissue with a delayed prosthetic reconstruction. Proponents of the osteocutaneous reconstruction favor the one-stage surgery, whereas those in favor of delayed prosthetic reconstruction with soft tissue argue that the TMJ prosthesis is superior in replicating an anatomical and functional joint. There is no definitive study that shows one to be functionally superior as both have the same limitations of restricted rotational movements and minimal translational function.

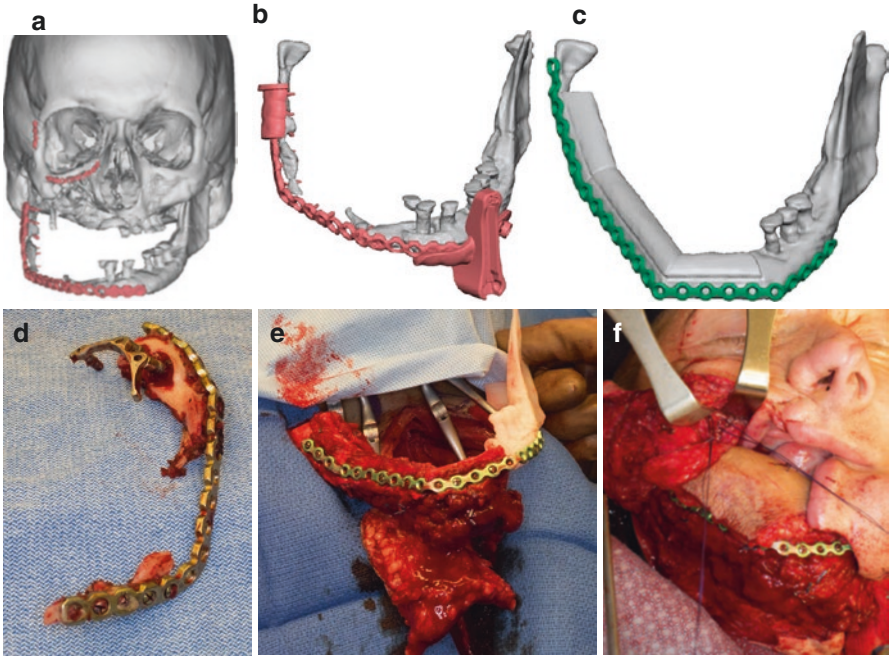

Fig. 11.1 40 y/o police officer s/p gunshot to the face in the line of duty. He was initially reconstructed with a scapula free flap and free bone grafts at an outside institution. He presented 5 years later with failing hardware and bone loss. Patient was reconstructed with fibula free flap and skin paddle for soft tissue bulk while maintaining native condyle without disarticulation. (**a**) Preoperative 3D reconstruction. (**b**) Planned resection margins maintaining native condyle. (**c**) Planned reconstruction with condyle preserved. (**d**) Resected specimen. (**e**) Accurate recreation of surgical plan. (**f**) Suspension of the condyle segment to the zygomatic arch with SonicWeld anchors and Prolene sutures

11.4 Ablative Surgery Involving the TMJ

The incidence of direct extension of tumors into the condyle from head and neck neoplasms is rare and even less so for metastasis to the joint [9, 10]. The need for safe oncologic margins in these settings may necessitate total or subtotal mandibulectomy including the condyle, followed by possible adjuvant radiation and chemotherapy. Advanced mandibular squamous cell carcinomas, the most common cancers of the oral cavity, are usually treated with adjunctive radiation therapy commencing within 6 weeks of surgical resection. At that time, an avascular bone graft placed primarily will have been revascularized, but incorporation into the native mandible will not be close to maturity. Radiation damage will almost certainly destroy any neovascularization as well as the tenuous osteocytes within the bone graft. If the bone graft is placed secondarily, a second surgery is required that places the bone graft into a poorly vascularized tissue bed. Bone morphogenetic protein-2 (BMP-2) mixed with harvested stem cells derived from bone marrow aspirate

concentrate has been used; however the safety of using a growth factor in a cancer patient is not well defined and seems counterintuitive. In addition, the quantity, quality, and type of stem cells that are produced from such a procedure are unknown [11]. Similarly, alloplastic total joint reconstruction in this setting is theoretically at increased risk of infection secondary to poor vascularity and a potentially reduced immune response if on adjuvant chemotherapy. There are no demonstrable studies comparing TMJ infection rates in healthy patients to immunosuppressed patients; however, the orthopedic literature shows increased joint infection rates with immune suppression for solid organ transplant and immunosuppressive disease such as HIV and hepatitis [12, 13]. In addition, TMJ prostheses have been shown to have risk of erosion, bony destruction, extrusion, and exposure in head and neck cancer patients [14]. Combining the theoretical risk of infection with the reconstructive need of hard and soft tissue, post-ablative defects in patients requiring adjuvant radiation therapy/chemotherapy make nonvascularized tissue and prosthetic joints an impracticable option (Fig. 11.2).

11.5 Osteoradionecrosis

The odious complication of osteoradionecrosis is an unfavorable environment for nonvascularized bone grafts secondary to radiation changes causing mucosa breakdown and hypovascularity, potentially increasing the risk of infection [15, 16]. The body of the mandible is the anatomic location most commonly affected by ORN [17, 18]. The vulnerability of the buccal cortex in the premolar, molar, and retromolar regions is theorized to be secondary to increased radiation absorption as a result of the denser bone and higher mineral content of the bone in these regions [19]. The composite defects created by the removal of necrotic bone, fistulas, and infected tissue in advanced ORN generally require vascularized tissue for adequate and predictable reconstruction. Reconstruction to acceptable form and function requires bridging of the bony continuity defect and coverage of any soft tissue defects. Complications arise when reconstructing with metal plates alone covered with soft tissue, lateral plate extrusion being the most common and strongly correlated to radiation and smoking [14, 20–22]. In Etti's review of 334 patients undergoing segmental mandibular resection for oral squamous cell carcinoma and immediate reconstruction with a titanium bridging plate, 41% of the patients had their plates removed secondary to infection and plate exposure, 93% of which occurred in the first year [23]. Although not eradicated, this complication is significantly decreased with composite reconstruction using microvascular free flaps. A systematic review by Lee et al. found the most common complication of the 368 microvascular mandibular reconstructions for ORN was fistula formation (8%) with plate exposure occurring in 7% [24]. Hence, it is our belief that vascularized autologous reconstruction of the mandible and joint is a standard for composite reconstruction of the condyle and mandible involved in ORN resections, including those that involve the TMJ (Fig. 11.3).

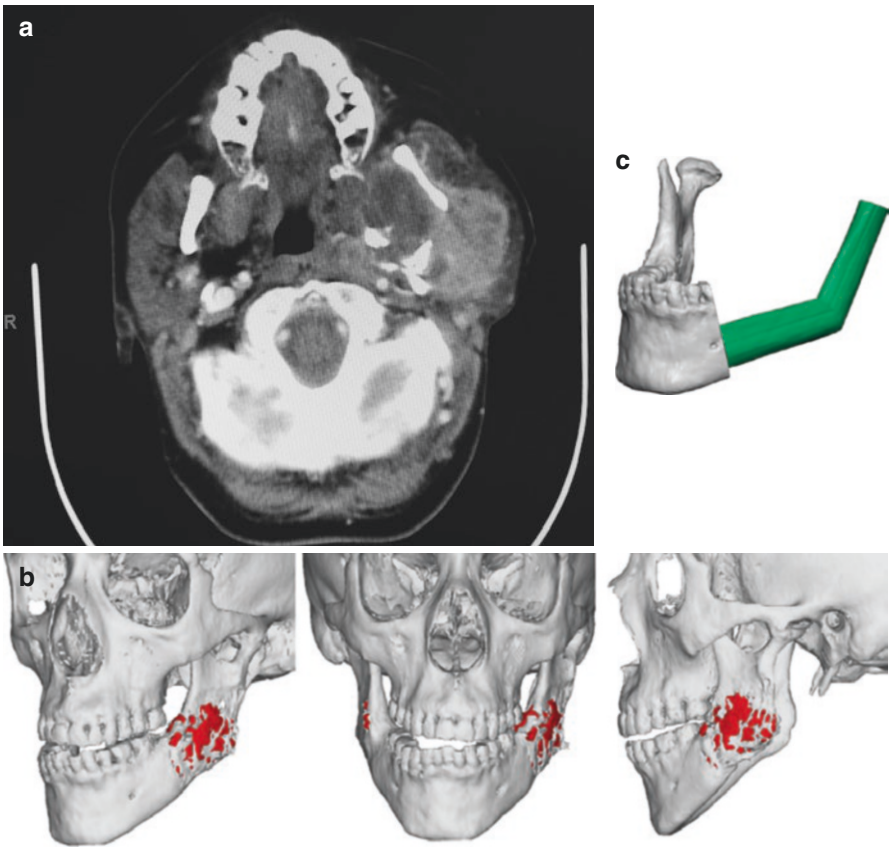

Fig. 11.2 56 y/o F with large expansive left parotid adenocarcinoma presenting with diplopia, left abducens nerve palsy, and facial swelling. Final pathology: pT4aN0M0 left parotid adenocarcinoma NOS with lymphovascular invasion. (**a**) CT scan reveals left parotid mass with calcification and destruction of the mandible and mass effect on adjacent tissues. (**b**) 3D reconstruction showing osseous invasion of tumor. (**c**) Mirror image of contralateral condyle used to shape fibula during virtual surgical planning. (**d**) Fibula articulating into the glenoid fossa, recreating posterior face height. (**e**) Tumor in situ with skin/subplatysmal flaps elevated, note proximity of facial nerve. (**f**) Specimen after left total parotidectomy, facial nerve dissection, composite mandible resection, and selective neck dissection. (**g**) Composite defect with majority facial nerve preservation (temporal branch sacrificed). (**h**) Fibula osseocutaneous free flap in place reconstructing composite mandibular defect including condyle—deepithelized skin paddle retracted. (**i**) Reconstruction of bony and soft tissue defects from composite tissue resection

11.6 Surgical Concepts

11.6.1 Vascularized Options of Reconstruction of the Mandibular Condyle

Vascularized flaps used in condylar reconstruction include the fibula, radial/ulnar artery forearm, vascularized metatarsal or metatarsal-phalangeal joint, costochondral,

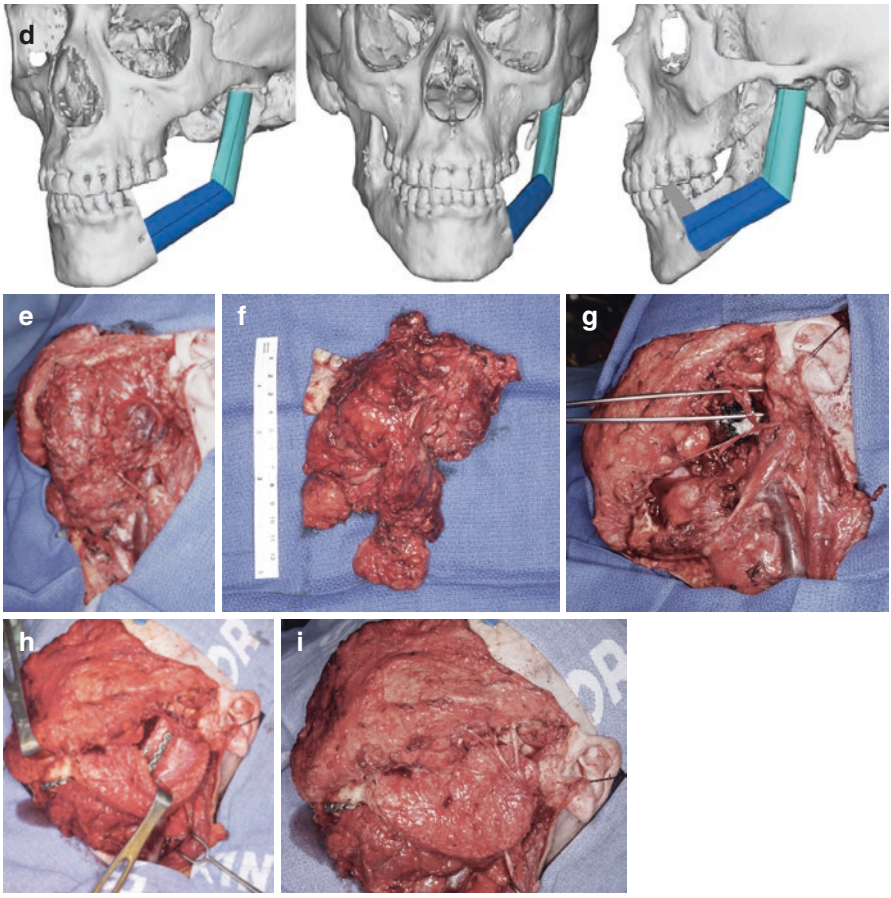

Fig. 11.2 (continued)

and the deep circumflex iliac artery (DCIA) graft. Overall the reported failure rate of microvascular free flaps has been reported to be less than 5% [25]. In Brown's recent 25-year retrospective review of vascularized reconstruction of the mandible, the fibula flap had the lowest reported complication rate (4.1%) and was the most common vascularized flap used to reconstruct the TMJ; the DCIA had the highest rate of failure (6.2%). The DCIA flap is less favorable for oromandibular reconstruction due to the higher failure rate, technical difficulty, and bulky non-pliable skin paddle. The metatarsal flap, initially heralded as an excellent reconstructive option for the TMJ has several limitiations. These include limited bone stock of 7 cm if simultaneous mandibular body reconstruction is needed, variable vascular anatomy, susceptibility to atherosclerosis and postoperative gait disturbances [26, 27]. Costochondral grafts have limited bone stock, an unreliable vascular supply to the skin paddle if composite reconstruction is planned and unpredictable growth; in addition the posterior approach can place the blood supply to the thoracolumbar spinal cord at risk. The minimal bone with radial and ulnar artery forearm flaps and increased risk of radius fracture limit these flaps' use to soft tissue coverage only [7, 25, 28].

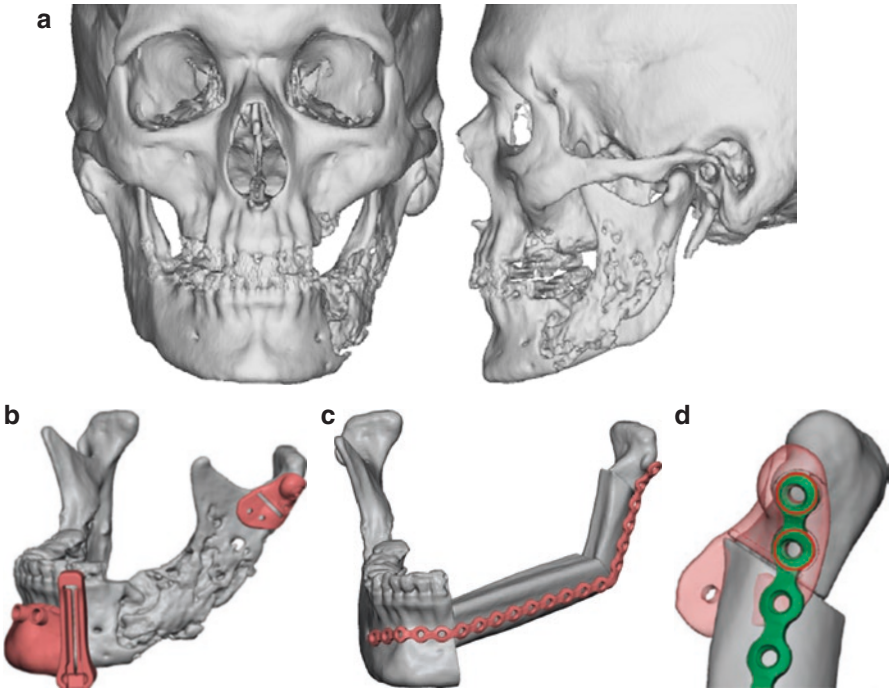

Fig. 11.3 71 y/o M with hx of tonsillar SCC treated with chemoradiation presenting with stage III ORN. (**a**) Bony involvement. (**b**) Condylar head left intact, planned resection margins. (**c**) Custom plate fabrication for securing the fibula to remnant of the condyle. (**d**) Two-hole fixation onto condyle head

11.6.1.1 Fibula Free Flap

Ever since Hidalgo reported the use of the fibula free flap for mandibular reconstruction, it has become the workhorse for such defects [29]. The ability to perform multiple osteotomies among the length of the on average 25 cm of useable bone adds to this flap's versatility. We base our reconstruction on the Brown classification, where Brown class IC, IIIC, and IVC defects involve the condyle with the ipsilateral lateral mandible, hemimandible, or extension into the contralateral mandible, respectively. The resection margins are designed using the Brown subunit principles to facilitate reconstruction during the virtual surgical planning phase. If margins allow, we prefer to leave a condyle-ramus portion, with minimal stripping of attachments to secure the fibula. We also attempt to preserve the articular disc and infrequently encounter the need to reconstruct the glenoid fossa. The vascular pedicle of the fibula is typically planned to run anteriorly as to not induce a hairpin at the condyle reconstruction. At the time of surgery, the articular disc is usually left in place when the condyle is disarticulated, which potentially can discourage ankylosis and support natural reshaping of the neo-condyle [30]. The fibula head is then seated into the fossa and rarely requires reshaping. The purpose of this condyle-ramus reconstruction is to establish posterior face height and facilitate rotation at

the neo-condyle and the contralateral native joint in hemimandibulectomies. Similar to other reports, we have observed acceptable maximal incisal opening, maintenance of intelligible speech, satisfactory esthetics, and the ability to resume oral feeds [31].

Hidalgo [29] reported a technique of attaching the resected native condyle, once verified to be free of tumor by frozen section (albeit a controversial technique), to the end of a fibula. In this approach, the disarticulated condyle is completely devoid of muscle attachments before it is secured to the fibula with plates and screws. It is then seated into the glenoid fossa as a free graft and is anchored to the glenoid fossa by closing the joint capsule around it with a non-resorbable suture or affixing the joint capsule to the rigid fixation between the condyle and fibula. The MIO in the 14 patients in this series was on average 37 mm, 28 mm in the radiated patients and 43 mm in the non-irradiated. Hidalgo noted that on long-term follow-up (13–56 months), some patients completely resorbed their condylar heads, whereas some did not, independent of radiation. Remarkably, this resorption did not affect function. The goal of this reconstruction was not to preserve maximal incisal opening as many patients with a unilateral functioning joint can already accomplish this, but rather to maintain occlusion and posterior face height and reduce deviation on opening. Opponents to this technique note the risk of positive margins (although Hidalgo reported none in his series), the technique sensitivity, and the concern of nonunion as the condylar head stripped of attachments represents a nonvascularized bone graft. This could lead to increased resorption, apertognathia in bilateral joint reconstruction, and a potential nidus for infection. The concept of free bone grafting to restore resected or traumatically disarticulated condyles is a controversial technique popularized by Boyne, who showed early favorable outcomes [32]. However, analysis of the microvascular supply of the condylar head and careful radiographic examination have clearly shown an unpredictable risk of aseptic necrosis and graft resorption with this technique [33–35].

A clever modification to this technique, reported by Nahabedien and Manson and later modified by Potter and Dierks, is affixing the fibular stump to the condyle without disarticulating it and stripping its attachments [27, 36]. Although originally described with plate and screw fixation, Potter and Dierks suggested simple transosseous wire fixation had the added benefit of minimal stripping of the soft tissue cuff, and the concern of insufficient bone for screw fixation is negated. In this sense, the condylar vascularity is maintained which theoretically decreases the risk of resorption (Fig. 11.4).

Bredell et al.'s literature review comparing reconstructive techniques in postablative defects, including patients reconstructed with plates attached to metal condyles (n = 17), costochondral grafts (n = 28), custom joints (n = 25), and fibula reconstruction (n = 33), concluded that the fibula free flap had the lowest complication rate while maintaining good function [37]. Complications included trismus, dislocation, and plate exposure but were rare compared to other techniques, particularly the frequency of plate exposure in metal condyle/plate reconstruction. The nonvascular techniques included more serious complications including facial nerve injury, erosion into the skull base/middle ear, fracture, overgrowth/undergrowth,

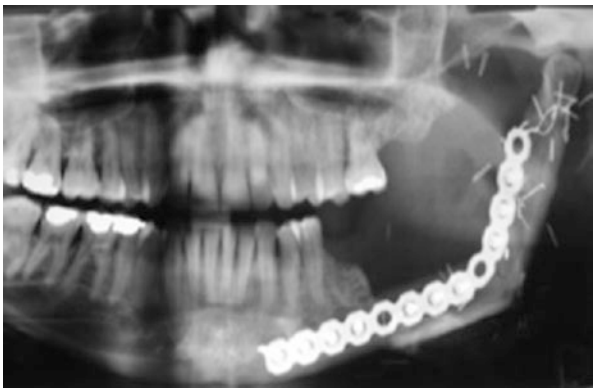

Fig. 11.4 Attachment of fibular stump to the head of the condyle with transosseous wire fixation without disarticulation

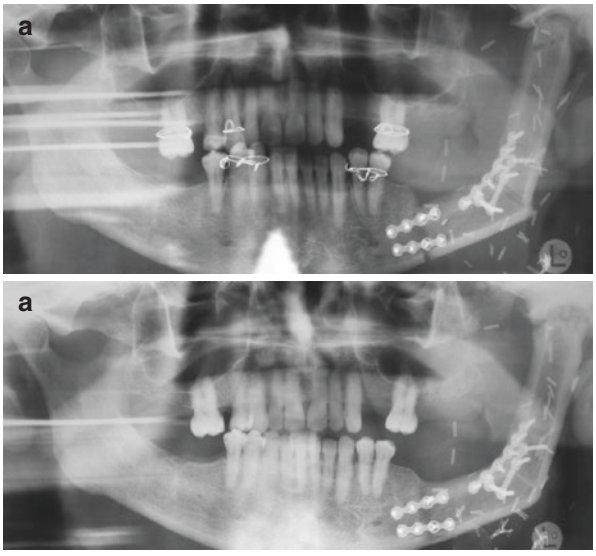

Fig. 11.5 (**a**) Fibular stump placed into the glenoid fossa to reconstruct defect following extensive resection for multiple recurrent KOT. (**b**) Nine years later the patient has painless function with MIO 35mm. Radiograph shows pseudarthrosis

and infection. The reduced facial nerve injury is likely explained by the minimal access required to place the fibula into the glenoid fossa compared to that of a total joint reconstruction with a prosthesis. The long-term radiographic findings of the fibula free flap have been reviewed by Guyot who advocates maintaining the native articular disc when possible. All 11 patients reviewed remodeled the neo-condyle created by the distal fibula with resorption anteriorly and posteriorly and bony apposition in the center of the articular disc; this effectively rounded off the fibular head. No cases or ankyloses were reported [30] (Fig. 11.5).

11.7 Summary

The need for functional reconstruction of the TMJ in post-ablative and traumatic defects proves to be a difficult and unique setting that can be effectively managed with microvascular free flap reconstruction, the fibula osteocutaneous flap being the most versatile.

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12

Treatment of Advanced Osteoradionecrosis (ORN) of the Mandible (Resection/ Disarticulation and Staged Reconstruction), a Protocol and Rationale

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Abstract

For many reasons, reconstruction of the defect resulting from resection of mandibular ORN is not analogous to reconstructing a defect resulting from tumor ablation or trauma. Patients with mandibular ORN tend to have chronically exposed, infected bone in a bed of densely fibrotic, hypoxic, hypovascular, and hypocellular tissue. These tissue characteristics are much more harsh than those found after a primary tumor resection. Further, reconstruction after tumor ablation is more amenable to a combined one-stage procedure including the ablation with immediate reconstruction, typically using a microvascular free flap,

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because the host tissue is of better quality and often both hard and soft tissues are needed to correct the defect and close any intraoral communication. Additionally, in cancer surgery, it is rare to have involvement of the condylar ramus/head so as to necessitate a full disarticulation. Thus, the functional anatomy is maintained, and there is a surface to fixate the reconstruction plate carrying the fibula. It is important to appreciate that in an irradiated field, the region of affected bone very often extends a considerable distance from the site of pathologic fracture; often the extent of affected bone includes the hard tissue up to the condylar head. Experience has taught us that attempting to stabilize a reconstruction plate on this compromised bone often leads to failure of the entire reconstruction, resulting in pain and significant dysfunction. In this chapter we present a protocol that includes disarticulation of the joint in the setting of mandibular resection for ORN; this has been developed over time and with experience. This protocol is staged to allow for multiple stopping points if for any reason the sequence cannot be completed, but yet leaves the patient functional with minimal pain.

12.1 Introduction

Head and neck cancer accounts for nearly 3% of all cancer in the United States. Although there has been a recent trend toward younger populations being affected (HPV+ tumors), the majority of patients are of an advanced age and often burdened with multiple medical comorbidities [1]. After initial tumor staging, the treatment of head and neck cancer is often very long and strenuous with patients left managing the negative sequela of their primary surgery as well as any adjuvant chemo- and/or radiation therapy. While some of these sequelae are limited to the perioperative period, some are progressive and lifelong. These persistent adverse conditions include xerostomia, dental caries, dental abscesses, lymphedema, dysphagia, pain, fibrosis, and trismus as well as one of the most feared potential complications, osteoradionecrosis of the jaws (ORNJ). ORNJ frequently involves the posterior mandible due to its inclusion within the radiation field, especially in tonsillar and base of tongue tumors. This chapter will outline a protocol for treatment of advanced ORNJ that involves resection of the affected posterior mandible, including the ramus and condyle, and staged prosthetic reconstruction that stabilizes the mandible and replaces the condyle.

ORNJ is a condition characterized by an area of exposed, non-healing, necrotic, irradiated jawbone in the absence of recurrent or residual tumor that is often chronically colonized with pathogenic bacteria. The inciting traumatic event is typically a tooth extraction; however spontaneous cases do occur. The incidence of ORNJ ranges from 5 to 25%; however this number is an estimate of the population of patients that receive radiation therapy for head and neck cancer and not specific to the population that also have had tooth extraction(s); one would expect the level of ORNJ in the latter group (radiation plus extraction) to be higher. It is most common in the mandible, but can occur in any bony tissue within the radiation field or even outside of the direct radiation field due to scatter [2–4]. Although an exact definition

or classification has not been agreed upon [5, 6], it is commonly accepted that the risk factors for developing ORNJ include radiation to the head and neck (particularly at doses above 60 Gy), dental extractions after irradiation, poor dentition, chronic infection, and any other type of surgical injury to the irradiated bone [7]. Patients suffering from ORNJ can experience pain, dysphagia, swelling, infection, fistula formation, and pathologic jaw fracture. There is a severe reduction in overall quality of life and increase in pain as the level of ORNJ increases [4, 8, 9]. Further, patients can suffer from malnutrition, drug dependence, sepsis, disfigurement, and decrease in social interactions. There are many classifications in the literature for ORNJ, but for the purposes of this discussion, we will refer the Notani classification [10] in Table 12.1.

Although there is no universally accepted theory explaining the pathogenic process responsible for the development of ORNJ, one of the leading proposals is Marx's well-known "three Hs" hypothesis, which he first described in 1983. This hypothesis characterizes irradiated bone as being hypoxic, hypocellular, and hypovascular, a result of the progressive fibrosis that occurs in response to radiation. It follows then under these poor tissue conditions that a tooth extraction or other trauma to the bone can result in poor wound healing and eventual necrosis. Hyperbaric oxygen [HBO] has been shown to improve these tissue parameters [11], and studies demonstrate it has a significant benefit when used as an adjuvant in patients who require tooth extraction in irradiated bone [12–14]. However, as pointed out by Marx, HBO therapy alone does not completely resolve established ORNJ, but rather should be used as an adjunctive therapy in the treatment of ORNJ in conjunction with debridement or resection. In the ORNJ treatment protocol described in this chapter, HBO is used as an adjuvant treatment modality to improve tissue oxygenation and vascularization.

In 1998, Delanian and Lefaix introduced the theory of a radiation-induced fibroatrophic [RIF] process to explain the pathogenesis of ORNJ [15–17]. This theory underlies the rationale for pentoxifylline-tocopherol (PTX-Vit E) treatment for ORNJ. The general notion of RIF is that the progression of ORNJ is based on the dysregulation of fibroblastic activity, leading to atrophic tissues, tissue breakdown, and subsequent bony exposure that allows for colonization by pathogenic bacteria and the development of secondary osteomyelitis; it is not all that dissimilar from Marx's hypothesis. Animal models [18] demonstrate a decrease in bone metabolism and mineralization, a decrease in osteocytes, and increased fibrosis. In an analysis of irradiated mandibles, it has been demonstrated that as the radiation dose increases, the quantities of myofibroblasts (activated contractile fibroblasts characterized by the expression of smooth muscle actin) increase, which in turn increases the fibrosis seen in irradiated bone. The PTX-Vit E protocol takes advantage of the antioxidative actions of vitamin E, while pentoxifylline has been shown to significantly

Table 12.1 Classification of ORNJ

Notani classification of osteoradionecrosis (ORN)	
I	Confined to the alveolar bone
II	Limited to the alveolar bone and/or mandible above the level of the inferior alveolar canal
III	Involving the mandible below the level of the inferior alveolar canal and/or skin fistula and/or pathologic fracture

decrease the duration of non-healing ulcerations by increasing erythrocyte flexibility and causing vasodilation, both of which improve the red blood cells' ability to navigate the fibrotic vasculature and increase the delivery of oxygen to the irradiated tissue [19]. The combination of PTX-Vit E demonstrates drug synergy and creates an overall anti-fibrogenic environment and has become an accepted treatment adjunct for ORNJ [15–17, 20]. Similarly, the protocol described in this chapter takes advantage of the PTX-Vit E treatment regimen to improve the overall tissue characteristics prior to the resection of dead bone and the subsequent reconstruction.

There is no consensus on how to manage patients with Stage 3 ORNJ. However, the ideal treatment goals should include the following: enhancement of the compromised tissue, removal of all or as much of the necrotic/infected bone as possible, providing anatomic continuity, optimizing function, reducing or eliminating pain, and closure of both intraoral and extraoral communications/fistulas. The question of whether dental rehabilitation should be part of the plan is very much patient-specific. One significant obstacle in many irradiated patients is the existence of severe fibrosis and trismus, thus limiting their maximal incisal opening, often to the point where the construction of a prosthesis is just physically impossible.

Previous chapters in this book describe methods to reconstruct the mandible, particularly in the setting of trauma or status post ablative treatment of cancer. Advancements in microvascular surgical techniques have truly been revolutionary, allowing for single surgery resection and reconstruction of the mandible with autogenous, bony tissue that can include the placement of dental implants and construction of a prosthesis. Although patients can obtain very acceptable levels of appearance and function, they can still have problems [21] with esthetics, swallowing, chewing (prosthetic dental reconstruction) [5], speech, pain, and social interaction [4, 8, 9, 21, 22]. Further, reconstruction of a defect resulting from the resection of mandibular ORN is not analogous to reconstructing a defect resulting from tumor ablation or trauma. The main difference is obvious: patients with mandibular ORN present with chronically exposed, infected bone in a bed of densely fibrotic, hypoxic, hypovascular, and hypocellular tissue (as described by Marx; see above). Although the free flap carries with it a blood supply, the compromised host tissues are much less amenable to short- and long-term flap integration compared to flap placement and integration in a non-irradiated, non-infected host site. Complication rates in ORNJ microvascular reconstructions range around 20–40% and include fistula formation, hardware exposure, infections, and flap failure [23, 24] in comparison with microvascular reconstructions in non-irradiated patients.

In advanced ORNJ, the affected bone is often widespread. Indeed, the typical defect or pathologic fracture initiates in the body region of the mandible; however, radiographically and histologically it is evident that the radiation-affected bone often extends much further than this to include the condylar neck and head, particularly in patients that have received radiation for base of tongue and tonsillar cancers. This situation necessitates a full disarticulation of the condyle, for experience dictates that a reconstruction plate secured to physiologically compromised or dead

bone is ultimately doomed to failure. On the other hand, in cancer surgery, it is rare to see involvement of the condylar ramus/head so as to necessitate a full disarticulation. Thus, the functional anatomy of the joint can be maintained, and there is a viable hard tissue available to fixate the reconstruction plate carrying the flap.

A solution to reconstruct a partial mandibular defect that includes the loss of the native functional TMJ, in the irradiated patient, is to take advantage of recent advances in techniques and materials in TMJ total joint reconstruction. As covered in previous chapters, total joint reconstructions have become much more reliable, functional, and predictable than in the past and with the ability to customize the prosthesis. It is now possible to design a customized total joint prosthesis that extends all the way from the fossa/condyle/ramus unit to the symphyseal region, thus providing a method to reconstruct these large mandibular defects in the ORNJ patient without the morbidity associated with free flaps at both the recipient and the donor sites.

The workflow for these cases is not straightforward. The simple reason for this is that there is often an intraoral communication left after the resection of the necrotic mandible. Under the best of circumstances, this communication located in highly compromised tissue can take weeks to months to achieve closure, chronically exposing any hardware to oral flora, which contributes to breakdown of the skin overlying the plate in the neck and subsequent plate exposure or a chronic fistula. Thus, placing a large, complicated, and expensive custom prosthesis in such a situation is highly discouraged. Fortunately, an intermediate solution has been developed that allows time for the intraoral communication to close and does not put a final customized prosthesis at risk of failure with the need for removal. For this protocol, the virtual surgical planning includes the resection of the hemi-mandible from at least 1 cm anterior to the affected region. This is followed by the fabrication of a pre-bent reconstruction plate fitted with an add-on temporary condylar prosthesis. The pre-bent plate does not mirror the contralateral mandible. Instead, it is designed to be more medial in position, with a gentle curve at the angle. The temporary condylar prosthesis articulates against a stock fossa prosthesis (Biomet Microfixation, Jacksonville, FL, USA), providing stability, functionality, and space maintenance for the future, final reconstruction. Once the wound is reliably healed so that there is no communication remaining between the neck and oral cavity, it is safe to proceed with the design and placement of the custom prosthesis.

The design of the custom final prosthesis follows the principles laid out in the previous chapter on virtual planning for total joint reconstruction. The main differences are the following: (1) the patient undergoes a repeat postoperative CT scan to send to TMJ Concepts, and (2) the design of the final extended-ramus custom prosthesis mimics the shape and contour of the initial pre-bent reconstruction plate. The surgery to remove the pre-bent reconstruction plate with temporary add-on condyle and place the final custom prosthesis is reasonably uncomplicated, as the incisions have already been made and the tissue planes dissected during the first surgery when the ORNJ was resected. In general, it is preferable to place the final prosthesis rather than leave the pre-bent reconstruction plate because it is stronger and more stable in the long term. Also, it allows for the placement of a patient-specific fossa/condyle/ramus unit that provides optimized long-term joint function.

Overall, the treatment protocol described in detail in the following paragraphs and case presentations has been designed to provide comprehensive management of mandibular ORN aimed at delivering the most definitive treatment possible. The ORNJ patient population is typically burdened with multiple medical comorbidities that can make it difficult or impossible to complete the entire protocol. In fact, the protocol described herein has built-in contingencies that allow for adaption of the surgical sequence and offer the medically compromised patient multiple possible ending points (Table 12.2), depending on the clinical situation and the tolerance level of both the patient and tissue bed. The possible endpoints include (1) the final custom extended prosthesis (Case #1), (2) the intermediate prosthesis (Case #2), and (3) no prosthesis or continuity at all, a "free-swinging" hemi-mandible (Case #3).

Table 12.2 Summary of staged approach to ORNJ management

The ORNJ protocol		
Optimization	– Optimization of comorbid conditions (CHF, diabetes, etc.)	Variable time frame
Pretreatment and surgical planning	– HBO therapy – Vitamin E and pentoxifylline – Antibiotics, if needed – PEG tube placement – VSP session to design the pre-bent plate	30 HBO dives PEG placement 1 week prior to surgery
Stage 1: ORNJ resection and intermediate reconstruction	– Arch bar system – NIM electrodes for facial nerve monitoring – Disarticulation of joint – Resection of ORN – Closure of oral communication – Placement of a stock polyethylene Biomet TMJ fossa prosthesis – Placement of pre-bent plate and temporary add-on condyle – Possible pectoralis major flap to add soft tissue for closure over the plate, if needed – Short-term maxillomandibular fixation (MMF) to prevent dislocation	1 OR session
Healing phase	– Infectious disease consultation – PICC line placement – Additional HBO – Physical therapy – No food by mouth – Obtain new CT – Design TMJ concepts extended-ramus prosthesis	6 weeks of IV antibiotics
Stage 2: Placement of the custom extended-ramus TMJ prosthesis	– Explantation of initial pre-bent reconstruction plate with add-on condyle and Biomet fossa – Placement of TMJ concepts custom joint prosthesis	1 OR session

12.2 Eligibility Criteria

Inclusion criteria for the ORNJ protocol
1. Refusal of a second site surgery
2. Severe comorbid conditions contraindicating a larger two-site surgery
3. Peripheral vascular disease limiting the anatomic areas to harvest a free flap
4. Compromised bone that includes the mandibular angle, ± ascending ramus
5. Ability to undergo a procedure under general anesthesia from a medical and psychological standpoint

12.3 The Advanced ORN Protocol

12.3.1 Pretreatment and Surgical Planning: HBO Therapy, Vitamin E, Pentoxifylline, Antibiotics, PEG Tube Placement, and VSP Session

The ORNJ protocol begins well before the patient is taken to the operating room. After initial consultation and diagnosis of advanced-stage mandibular ORN, patients are arranged for hyperbaric oxygen. Most patients receive 30 dives preoperatively, but this is left to the discretion of the HBO physician. Many are also started on vitamin E and pentoxifylline preoperatively to further optimize blood flow and healing capabilities of the mandible. A typical regimen is vitamin E 400 IU BID and pentoxifylline 400 mg BID. To this regimen, an antibiotic may be added if purulence is noted. An oral antibiotic with high bioavailability is an alternative to parenteral therapy due to its simplicity, but the surgeon should also be guided by cultures, when available. A CT scan with fine cuts (no greater than 0.625 mm slice intervals) is ordered to prepare for surgery. The patient is instructed to bite teeth together in the best occlusion possible for the CT scan. If the patient cannot achieve normal intercuspation (e.g., due to pathologic fracture), dental impressions will be needed and poured in stone so that the dentition can be accurately scanned and inserted into the CT scan. The patient's occlusion can be set during the virtual surgical planning session. To ensure appropriate healing of intraoral wounds/communications, patients are made NPO postoperatively to avoid food contamination within the wound; thus they require PEG tube placement to allow for adequate nutrition during this phase of treatment. Arrangements for PEG placement occur within 1 week prior to surgery. Due to comorbid conditions (hypertension, diabetes, CHF, etc.), patients are also often sent to their primary care physician to ensure optimization of their health prior to undergoing surgery.

Virtual surgical planning is done to establish resection margins, set the occlusion (if normal presurgical occlusion cannot be achieved), and plan for the fabrication of a customized pre-bent reconstruction plate with add-on temporary condyle. Many craniomaxillofacial plating companies provide in-house or subcontracted VSP services and can design the pre-bent plate three-dimensionally. Mirroring the contralateral mandible is a mistake in many instances. Due to the poor quality of the

irradiated soft tissue envelop and overlying skin, it is usually best to shorten the length of the ramus, avoid recreating a mandibular angle, and angulate the plate more medially as viewed in an A-P plane. In other words, in visualizing the contour of the pre-bent plate, it should lie within the volume of the resected mandible, not more lateral to it. The position of the temporary condylar head so that it articulates against polyethylene Biomet TMJ fossa prosthesis. The Biomet fossa acts as a platform for the prosthetic condylar head articulation, and it functions as an ideal "temporary spacer," saving room for a future TMJ Concepts fossa prosthesis at Stage 2 surgery (see below). Unfortunately, the use of the Biomet TMJ fossa in this way is off-label, and the company may request that the surgeon justify its use as a spacer. If the surgeon elects to use a Biomet TMJ fossa as a temporary spacer, the Stage 2 surgery will be made easier, since little to no tissue resection and only a little additional tissue reflection will be needed to replace the Biomet fossa with the somewhat larger but similarly shaped TMJ Concepts fossa prosthesis. It should be noted that the VSP company will not have access to the Biomet fossa digital file; thus the surgeon must estimate its position on the virtual model. Experience has shown that the top of the add-on condylar head should be positioned 6 mm below the height of the natural fossa. This 6 mm gap is enough room for the Biomet TMJ fossa to fit over the temporary condyle, especially since the articular eminence is osteotomized and flattened as part of the surgical protocol for placing the Biomet fossa. In fact, the eminectomy can be virtually simulated during the VSP session as well.

12.3.2 Stage 1: ORNJ Resection and Intermediate Reconstruction

Stage 1 surgery is directed toward resecting the ORN-affected mandibular bone. If there is a tooth present at the anterior extent of the planned segment for resection, the case is started by removing those teeth to facilitate the osteotomy. An arch bar system is typically placed to allow for a short period of MMF after surgery. The authors prefer the new-generation hybrid arch bars because the anchorage is derived from screws in the bone, instead of wires around the teeth. Nerve integrity monitoring (NIM) electrodes are placed to allow neuromonitoring during dissection. The patient is prepped and draped in sterile fashion.

A preauricular incision is marked out and the dissection is carried out to expose the TMJ. With the condylar head and neck exposed, a condylectomy cut is made. The condylar head is dissected out followed by the removal of the articular disc. This surgical site is packed off and attention is turned toward the ipsilateral submandibular region. A standard Risdon incision is marked out with the length of the incision depending on the extent of the mandibular resection. Once the mandible is adequately exposed, the bony cut at the anterior extent of the resection can be made. If the VSP company designed a cutting guide, this makes the resection quick and accurate. Once this osteotomy is made, attention is turned back toward the preauricular incision. With the surgical assistant applying posterior-superior pressure to the ramus from below, the sigmoid notch becomes visible through the preauricular incision. A horizontal osteotomy from the anterior border of the ramus to the

posterior border of the ramus 5 mm below the level of the sigmoid notch is made, and the resected bone is delivered from the preauricular incision, including the condylar neck and the coronoid process. It is preferable to use an ultrasonic device for this cut instead of a standard reciprocating saw, to minimize potential bleeding. Waiting to make this osteotomy until after the submandibular incision is open and fully dissected allows for access to the external carotid if heavy bleeding is encountered during the osteotomy.

The rest of the ORN-affected bone can be dissected out through the submandibular incision. The bone specimen is sent to pathology, but a representative piece is also sent to microbiology for culture. With the resected bone removed, the extraoral surgical sites can be draped off, and the surgeon can enter the oral cavity to repair any intraoral communications. The poor tissue surrounding the communication must be excised or freshened prior to achieving secure, primary closure with a long-lasting suture material. Following soft tissue closure, the patient can be placed in MMF with wires or bands. The surgeon may now re-scrub and re-gown to decrease cross contamination of the extraoral wound with intraoral flora. Prior to placing the pre-bent reconstruction plate, it is highly recommended to reinforce the underside of the intraoral closure with a piece of supportive, viable tissue. The authors strongly recommend a 2 × 4 cm or 3 × 6 cm cryopreserved umbilical cord membrane, Stravix (Osiris Therapeutics, Inc., Columbia, MD, USA). Stravix is composed of the umbilical amnion and Wharton's jelly and retains the extracellular matrix, growth factors, and immuno-privileged endogenous neonatal mesenchymal stem cells, fibroblasts, and epithelial cells of the native tissue. Next, the articular eminence is osteotomized and a Biomet fossa prosthesis is placed and secured with one screw. With this in place, the pre-bent reconstruction plate with the temporary add-on condyle can be fixated. If the Biomet fossa aligns well over the condyle prosthesis, then the fossa is secured with a total of four screws. If the Biomet fossa position needs to be shifted because the condylar head is not articulating well against the fossa, it can be done easily by removing the single screw, shifting the fossa prosthesis, and restabilizing with four screws. After checking for a stable and reproducible occlusion, the wound is closed in typical layered fashion. In some cases, there is a paucity of soft tissue available for closure over the reconstruction plate. Radiation fibrosis dramatically affects the ability of the tissue to stretch and heal normally. If additional tissue is necessary to achieve primary closure at the submandibular incision, it may be necessary to elevate a pectoralis flap or even use a micorvascular soft tissue flap at this stage or during placement of the final prosthesis.

12.3.3 Healing Phase

Within one postoperative day, an infectious disease consultation is obtained and a PICC line is placed. The patient is started on a 6-week course of home-based IV antibiotics based on the culture report. Nutrition is delivered by PEG tube feeds and the patient is only allowed water by mouth. Oral hygiene is important, and many surgeons recommend chlorhexidine rinses, in addition to brushing, during this time.

Additional HBO dives are arranged, usually ten or more. During postoperative visits, examinations should include careful surveys of all incisions and the intraoral communication repair. Physical therapy may be initiated to assist patient in regaining jaw range of motion. Once complete healing of the intraoral wound is apparent, the PEG tube is discontinued and the patient may begin a soft diet. As the patient progresses with postoperative healing, a new maxillofacial CT scan is obtained to begin the planning for fabrication of a TMJ Concepts custom extended-ramus mandibular prosthesis and fossa component. The patient is now ready for Stage 2 surgery.

12.3.4 Stage 2: Placement of the Custom Extended-Ramus TMJ Prosthesis

Stage 2 surgery is directed toward explanting the intermediate hardware and fossa component after complete intraoral closure is obtained and replacing it with a TMJ Concepts custom extended-ramus mandibular prosthesis and fossa. Arch bars are placed at the start of the procedure to facilitate MMF. The preauricular and submandibular incisions are reopened, and the dissection is carried out to expose the existing hardware. Once the plate with connected condylar head is removed, the stock Biomet fossa component can be removed and replaced with the TMJ Concepts custom fossa component. With the fossa in place, the extended condylar component can be placed and fixated to the mandible. The occlusion is checked to ensure it is stable and reproducible. The patient is placed into MMF with elastics and all incisions are closed in layered fashion. This completes the entire ORNJ protocol; however as stated, not every patient makes it to the final surgery; some stop after Stage 1 surgery and some have Stage 1 reversed and are left with a "free-swinging" mandible. The following cases illustrate the ORNJ protocol in action and provide examples of the treatment decisions that sometimes have to be made.

12.4 Cases and Outcomes

We will highlight three patients in this section. These three cases will serve as an example of the different endpoints, which can be achieved through the staged protocol.

Case #1
A 53-year-old male was referred for consultation regarding a large area of exposed and necrotic bone. He was previously treated for metastatic adenoid cystic carcinoma of the right sublingual gland in 2005, which consisted of a suprahyoid neck dissection and removal of the right sublingual and submandibular salivary glands. He had recurrence of his cancer in 2012, which presented as a base of tongue mass and pulmonary nodules. In July of 2012, he received 6600 cGy of radiation to the head and neck. When initially referred, he had already received 40 HBO dives for treatment of the ORN. On initial exam he had a large area of exposed and necrotic

bone lingual to the lower right teeth #29–32 (Fig. 12.1a). The diagnosis was Stage 3 ORN, and he was taken to the OR for right hemi-mandibular resection with disarticulation of the condyle (Fig. 12.1b, c), repair of oral ORN communication, and placement of a pre-bent reconstruction plate with temporary add-on condyle to articulate against a stock Biomet fossa prosthesis (Fig. 12.1d). The patient had a

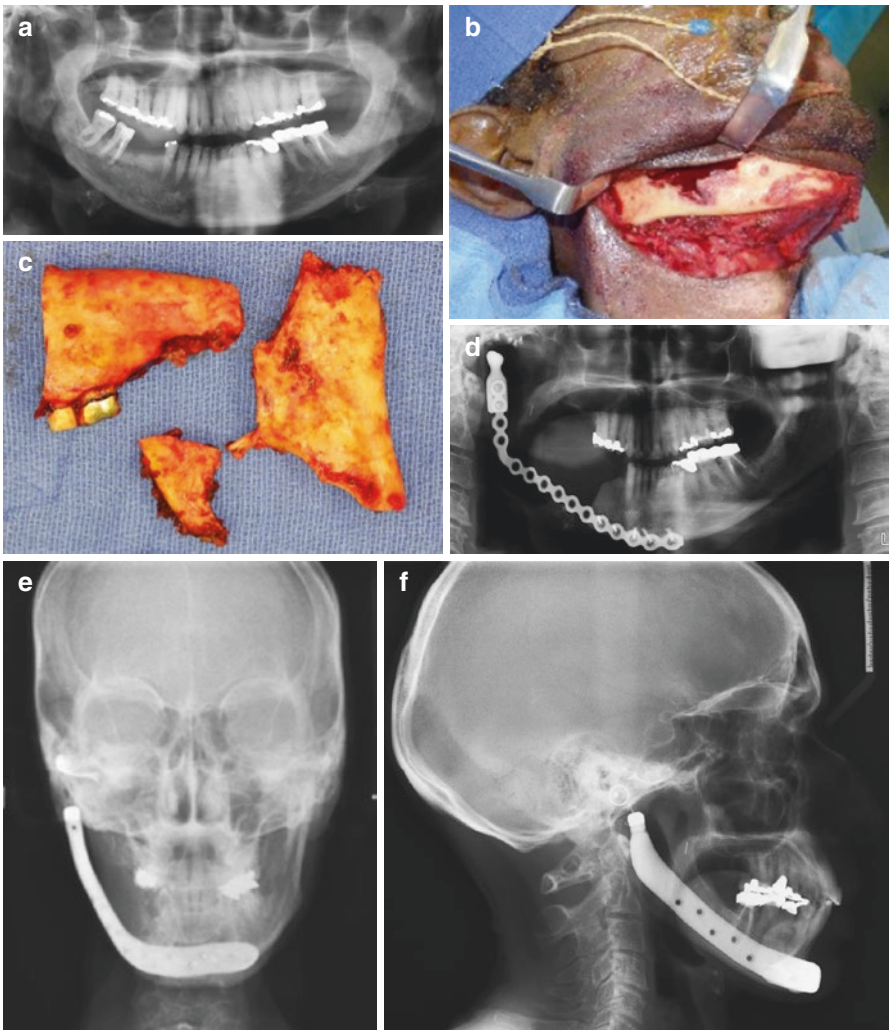

Fig. 12.1 (**a**) Preoperative panoramic radiograph demonstrating necrotic bone in the right mandible extending from tooth #29 posterior to #32. (**b**, **c**) Intraoperative photographs demonstrating right hemi-mandibular resection with disarticulation of the condyle. (**d**) Postoperative panoramic radiograph demonstrating immediate reconstruction with pre-bent reconstruction plate with temporary add-on condyle and Biomet fossa (not visible on X-ray due to polyethylene material and jaw position). Thirteen-month postoperative PA **cephalometric** radiograph (**e**) and lateral cephalometric radiograph (**f**) status post Stage 2 surgery

benign postoperative course and was ready for Stage 2 surgery. At that time a custom right-sided TMJ prosthesis was placed (Fig. 12.1e, f). After recovery the patient had a stable occlusion, with maximum opening of 25 mm.

Case #2

A 73-year-old man was referred due to 6 months of lower right quadrant pain and bleeding. He was treated for a T1N2bMo SCCA of the left tonsil 10 years prior. The treatment regimen consisted of tonsillectomy with left neck dissection followed by chemo/radiation. Radiation treatment consisted of a total dose of 6600 cGy. He was evaluated and was diagnosed with Stage 0 ORN and received 20 dives of HBO prior to having teeth 31 and 32 extracted with debridement of surrounding bone approximately 1 year following radiation therapy. He received an additional 20 dives of HBO therapy postoperatively. Unfortunately, the ORN quickly progressed and he developed a pathologic fracture at the site of the prior tooth extractions. Stage 3 ORNJ was diagnosed, and Stage 1 of the ORNJ protocol was done, including a right hemi-mandibular resection with disarticulation of the condyle, repair of oral ORN communication, and placement of a pre-bent reconstruction plate with temporary add-on condyle and a Biomet fossa. During the postoperative course, he developed a small intraoral plate exposure, which closed on its own with conservative wound care over 5 months. During his recovery and early planning of the Stage 2 surgery, the patient had multiple thromboembolic events (unrelated to his ORNJ surgery) leading to a cerebral vascular accident and worsening dementia. He was deemed too high of a risk to be placed under anesthesia and undergo the more definitive Stage 2 reconstruction. The pre-bent plate with temporary condylar component has remained in place, and the patient has acceptable functional and esthetic outcomes with it. If the pre-bent plate becomes compromised in the future, the decision to proceed to Stage 2 surgery may have to be made (Fig. 12.2).

Case #3

A 77-year-old male was referred for consultation regarding exposed bone in his lower right quadrant. The oncologic history included treatment of a T1N2bMo SCCA of the right retromolar trigone area. The treatment course consisted of excision of the tumor with a right selective neck dissection, followed by chemotherapy and radiation (total of 6600 cGY). The patient, who was edentulous, developed spontaneous exposure of the mandibular bone in the right retromolar area. He was sent for preoperative HBO, the exposed bone was debrided, closure was obtained, and postoperative HBO dives were completed. On subsequent visits, full mucosalization of the exposed bone was achieved in 6 weeks. Unfortunately, within 6 months the bone in the retromolar area became exposed again. Despite conservative management with antibiotics and chlorhexidine rinses, the area of exposed bone continued to enlarge. The patient was diagnosed with Stage 3 ORNJ, accepted into the ORNJ protocol, and underwent hemi-mandibular resection with disarticulation of the condyle, repair of oral ORN communication, and placement of pre-bent reconstruction plate with temporary add-on condyle component and Biomet fossa. Approximately 4 weeks postoperatively, a 1 cm skin breakdown along the

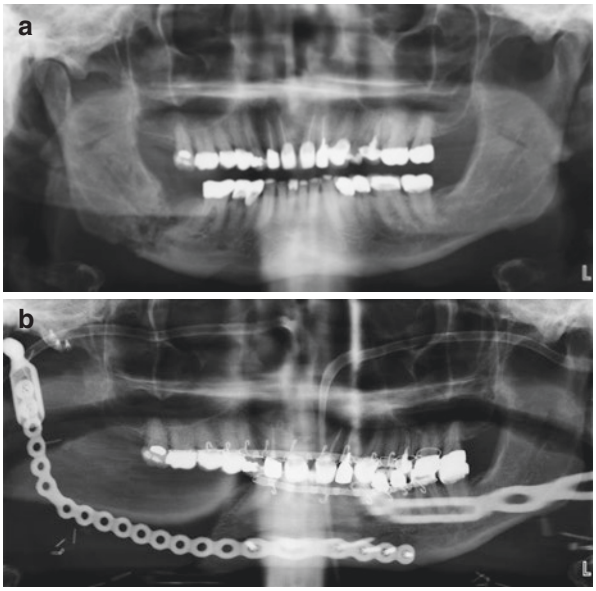

Fig. 12.2 (**a**) Preoperative panoramic radiograph demonstrating ORN Stage 3 and pathologic fracture of the right posterior mandible in July of 2014. (**b**) Postoperative panoramic radiograph status post Stage 1 surgery for resection of the right posterior mandible and immediate placement of pre-bent reconstruction plate with temporary add-on condyle and Biomet fossa. Patient was deemed high risk for Stage 2 surgery due to thromboembolic events leading to CVA; however patient has reported acceptable functional status and esthetics

submandibular incision occurred with scant serosanguinous fluid. Despite aggressive wound care, a draining fistula with plate exposure developed. It was the patient's desire to have the hardware removed and nothing else done to replace it. He was brought back to the OR for hardware removal and left to swing with no right-sided hardware. He had full healing of the wound postoperatively and remained functional despite not reconstructing the resected mandibular bone (Fig. 12.3).

12.5 Rationale

12.5.1 Clinical Justification for Staged Protocol

There are several reasons why a staged protocol benefits the patient with advanced ORNJ. Placing a definitive prosthesis into a chronically infected wound raises concern for future hardware failure, due to seeding of intraoral flora. A staged protocol allows for the healing of the intraoral communication over temporary hardware, while ensuring function and symmetry, without the need for a second site surgery as in a free flap. A definitive prosthesis can then be placed in a healthy and sterile environment.

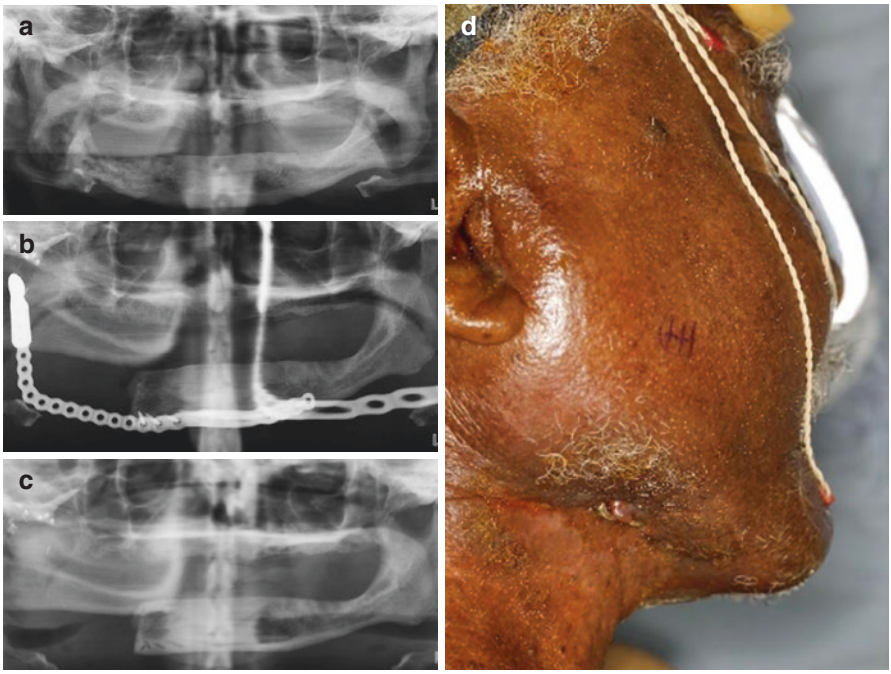

Fig. 12.3 (**a**) Preoperative panoramic radiograph demonstrating ORN of the right posterior mandible after extractions of teeth due to caries. (**b**) Postoperative radiograph status post Stage 1 surgery consisting of hemi-mandibular resection with disarticulation of the condyle, repair of oral ORN communication, placement of pre-bent reconstruction plate with temporary add-on condyle, and Biomet fossa. (**c**) Removal of hardware 4 weeks postoperatively due to skin breakdown. Patient remains functional without reconstruction of resected right mandible. (**d**) Demonstrating wound breakdown

Another factor that one cannot over look in this patient population is the multiple acute and chronic comorbidities that are likely to accompany them. Surgical complications in this population arise often, such as infection, wound breakdown, or systemic complications secondary to chronic cardiopulmonary and vascular pathology. As demonstrated by our three featured cases, a staged protocol allows for multiple endpoints when complications or systemic health problems present themselves.

12.5.2 Benefits of Custom Prosthesis Over Free Flap Reconstruction

In the staged protocol presented, although the final prosthesis is not obtained for at least 6 weeks to ensure that all soft tissue is healthy, both the temporary reconstruction with the condylar head/fossa components and the final prosthesis are designed to function as a complete temporomandibular joint unit. Both prostheses more

closely restore the premorbid state of the TMJ anatomical form and function than a fibula free flap. This allows for a better range of motion throughout the process. In this elderly and medically complex patient population, both types of prosthetic joints can be used as an acceptable possible endpoint in reconstruction in the setting of medical complications as well as allow for decreased OR time and shorter hospital stay, as demonstrated by Case 1 and Case 2.

Due to the nature of head and neck cancer, radiation therapy is almost always carried out, resulting in fibrosis of the neck and decreased vascularity of the site, making it a less suitable recipient site for a fibula free flap. The use of custom prosthetic joints in the final prosthesis eliminates the risk for donor site comorbidities along with decreased site breakdown and hardware failure due to the dependence of a bone-to-bone interface.

12.5.3 Adjuncts to Treatment

Along with the staged protocol benefits previously discussed, after a thorough medical assessment and discussion of risks and benefits with the patient, adjunctive therapies can easily be incorporable. Pentoxifylline and vitamin E can aid in a synergistic way for the preoperative healing of intraoral wounds, with or without HBO, as discussed in our protocol section. Supporting the closure of the intraoral wound is critical, and the protocol presented takes advantage of the healing and antimicrobial properties of cryopreserved placental tissue, which is placed just under the oral mucosal closure. The use of exciting new data is also emerging regarding mesenchymal stem cell therapy in aiding of mucocutaneous fistulas in patients with fistulizing Crohn's disease [25]. In this innovative technique, concentrated mesenchymal stem cells are derived from autologous adipose tissue and attached to a bioabsorbable matrix that can be surgically placed on the wound.

Although we have successfully avoided donor site in most of our patients, a history of radiation therapy compounded with multiple dissections through the neck predisposes some patients with an inadequate soft tissue profile required for primary closure, even though the prosthesis is always designed to lie medial to the original bone contour and employs a gentle curve at the recreated mandibular angle. In the event primary closure is not achievable, we have utilized pectoralis flaps to achieve cutaneous closure after placement of the final prosthesis. This technique can also be utilized to add soft tissue bulk on the lateral aspect of the prosthesis in patients where the final prosthetic contours can be visualized due to a thin tissue profile.

12.6 Conclusion

A novel staged treatment protocol is an excellent option to vascularized free flap for patients presenting with advanced ORN of the posterior mandible. This treatment approach represents comprehensive management for a medically complex patient

population while preserving an esthetic and functional outcome and reducing complications and morbidities commonly encountered in free flap surgery. The nature of the staged approach allows for multiple definitive endpoints for patients with advanced ORN.

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Pediatric Temporomandibular Joint Surgery

13

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Abstract

Pediatric temporomandibular joint (TMJ) deformities consist of congenital, developmental, and acquired abnormalities. This chapter will concentrate on pediatric TMJ surgery. It will begin with a description of growth and development of the TMJ. It will also discuss multiple treatment protocols for various pediatric TMJ abnormalities.

13.1 Introduction

Pediatric temporomandibular joint (TMJ) deformities consist of congenital, developmental, and acquired abnormalities. This chapter will concentrate on pediatric

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TMJ surgery. It will begin with a description of growth and development of the TMJ. It will also discuss multiple treatment protocols for various pediatric TMJ abnormalities.

13.2 Growth and Development of the Temporomandibular Joint

The mandible is derived from the first pharyngeal arch. At 4 weeks of prenatal development, neural crest cells travel ventrally to the mandibular and maxillary prominences. At 6 weeks, mandibular development takes shape [1]. At 41–45 days after conception, Meckel's cartilage, a non-ossifying template for the early mandible, forms [2]. The body and ramus of the mandible form as an ossification center for each half of the mandible which develops lateral to Meckel's cartilage and around the inferior alveolar nerve and artery from the bifurcation of the inferior alveolar nerve to the mental and incisive branches. At 7–8 weeks, the TMJ begins to form with condensation of the future condyle and the articular disc. At 9 weeks, masticatory muscle movement begins which leads to cavitation of the inferior joint [3]. At 11 weeks, the joint capsule forms. Between 10 and 14 weeks, secondary cartilages form and give rise to the coronoid process, mental protuberance, and condylar head [4]. The secondary process of the condylar head develops into the condylar head. It also forms the cartilaginous framework that will later develop into the condylar neck by endochondral ossification with the first endochondral bone deposition during the 14th week of gestation [5]. By 24 weeks, almost all of Meckel's cartilage is replaced by intermembranous bone and the sphenomandibular and sphenomalleolar ligaments develop from portions of the fibrous perichondrium associated with Meckel's cartilage [4]. Near birth, the secondary cartilage of the condyle is replaced with bone except for the upper end. This persists into adulthood [4]. Cartilage remains as an area for growth as well as articular cartilage. Fetal mastication produces a mechanical strain on the jaw, which allows for growth of the condyle and remodeling of mandibular woven bone to trabecular bone [6, 7].

In infancy, the TMJ is extremely unstable. The capsule provides some stability but it is a loose connection. The condyle is attached to the fossa with capsular and temporomandibular ligaments. The mandibular fossa is flat [8]. The condyle is connected in a straight position with the body of the mandible as there is very little ramus developed at this time. The coronoid process is larger than the condyle. Muscle attachments are similar to adult attachments [4].

In the first 3 years of life, there is a large portion of mandibular growth. The greatest change is in bicondylar width due to the lateral growth of the cranial base [9]. This width develops from the endochondral deposition at the symphysis and from growth of the condyles posteriorly and superiorly [10]. Nearly all of the

surfaces of the mandible grow and remodel [11]. The vertical length of the ramus increases as the condyles growth superiorly and posteriorly.

During early childhood, around age 5–6, the mandibular growth begins to parallel the growth of the midface. The vertical growth of the ramus follows the growth of the dentition. The anterior-posterior ramus growth increases and parallels growth of the middle cranial fossa and the pharynx. The length of the body increases with anterior resorption of the ramus and bony deposition on the posterior border of the ramus [12]. Bone deposition on the labial surface of the mandible has stopped.

By late childhood most of the mandibular growth is completed although the ramus can remodel to a more vertical position [4]. During growth from age 11 to 17, condylar height increases significantly [13]. By end of teenage years, normal TMJ and mandibular growth is complete.

13.3 Differences Between Adult and Pediatric Patients

When evaluating and treating pediatric patients, one must consider that there are significant differences from adults. Children are not just small adults; they vary greatly psychologically and physically. Understanding the psychological differences improves the patient's evaluation and surgical outcomes. The initial encounter includes discussing with the parents the child's behavior and personality. As children mature, their self-awareness improves, and they are able to participate in their own care. Assessment of the child's level of maturity, temperament, attachment to the parent and/or caregiver, and control of emotions is important. Personality differences in children include flexible, cautious, and active. Flexible children adapt easily, whereas a cautious child needs a parent to feel secure or will be unable to adapt to a new situation. Active and/or difficult children respond best to distraction. A simple understanding that children under the age of 5 cannot reason and respond with withdrawal or crying helps the practitioner better control a difficult situation.

Before any treatment, one must fully understand parental and/or caregiver support and education level. This helps with management of postoperative expectations and unforeseen complications. Unlike an adult patient who discusses their own history of present illness, in a pediatric patient, the majority of the history is told by the parent and/or caretaker. Family history can be extremely helpful in a young child in understanding potentially undiagnosed medical problems. In cases of nonsurgical TMJ interventions, postoperative results typically depend on dietary restrictions and physiotherapy. There must be a strong parent/caregiver support for children to comply with these instructions. In addition, there are multiple differences in anatomy and physiology between adult and pediatric patients. Differences in airway, pulmonary, and cardiovascular are important to understand (Table 13.1).

Table 13.1 Differences in pediatric anatomy and physiology

	Pediatric findings	Implication
Cardiovascular	Cardiac output depends on heart rate	Bradycardia is most lethal arrhythmia
Neural innervation	Sympathetic nervous system not fully developed	Parasympathetic nervous system has more control
Oropharynx	Larger tongue, possible larger tonsils, larger epiglottis	Airway is more prone to obstruction
Upper airway anatomy	Larynx is funnel shaped with narrowest area at cricoid cartilage	Influences endotracheal intubation
Trachea and chest wall	More compliant	Cannot easily maintain negative intrathoracic pressure resulting in less mechanical efficiency
Diaphragm	Inserts almost horizontally	Less contraction efficiency
Lungs	Less alveoli, compliant ribs	lower functional residual capacity
Kidneys	Decreased glomerular filtration rate	Decreased drug metabolism
Liver	immature	Altered drug metabolism
Thermoregulation	Greater surface area to body weight	More prone to hypothermia

13.4 Clinical Problems in the Pediatric TMJ

13.4.1 Congenital

Congenital TMJ deformities are present at birth. Appropriate timing for treatment of the TMJ deformity must be carefully considered since it will affect the growth and development of adjacent structures and of nonaffected parts of the face. Hemifacial microsomia (HFM), Treacher Collins syndrome (TCS), and bilateral craniofacial microsomia are some of the more common congenital TMJ deformities.

HFM occurs in one in every 3500–5600 children [14]. It has variable clinical findings and involves the structures of the first and second brachial arches. It is most commonly unilateral and involves the ear, mandible, orbit, cranial nerve VII, and/or facial soft tissues. The etiology was described by Poswillo utilizing an animal model [15]. A hematoma develops from the stapedial artery causing compression on the first and second pharyngeal arches. The size of the hematoma determines the severity of the deformity [16]. It is now believed that there is an interference of neural crest cell migration during embryologic development [17]. The most commonly used classification of HFM is the Kaban classification which focuses on the mandible (Table 13.2). The OMENS classification includes five components of HFM: orbit, mandible, ear, nerve, and soft tissue (Table 13.3).

Treatment planning involves the patient's clinical exam and craniofacial imaging (i.e., panoramic radiograph, lateral cephalogram, posterior-anterior cephalogram).

Table 13.2 Skeletal defects of hemifacial microsomia

Type	Morphology
I	Ramus/condyle are of normal morphology but smaller in size
IIA	Abnormal morphology of ramus/condyle but normal position in temporal bone
IIB	Hypoplastic, malformed, displaced ramus/condyle
III	Complete absence of mandibular ramus and TMJ

Modified from Pediatric Oral and Maxillofacial Surgery by Leonard Kaban, Saunders, 2004

Table 13.3 OMENS classificationsystem[a]

Orbit	Facial nerve[b]
00 Normal orbital size, position	N0 No facial nerve involvement
01 Abnormal orbital size	N1 Upper facial nerve involvement (temporal or zygomatic branches)
02 Abnormal orbital position	N2 Lower facial nerve involvement (buccal, mandibular, or cervical)
03 Abnormal orbital size, position	N3 All branches affected
Mandible	Soft tissue
M0 Normal	50 No obvious tissue or muscle deficiency
M0 Small mandible and glenoid fossa with short ramus	51 Minimal soft tissue or muscle deficiency
M2 Ramus short and abnormally shaped	52 Moderate soft tissue or muscle deficiency
Subdivisions A ans B are based on relative positions of the condyle and temporomandibular joint (TMJ)	53 Serve soft tissue or muscle deficiency
2A Glenoid fossa in anatomically acceptable position	
2B TMJ inferiorly, medially, and anteriorly displaced, with severely hypoplastic condyle	
M3 Complete absence of ramus, glenoid fossa, and TMJ	
Ear	
E0 Normal ear	
E1 Minor hypoplasia and cupping with all structures present	
E2 Absence of external auditory canal with variable hypoplasia of concha	
E3 Malpositioned lobule with absent auricle, lobular remnant usually inferior anteriorly displaced	

Adapted from Vento AR, LaBrie RA, Mulliken JB. The O.M.E.N.S. classification of hemifacial microsomia. Cleft Palate Craniofac J. 1991 Jan;28(1):68–76. Need permission to reprint

[a]OMENS indicates the following: *0* orbital asymmetry, *M* mandible hypoplasia, *E* auricular deformity, *N* facial nerve involvement, and *S* soft tissue deficiency

[b]Other involved nerves were analyzed, i.e., the trigeminal nerve and hypoglossal nerve

In the past, these were the only images available and were the ones used to classify the deformity. Now, maxillofacial computed tomography (CT) with three-dimensional (3D) reconstruction or cone beam CT (CBCT) is the preferred imaging for patients with HFM. This allows for better evaluation of the defect and performs virtual surgical planning.

Treatment for HFM is complex and involves multidisciplinary collaboration. Treatment includes repair of hard and soft tissue abnormalities. Posnick proposed that the degree of mandibular asymmetry remains constant throughout growth; therefore, treatment should begin at the completion of growth [18]. On the other hand, Kaban and others have proposed that the affected side does not grow at the same rate as the unaffected side and the facial asymmetry worsens over time. He advises that early treatment should take place to reduce deformities in the maxilla, improve mandibular growth, and decrease facial asymmetries [19]. For purposes of this chapter, only treatment of the mandible will be discussed.

Treatments for type 1 and type 2A are essentially the same. Early surgical correction takes place in the mixed dentition phase. The goal is to bring the chin point to the midline of the face and to create an open bite on the affected side. This involves rotation, elongation, and advancement of the affected side of the mandible. This is done through ramus surgery such as a bilateral sagittal split osteotomy (BSSO) or distraction osteogenesis (DO) followed by orthodontic therapy with a bite-opening splint that maintains the open bite for 3–6 months. The orthodontist sequentially reduces the open bite splint during 18–24 months to allow for eruption of the permanent maxillary dentition [20, 21]. For surgeons that prefer delayed surgical treatment, treatment is performed once growth is complete. Treatment is similar to orthognathic surgery for facial asymmetry consisting of orthodontics and orthognathic surgery to rotate, elongate, and advance the affected side of the mandible, Lefort I osteotomy to level the cant and steep occlusal plane, and possible genioplasty for correction of chin asymmetry.

Treatments for type 2B and type 3 vary slightly. Early surgical correction involves treatment in the mixed dentition phase. Treatment options include costochondral graft (CCG) and calvarial or iliac crest grafts to construct the ramus, condyle, and glenoid fossa prior to the eruption of the permanent dentition. This is then followed by orthodontic therapy with a bite-opening splint as described above. Many would propose DO or osteotomy for repositioning the proximal segment for type 2B and costochondral graft to reconstruct the ramus-condyle unit (RCU) for type 3 HFM. However, patients may still require additional orthognathic surgery once growth is complete. Recently, reconstruction with custom-made total joint prosthesis (TJR) has been performed with successful results especially in patients who have a facial asymmetry due to relapse or progressive growth [22, 23]. Delayed surgical correction is performed after growth is complete. It involves an orthodontist to level, align, and decompensate the teeth in preparation for orthognathic surgery. The patient then undergoes orthognathic surgery with sagittal split osteotomy on the unaffected side, a Lefort I osteotomy, reconstruction of the affected side with a CCG, or a custom TJR and possibly a genioplasty.

TCS and bilateral craniofacial microsomia are bilateral first and second pharyngeal arch defects [24, 25]. They include hypoplastic TMJs, short mandibular

Table 13.4 Features of Treacher Collins syndrome

Region	Features
Cranio-orbito-zygomatic region	Hypoplasia of lateral orbital rims, malar hypoplasia, decreased upper face width, hypoplasitic zygomas, antimongoloid slant of the palpebral fissure, colobomata and hypoplasia of lower lids and lateral canthi
Maxillomandibular region	Retrusive chin and lower jaw, convex facial profile, prominent nasal dorsum, class II malocclusion, dental anomalies, variable TMJ effects, cleft palate with variable cleft lip, choanal atresia
External auditory canal, middle and inner ear structures, audiologic findings	Hypoplastic middle ear, conductive hearing loss, abnormalities of external auditory canals
Facial soft tissues	Variable; affects external ears, eyelid, preauricular cheek skin, temporal fossa

rami, and decreased posterior face height. The TMJs are typically in the correct position but are often too shallow to be stable with a longer ramus. TCS occurs in 1:25,000–50,000 live births [26] and is autosomal dominant [27]. The mutation is in the TCOF1 gene [28] (Table 13.4). Those with bilateral craniofacial microsomia have similar skeletal deformities to those with TCS, but they do not have the characteristic findings around the eyelids that are seen in TCS. Bilateral craniofacial microsomia is typically an isolated event without a known inheritance pattern [25].

Maxillofacial CT with 3D reconstruction is the standard imaging needed for treatment planning and diagnosis. Treatment can be performed while the patient is still growing or after growth is complete. Sometimes DO is performed at an early age for airway improvements in order to avoid a tracheostomy or to decanulate a patient. These patients require a Lefort I or II osteotomy at a later date. Early treatment can be performed in the mixed dentition phase; if there is adequate ramus, then DO is performed. If the ramus is inadequate, then reconstruction with CCG is performed. If reconstruction takes place after cessation of skeletal growth, then orthognathic surgery and reconstruction of CRU via bone graft or TJR take place concomitantly.

13.4.2 Acquired

Acquired abnormalities of the TMJ consist of overdevelopment, resorption, and underdevelopment. Overdevelopment is an overgrowth of the condyle leading to facial asymmetry. It includes condylar hyperplasia (CH) and tumors. Resorption is caused by various forms of arthritis or other reactive diseases. Underdevelopment is often caused by trauma or radiation.

Wolford described a classification for CH with varying treatments. CH type 1 is an accelerated and prolonged growth of the growth center of the condyle. CH type 1A is the more common bilateral form and CH type 1B is the unilateral form. CH type 2 is the most common forms of benign unilateral tumors of the TMJ. CH type 2A is osteochondromas and CH type 2B refers to osteomas. CH type 3 is any

Table 13.5 Classification of condylar hyperplasia

Type	Condylar hyperplasia
Type 1	Accelerated and prolonged growth of condyle
Type 1A	Bilateral
Type 1B	Unilateral
Type 2	Benign unilateral tumors of TMJ
Type 2A	Osteochondromas
Type 2B	Osteomas
Type 3	Any pathology that causes condyle enlargement
Type 3A	Benign tumors
Type 3B	Malignant tumors

Modified from Wolford LM, Movahed R, Perez DE. A classification system for conditions causing condylar hyperplasia. J Oral Maxillofac Surg. 2014 Mar;72(3):567–95

pathology that causes condylar enlargement. CH type 3A is other benign tumors. CH type 3B is malignant tumors (Table 13.5).

CH type 1 involves growth of the condyle's growth center causing mandibular prognathism and facial deformity. If it is unilateral, then it causes facial asymmetry. The growth usually starts with the pubertal growth spurt and stops when the patient reaches their mid-20s. The chin will be deviated away from the side with accelerated growth. Bilateral cases sometimes have a family history [29]. Hormonal etiology is implicated because this accelerated growth starts during puberty although other factors such as trauma, infection, genetics, etc. have been proposed as well. The condyle is of normal shape; it is just larger in size.

CH type 1 is most commonly evaluated through repeat lateral cephalometric radiographs. Growth is slow so this tends to be a better way to monitor if growth has ceased. Dental models and clinical exam help with diagnosis if growth is still active. Additional imaging includes a panorex and/or a cone beam CT. Technetium-99m bone scan may not be of value as the growth is slow and may have about the same amount of isotope uptake when compared to the normal joint.

Treatment is based on if there is active condylar growth or if it has ceased. If the growth has stopped, then conventional orthognathic surgery can be performed to correct the malocclusion and facial asymmetry. If the jaw is still growing in cases where the patient is a teenager or in his or her early 20s, then a high condylectomy can be performed [30, 31]. A standard preauricular approach is used to remove 5–6 mm of the superior condylar surface on the side that is affected. If needed, the disc is repositioned over the condyle. Finally, the facial asymmetry and malocclusion are corrected with orthognathic surgery. A minimally invasive endoscopic technique for high condylectomy has been described by Troulis and Kaban [32]. Lefort I and BSSO are then necessary to correct the facial asymmetry and malocclusion. Growth on the unaffected side should be complete prior to performing a high condylotomy because growth will stop on the side that the condylotomy is performed on. If performed too early, then the unaffected side will continue to grow although the affected side stopped. This has potential to lead to a facial asymmetry. Another option is to wait until growth has stopped on the affected side and then perform orthognathic surgery. The malocclusion and facial asymmetry will become worse over time, which can compromise the final functional and esthetic result.

CH type 2 includes osteochondroma and osteoma. They can occur at any age and are commonly seen in adult patients [33]. Osteochondroma is a pseudotumor that is a metaplasia of the condylar periosteum, whereas osteoma is a benign TMJ tumor that is a continuous formation of cortical and cancellous bone. Histologically, osteochondromas have cartilage and bone in the condylar head, whereas osteomas may have normal bone. Unilateral enlargement of the mandible is seen, which leads to facial asymmetry, including chin point deviation to the unaffected side and a posterior open bite on the affected side. There is elongation of the ramus and body on the affected side. Imaging includes panorex and lateral cephalogram and/or maxillofacial CT. Treatment consists of a low condylectomy on the affected side, inferior border ostectomy on the affected side, reshaping of the condylar neck to the new condyle, repositioning the articular disc over the new condyle, and orthognathic surgery to correct the malocclusion and facial asymmetry. Other treatment options include condylectomy with TJR, CCG, iliac crest bone graft, or a microvascular free flap.

CH type 3 includes benign and malignant tumors of the TMJ. Tumors of the TMJ are extremely rare in the pediatric population, but they include giant cell lesions, myxomas, fibro-osseous lesions, and Langerhans cell histiocytosis. The history consists of a slow-growing mass, progressive limitation in mouth opening, or deviation of the jaw to one side. Panorex is the most common initial imaging. A maxillofacial CT reveals a radiolucent or a mixed radiolucent-radiopaque lesion of the mandible. Management of the tumors is based on the specific treatment recommendations for each particular type of tumor. If resection of the tumor is necessary, then a preauricular approach is used. In a growing child, reconstruction includes a CCG for reconstruction of the ramus. A retromandibular or submandibular approach may be needed for reconstruction.

Condylar resorption or condylysis is a progressive, bilateral, and symmetric resorption of the condyles. It is self-limiting once resorption reaches the sigmoid notch. Clinical exam reveals retrognathia, progressive anterior open bite, and decreased posterior facial height. In most patients, the etiology is unknown (i.e., idiopathic), but there can be an association with juvenile idiopathic arthritis (JIA), steroid use, trauma, and orthognathic surgery. Idiopathic condylar resorption (ICR) is most commonly seen in females aged 15–35 particularly in teenage girls during pubertal growth spurts. They often have preexisting TMJ pain or dysfunction as well as a high mandibular plan angle [34–37].

Panorex and serial lateral cephalometric radiographs or cone beam CT (CBCT) are initial radiographs. A technetium-99m bone scan may be useful to determine if condylysis is still active. If condylysis is no longer active, then orthognathic surgery versus condylectomy and reconstruction with TJR or CCG can be performed. If condylysis is active, then treatment with nonsurgical intervention directed at managing TMJ symptoms includes splint therapy, NSAIDs, and soft diet until 2 years without active condylysis. If disease is progressive and TMJ symptoms are persistent, then condylectomy and reconstruction with TJR or CCG and orthognathic surgery should take place.

JIA is a heterogeneous group of conditions. It includes all forms of arthritis of unknown etiology lasting for at least 6 weeks and with onset before the age of 16 years [38, 39]. It is more common in females than males. TMJ involvement can be unilateral or bilateral. Patients occasionally present with pain, limited mandibular movement, and preauricular pain which are common [40]. Anterior open bite and

retrognathia with loss of posterior facial height and class II malocclusion are potential sequelae. Ankylosis can be seen in late stages. Imaging often includes panorex, lateral cephalogram, CBCT, or maxillofacial CT. MRI with contrast is used to evaluate synovitis, condylar cortical bone erosion, disc thinning, and loss of ramus height [40, 41]. Diagnosis includes clinical, physical, and radiographic findings. Treatment involves disease management with rheumatologist via medical management. When TMJ is involved, NSAIDs, soft diet, physical therapy, behavior modifications, and medical management take place. Arthroscopy with lysis and lavage may also help with decreasing intra-articular inflammation [42]. TMJ and orthognathic surgery as described above should take place once disease is controlled [43]. Further details regarding management of TMJ in a child with JIA are beyond the scope of this chapter and can be found in another chapter in this book dedicated to this subject.

Intracapsular and/or subcondylar fractures are the most common mandible fractures in children. Ankylosis is the most severe complication. This can occur after prolonged maxillomandibular fixation (MMF). Therefore, MMF should not last longer than 10 days. Unilateral ankylosis and failure to grow on that side will lead to facial asymmetry. Bilateral ankylosis will lead to retrognathia and open bite. Ankylosis is treated with total excision of the ankylotic segment, coronoidectomy to the affected side, removal of the opposite coronoid if needed to increase range of motion (ROM), and reconstruction with CCG/TJR and rigid fixation. Sometimes, the surgeon creates an intentional open bite on the affected side (maintained by orthodontic appliance for 3–6 months) to level the occlusion. This is followed by early mobilization and aggressive physical therapy. Even in growing children, TJR is occasionally accepted with intention of replacement of the prosthesis once growth is complete [44, 45]. Occasionally, orthognathic surgery and TJR take place concomitantly in order to restore facial symmetry and function.

13.5 Conclusions

Treatment of pediatric TMJ abnormalities is complex. Management of these abnormalities depends on the patient's stage of growth and development. It is important to consider the child's developmental stage and involve the child in his/her care. The ultimate goal of surgical reconstruction is to restore the mandible and TMJ to a functional state while maintaining facial symmetry.

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Treatment of Mandibular Deformities Related to TMD by Vertical Ramus Distraction Osteogenesis

14

Thomas Klit Pedersen and Sven Erik Nørholt

Abstract

To re-establish the dental occlusion, mandibular position and facial appearance, different orthognathic surgical options may be considered. These options include mandibular or bimaxillary surgery or alloplastic joint reconstruction, possibly combined with maxillary surgery. In cases with moderate deformity and minor malocclusion, an acceptable result can be achieved with orthodontic compensatory treatment combined with chin augmentation. Finally, vertical distraction osteogenesis (DO) with or without maxillary surgery may be considered and will be the focus of this chapter.

14.1 Introduction

Inflammation of the temporomandibular joint (TMJ) often gives rise to condylar deformities and structural changes of other joint components such as the disc and fossa. Impaired dentofacial development may therefore occur in growing individuals [1] (Fig. 14.1), and in adults a change in mandibular position may occur over time (Fig. 14.2) [2, 3].

TMJ inflammation can be the result of a local chronic joint disorder and traumatic loading (disc dislocation and degeneration, compression, i.e. idiopathic condylar resorption) [4] or involvement of the TMJ in general arthritic diseases

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Fig. 14.1 Development of micrognathia from the age of 13–17 in a female with JIA

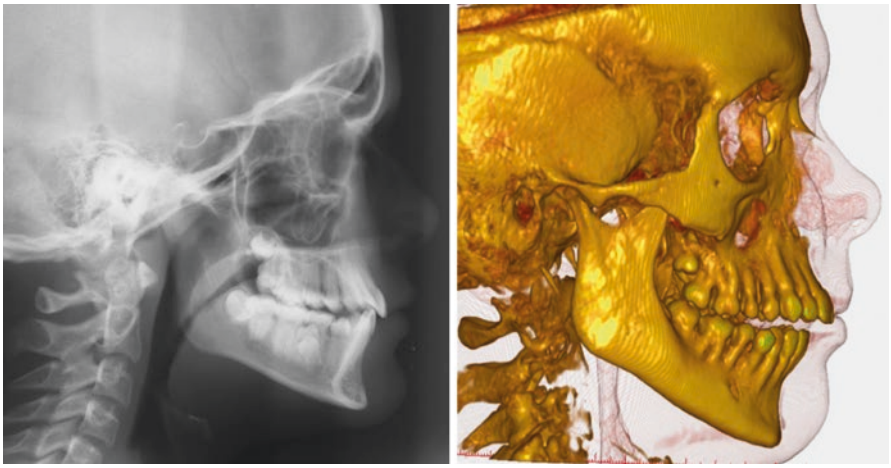

Fig. 14.2 Change of mandibular position in an adult patient with TMJ arthritis

(rheumatoid arthritis, juvenile idiopathic arthritis) [5, 6]. Some of the patients suffering from these diseases need reconstruction of the mandibular position to enhance occlusion, function and aesthetics.

In growing individuals, TMJ inflammation may hamper the growth and development of the condyle and fossa. In most cases, this will result in a short condylar height and decreased ramus length [5, 7, 8]. This affects the posterior face height; and when growth has ceased, the end result is a retrognathic mandible, a steep occlusal plane and various dentoalveolar compensatory or dysplastic changes (Fig. 14.1). An open bite with contact only on the posterior teeth characterises the dental occlusion.

In nongrowing individuals, progressive condylar degradation can be followed by a change in mandibular position. The mandible rotates clockwise, and, like the growth disturbance described above, an open bite develops, although without the characteristic changes in mandibular morphology (Fig. 14.2).

To re-establish the dental occlusion, mandibular position and facial appearance, different orthognathic surgical options may be considered. These options include mandibular or bimaxillary surgery or alloplastic joint reconstruction, possibly combined with maxillary surgery. In cases with moderate deformity and minor malocclusion, an acceptable result can be achieved with orthodontic compensatory treatment combined with chin augmentation. Finally, vertical distraction osteogenesis (DO) with or without maxillary surgery may be considered.

14.2 Condylar Stability

Two main concerns, regarding stability, influence the final treatment of the occlusion and mandibular deformity: 1) the stability of the joint, especially the condyle, and 2) the stability of the skeletal reconstruction. In addition, soft tissue constriction related to limited growth might play a role as well.

Condylar fibrocartilage has a pronounced ability to undergo adaptive remodelling [9] also holding characteristics of pathology. The homeostatic balance between normal condylar growth and adaptive remodelling on the one hand and pathological bone resorption on the other hand is most likely vulnerable to inflammation and repetitive microtrauma. There is a risk of condylar remodelling due to joint compression in orthognathic surgery [9, 10], specifically in high-angle cases (Fig. 14.3). It remains unknown whether this risk is increased in compromised condyles, but the preoperative volume is a prognostic factor for postoperative reduction in condylar volume and for skeletal relapse [10]. The process of condylar deformation may be expected to evolve in the course of several years, and no significant methods for assessment of condylar stability have so far been described. Luder [11] found that

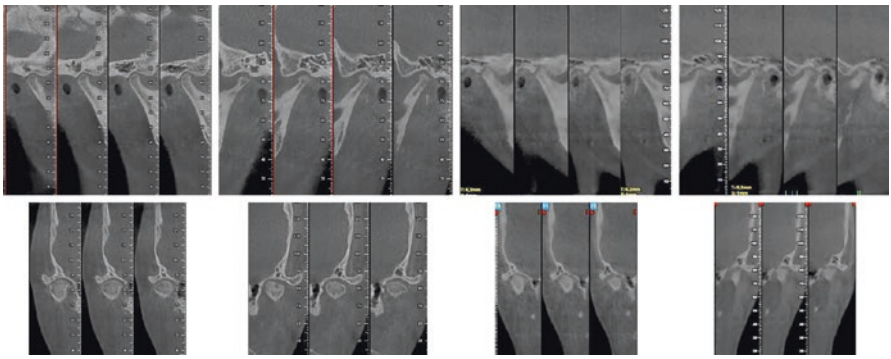

Fig. 14.3 Condylar degenerative changes over a 9-month period related to peroperative compression of the joint in orthognathic surgery

gradual transition of the condylar tissue (i.e. hypertrophic cartilage and fibrocartilage) was completed at the age of 30 years and reported a probably lifelong remodelling, indicating a late maturation and continuous adaptation ability. Formation of a subchondral bone plate is part of this transition. These findings confirm a clinical impression of joint remodelling in young adults. TMJ pathology may be hypothesised to disturb maturation, resulting in joint instability which, in turn, compromises the long-term results of the orthognathic surgery undertaken to solve skeletal anomalies originally caused by the TMJ pathology.

14.3 Assessing Condylar Stability

No evidence-based recommendations are available for assessment of the condyle in regard to joint stability or final maturation. Schiffman et al. [12] demonstrated soft and hard TMJ tissue stability to be the most common finding in disc displacement and degenerative joint diseases which is not supporting the classic perception of a progressive development of these two TMJ diagnoses. Furthermore, change towards a less complicated diagnosis was seen in the long term. This seems to indicate adaptive remodelling beyond the age of growth cessation. Acute impacts (such as compression) to the TMJ and highly inflammatory conditions (such as rheumatic diseases) may not develop in the same way. Condylar changes can be seen with compression of the condyle into the fossa, changing the condylar morphology and the mandibular position [10, 13]. Figure 14.4 shows a patient with progressing degenerative condyles causing a change in mandibular position. In JIA patients, alterations in condylar morphology and dentofacial appearance seem to change between 9 and 12 years of age [14, 15].

In the context of condylar maturation and pathogenesis, stability is an issue that must be considered when orthognathic surgery is planned in patients needing reconstruction of deformities caused by TMJ degeneration. Correct diagnosis of the TMJ pathology plays an important role. Age will also influence the course of condylar deformity. According to the diagnostic criteria (DC) [16], two main diagnoses with several subdivisions seem relevant: *TMJ disorders* and *TMJ diseases*. Joint disorders comprise disc displacements and other mobility disorders, while joint diseases include systemic arthritis, osteoarthritis and idiopathic condylar resorption. Condylar deformities caused by TMJ disorders seem to be relatively stable and they may possibly improve [12], whereas TMJ diseases may be prone to further deterioration, depending on general disease activity.

There are several suggestions for assessment of joint stability, although only little is known about the sensitivity and specificity of these methods. Clinical examination, radiographic imaging and observation over time are by far the most commonly used methods.

Using DC is an option that enjoys a relatively high sensitivity and specificity for correct diagnosis of TMD [16]. For children and adolescents with juvenile idiopathic arthritis, the TMJaw (the former euroTMjoint) recommendations for clinical examination and TMJ diagnose [17] are a clinical standard for following this specific group

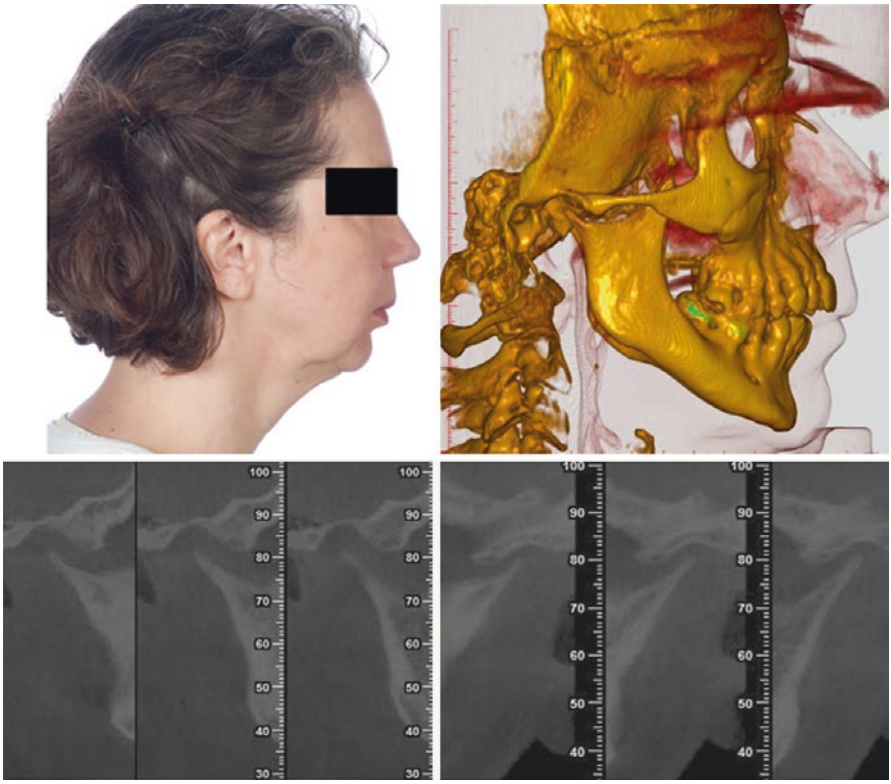

Fig. 14.4 54-year old female with rheumatoid arthritis and bilateral involvement of the TMJ

of diseases. To monitor occlusion, an occlusal splint can be used in which small dental impressions can disclose changes in the mandibular position over time.

Imaging technique includes cone beam computerised tomography (CBCT), magnetic resonance imaging (MRI) and scintigraphy. The use of CBCT makes it possible to quantify condylar dimensions [18] and follow condylar hard tissue changes, but soft tissue inflammation and an increase in active remodelling processes cannot be traced with CBCT. CBCT was found to be superior to other radiographic modalities [19]. MRI can be used in order to reveal soft tissue, bone and bone marrow oedema [20]. In arthritis patients, active inflammation can be revealed by using a contrast-enhanced imaging technique [6]. Scintigraphy [21] has been suggested as a feasible method for assessment of condylar stability, although the sensitivity and specificity of the method remain unknown for condylar degradation. Scintigraphy is a common method for determination of condylar hyperplasia and is rarely used to assess condylar hypoplasia.

Clinicians have different views on how and for long condylar changes should be monitored before treatment institution, and they recommend using various imaging techniques; however, for orthognathic surgical treatment of TMJ-induced dentofacial deformity, a treatment protocol specifying precisely when to commence treatment is

mandatory. A correct TMJ diagnosis is important for determining condylar stability. The patient should therefore be followed for a period of time with a standardised clinical examination method that includes evaluation of any occlusion change. Furthermore, cortical bone integrity and stability should be confirmed on CBCT. In case of general arthritis disease, contrast-enhanced MRI should be used to establish TMJ inactivity; and remission should be defined as a 2-year period without symptoms, without clinical signs of arthritis in general and without medication. The decision to initiate orthognathic surgery should not be taken in periods with symptoms and general disease activity unless it is a part of an overall and long-term treatment plan.

Keeping in mind the uncertainty regarding condylar stability and the relatively long period of observation required, it may be relevant to consider an alternative treatment approach dividing the surgical procedure into less extensive parts. Immediate aesthetic issues could be solved without delay and remaining growth be used to improve dentoalveolar development. Minor changes in jaw relations due to condylar adaptation can then be adjusted in a final surgical/orthodontic procedure. DO offer a possibility to obtain the required lengthening of bone; and DO could be followed by an observation period before final adjustment of the occlusion is made.

14.4 Distraction Osteogenesis

Distraction osteogenesis (DO) of the mandible was first described by McCarthy et al. in 1992 [22]. Since then, a considerable number of studies have reported that mandibular DO (MDO) may be an alternative or a supplement to conventional osteotomies.

The DO treatment option may be considered in patients diagnosed with diseases involving mandibular growth impairment. Growth impairment of the jaws may lead to malocclusion, impaired chewing capacity, unequal loading of the joints and muscles, insufficient lip function, poor aesthetics and psychosocial malfunction [23]. The treatment objective is elongation of the mandibular bone corresponding to the lacking growth and thereby normalisation of jaw morphology and improvement of the function of the masticatory system. DO may be performed at all ages, as it is based on the basic principles of bone healing with callus formation, which takes place regardless of age [24, 25]. In general, the procedure is faster and has fewer side effects and complications in young than in older individuals [26, 27]. Furthermore, if DO is applied in growing individuals, growth can be exploited to improve dentoalveolar development.

The literature describes that DO for mandibular ramus distraction has been used on the following indications:

- Ankylosis of the TMJ [28, 29]
- Craniofacial microsomia [30, 31]
- Condylar fracture sequelae [32, 33]
- Juvenile idiopathic arthritis (JIA) sequelae [34–36]
- Growth impairment caused by temporomandibular joint disorders (TMD) [37]
- Idiopathic condylar resorption [38]

This chapter will consider only situations in which the growth abnormality stems from an acquired degenerative pathological condition of the TMJ. Therefore, congenital malformations, such as craniofacial microsomia, and deformities related to fractures or ankylosis are not described. Significant relapse at long-term follow-up of DO treatment in children with craniofacial microsomia has been reported [39, 40]. Early DO in these patients should therefore be considered only if there is a high psychosocial demand for treatment.

The acquired pathological conditions of the TMJ can cause a decrease of the total condyle-ramus height, and the resulting mandibular deformity will be an asymmetry with variance in rotation around the *z*- and *y*-axis in unilateral involvement of the joints, or micrognathia, if both joints are involved. The treatment objective is to restore the posterior face height by elongation of the mandibular ramus. This can be achieved by conventional orthognathic surgery or with DO, which are fundamentally different treatment principles. Conventional orthognathic surgical treatment aims to establish stable dental occlusion. In contrast, DO, aiming to correct skeletal abnormality, will bring the teeth out of occlusion as a consequence of ramus elongation and the following intermaxillary separation. Subsequently, occlusion will be corrected at the dental level, through orthopaedic vertical dentoalveolar development and/or orthodontics or through surgical adjustment of the position of the maxilla. The orthopaedic dentoalveolar option can be effectuated when growth is still present, and the occlusion can be developed using an appropriate orthopaedic/functional appliance (Fig. 14.5).

The choice of treatment methods is usually based on the presentation of the deformity, on the need of the patient and on the experience and preferences of the

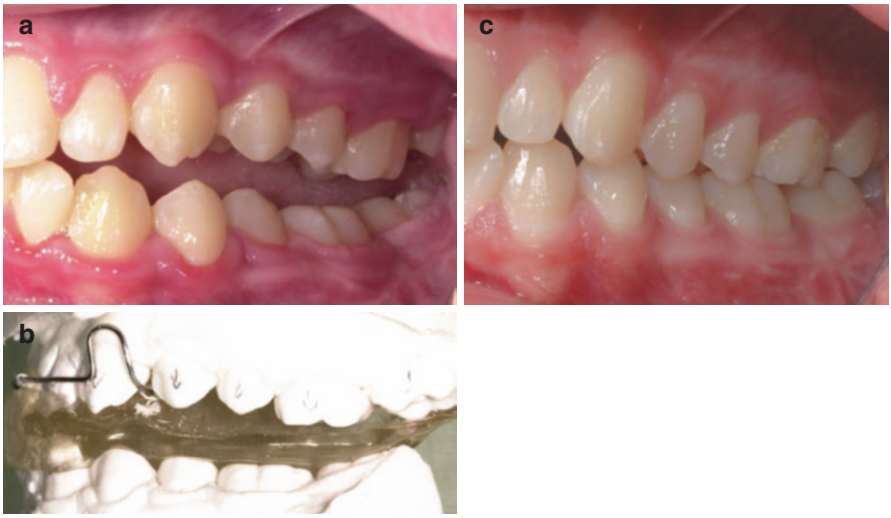

Fig. 14.5 Distraction osteogenesis of left mandibular ramus in a 13-year-old boy with previous JIA in the left TMJ. (**a**) Open bite immediately after DO, (**b**) functional appliance allowing eruption of upper premolars and molars, (**c**) occlusion at age 18; no fixed appliances have been used

surgeon and orthodontist. Some basic features differ between MDO and conventional orthognathic surgery. An MDO treatment always requires two surgical interventions: one for inserting the distraction device and one for removing the device after the consolidation period. Conventional orthognathic surgery is done in one surgical procedure with movement of the bony segments and fixation using osteosynthesis material. The soft tissues surrounding the mandible are acutely stretched in the conventional procedure, whereas the gradual process of distraction, usually 1 mm per day, allows for a corresponding elongation of the soft tissue matrix accommodating the above-mentioned concern of soft tissue limitations. This is believed to be a factor of importance for large elongations. A retention period of 3–6 months following the phase of active distraction is always required. The duration of retention depends on the amount of distraction, the patient's age and any general conditions affecting bone healing.

The surgical trauma associated with DO is relatively small, as only minimal mobilisation of the bone and soft tissues is required. Accordingly, most patients are discharged on the day of surgery or the following morning. Removal of the distraction device can cause a short period of extensive swelling due to the increased vascularity of the newly formed tissues.

The aim of DO treatment is to relieve or prevent the issues related to function and appearance according to the patient's needs. In order to minimise the burden of treatment, it is important to make an individual long-term treatment plan in case of early abnormal development.

An important factor to consider when planning a surgical treatment is the chance of obtaining a result that fulfils the patient's expectations and that may be reached with a predictable and stable result. It is imperative to share the considerations with the family to ensure informed consent about the goal and any risks.

14.5 Treatment Planning: Timing of Surgery

An optimal treatment outcome is most easily obtained if involvement of the TMJs is detected and necessary treatment initiated as early as possible. Cases of JIA with arthritic TMJ changes require pharmacological interventions, including systemic and local medications aiming to relieve symptoms and decrease arthritis activity. Correct medication can limit TMJ degradation although some level of growth deviation will develop. Caution should be taken regarding intraarticular steroids due to their possible negative influence on mandibular growth [41, 42].

Orthopaedic treatment with a functional appliance to support normal growth is the first treatment option, and it may be used to correct or minimize jaw deformity depending on the activity level, severity of the arthritic condition and deformity of the TMJs. Still, it should be noticed that the individual's growth pattern and genotype influences his or her response to orthopaedic treatment. If, however, surgical treatment appears to be indicated, the timing of the intervention should be considered, which could be in infancy, early and late adolescence or after growth has halted, depending on the extent of both skeletal and soft tissue growth abnormality.

It is essential to outline a treatment plan where the different elements do not counteract each other. For instance, significant dentoalveolar compensations should not be undertaken if they would require later decompensations.

The local and general disease activities are important factors as is the need for medication for the joint disease.

For the definitive treatment, mandibular growth should have concluded, and any TMD or arthritic activity in the TMJs should be controlled in order to achieve stable results after orthognathic surgery [43] as described above.

14.6 Planning Direction of Distraction: Vector Calculation

In monodirectional distraction for mandibular ramus elongation, the vector of distraction is important for the position of the mandible after the distraction and thereby for the final result. The most preferential mandibular position for the succeeding treatment can be achieved by adjusting the vector. It is important to understand that some inaccuracy in the post-distraction mandibular position will always be present; however, a usable jaw relation can be achieved by thorough planning. It should also be recognised that deviating growth continues and a certain amount of relapse of the distance obtained will be a challenge at the next treatment level and for the orthopaedic support of normalised eruption of teeth and dentoalveolar development.

The challenge in relation to the mandible is its functional features, i.e. its ability to move. Ramus elongation will change the movement pattern, and because of the increasing distance between the upper and lower dental arch, autorotation of the mandible is possible, although limited. Thereby, the mandible will be more anteriorly placed, which is a desired position in cases of mandibular growth disturbances/displacement caused by TMJ pathology. It is necessary to distinguish between uni- and bilateral vertical ramus elongation.

Unilateral distraction: In asymmetric cases where the ramus is shorter on one side, the first step is to determine the difference between the molar and mandibular gonion level in the short and normal side. The distraction-related rotation around the *z*-axis will increase the distance from lower to upper incisors (Fig. 14.6). This distance needs to be estimated which can be done on a posterior-anterior cephalogram or, preferably, using CBCT. CBCT allows more precise location of particular landmarks and less distortion of the image than the cephalogram. A difference in canting at the molar level and the gonion level can be identified, and a decision has to be made as to whether the cant in the occlusal plane or in the mandibular basis is the main target for horizontal alignment. However, a similar cant is found in most patients resulting in a sufficient aligning of both the occlusal plane and the mandibular basis.

When a decision, as to the distance needed for establishing a horizontal occlusal plane, has been made, lateral tracing of the short side can be prepared. A CBCT is preferred in order to depict the particular side. Furthermore, the condyle on the ipsilateral side—representing the point of *z*-axis rotation for the mandible—can be established more adequately on the CBCT. On the lateral tracing, the

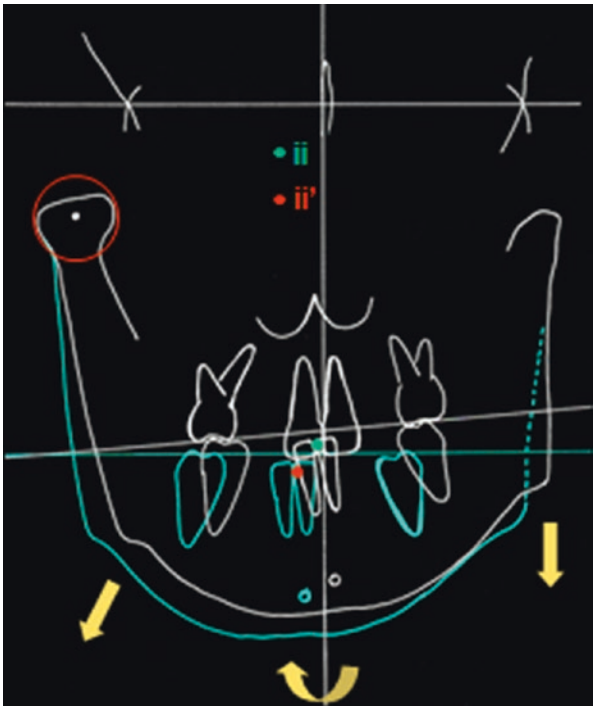

Fig. 14.6 *z*-axis rotation and incisal displacement with unilateral vertical ramus elongation. Calculation of vector, 1. step

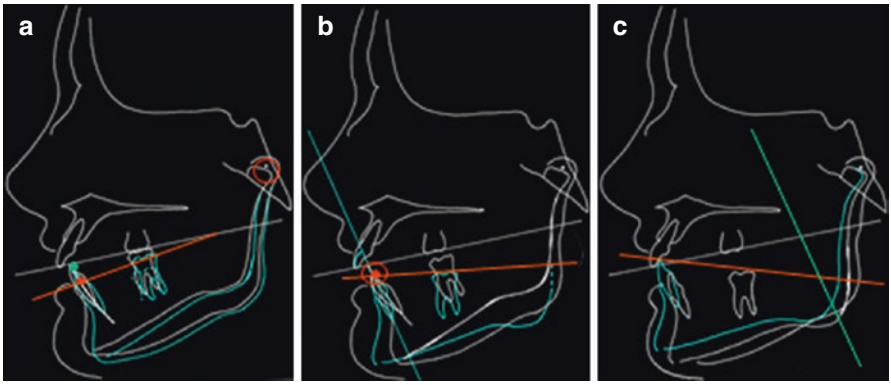

Fig. 14.7 Rotation sequence of the mandible for finding direction of the vector for distraction. Calculation of vector 2 step

mandible is rotated with the centre in the condyle bringing the incisors down to the distance from the upper incisors found on the coronal view in the previous estimation of the horizontal occlusal plane (Fig. 14.7a). The mandible is now rotated downward posteriorly to the position where the distance between the

upper and lower molar indicates a horizontal occlusal plane with the lower mandibular borders approximately at the same level (Fig. 14.7b). The centre of rotation is the incisal edge. The initial vector is found connecting the two incisal positions, i.e. the initial position and the position found after incisal movement by mandibular autorotation (Fig. 14.7c). The initial vector can be related as an angle to the occlusal plane. By mandibular autorotation, the initial vector will bring the incisor back to the original vertical position. If the patient has a horizontal overjet to correct, a horizontal anteriorly directed vector has to be added to the initial vector. The size and direction of the horizontal vector are found by connecting the lower incisal edge with the upper incisal palatal tuberculum. The sum of the two vectors gives the resultant vector. The more anteriorly incisal movement needed will open the angle between the resultant vector and the occlusal plane. It has to be noted that with large anterior incisal movement, the increase in ramus height is reduced; it is important to balance the direction of movement to the individual's need. See also Pedersen and Norholt [44].

Bilateral distraction: In case of bilateral TMJ pathology, a short ramus can be present in both sides. Although asymmetry in ramus length may be present, bilateral ramus distraction is simpler than unilateral ramus distraction. A lateral tracing is prepared, and the mandible/occlusal plane is translated forward and downward (Fig. 14.8). The preferred incisal position is controlled by mandibular autorotation. If the chin deviates from the midline, the vector is adjusted, i.e. the angle to the occlusal plane is opened on the side towards which the chin deviates. The effect of forward mandibular movement with a more open vector angle in relation to the occlusal plane also applies for bilateral distraction. In general, the more open the

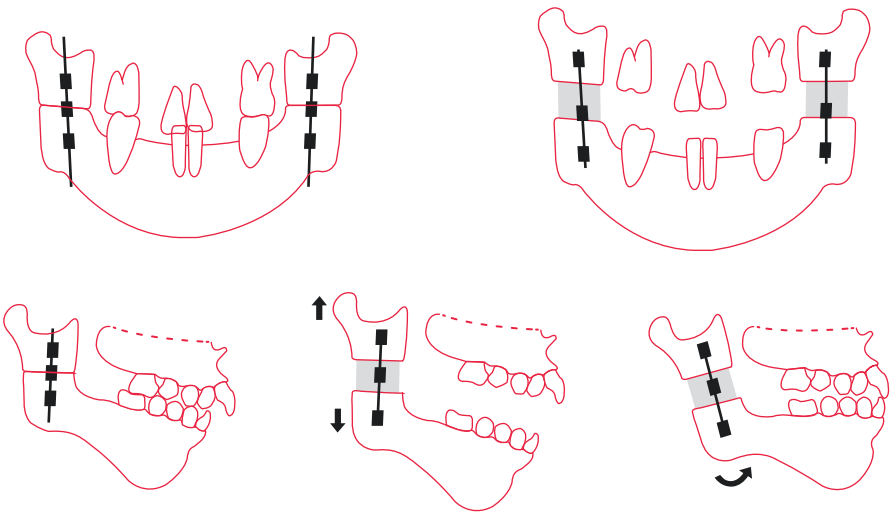

Fig. 14.8 Mandibular bilateral distraction with mandibular autorotation

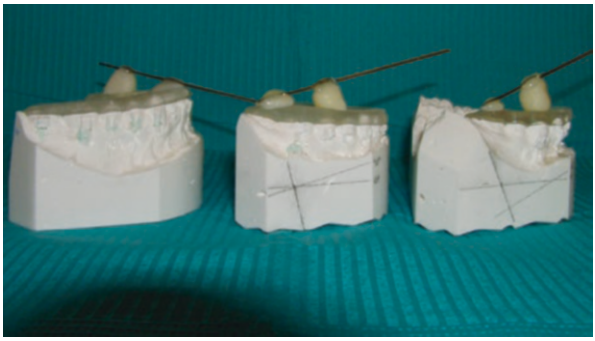

Fig. 14.9 Three different distraction indicator wires attached to a splint

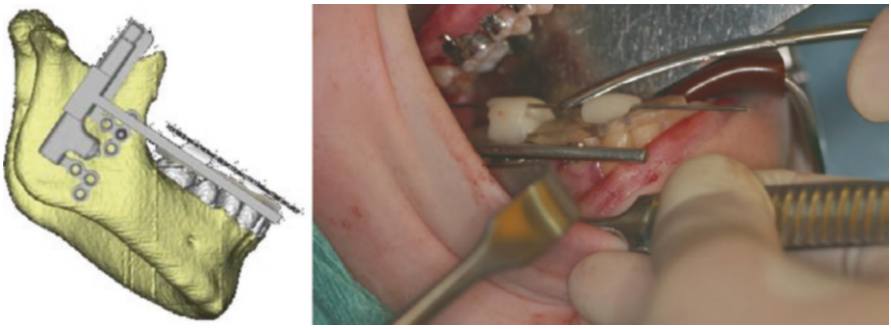

Fig. 14.10 Securing the vector for DO. (**a**) Schematic drawing illustration fixation of DO device with one screw which allows rotation for alignment of the indicator rod and the wire on the occlusal splint, (**b**) peroperative view of the aligned rod and wire

angle to the occlusal plane, the more forward movement of the anterior mandible (pogonion).

A distraction indicator wire is attached on an occlusal splint on the lower dental arch indicating the angle to the occlusal plane (Fig. 14.9). The indicator wire will serve as a guide for placing the distraction device in the correct position (Fig. 14.10).

14.7 Surgical Technique

MDO was originally performed by use of external distraction devices, which allowed for a long path of distraction and adjustment of the device during treatment. However, the penetration of pins through the skin causes scar formation, and carrying an external device for 4–6 months is a substantial psychosocial load for the patient. Reliable internal distraction devices placed directly on bone have

subsequently been developed, and these devices have become the devices of choice for most maxillofacial surgeons.

To obtain a predictable result of DO, a calculation of the vector of distraction should be performed, as previously described. The surgical technique of vertical ramus DO with internal devices includes an intraoral incision facing the anterior border of the ascending ramus followed by exposure of the entire lateral surface of the ramus with the patient in general anaesthesia. Sufficient space is created by bluntly stretching the soft tissue. The distraction device is applied on the lateral surface of the ramus and through a trocar entrance fixed loosely with a cortical screw. An indicator rod is fixed perpendicularly to the distraction device, the surgical guide is placed on the teeth, and the correct vector of distraction is ensured by rotating the distraction device around the one screw until the rod and the indicating wire attached to the splint are parallel (Fig. 14.10). A second screw is inserted to secure the position of the distraction device. The remaining screw holes are drilled, and the distraction device is removed to allow for osteotomy of the ramus by use of a piezoelectric device. The lingual periosteum is kept attached to the bone and the fracture completed. Free mobility across the osteotomy is mandatory. The distraction device is reinserted and fixated in the predrilled screw holes. The device is activated to ensure movement without bony adherences of the lingual cortex, and the wounds are sutured. After 4–7 days, the distraction process is initiated by activations of 1 mm per day until the planned bone elongation is obtained. During the entire activation period, a supporting occlusal splint should be used in order to keep the occlusal load on the dentition, while minimising pressure on the joint and distraction area. The splint is worn full-time and is adjusted several times in the active period. A final adjustment is made when the activation period is completed and the consolidation period starts. A minimum consolidation period of 3 months should pass before the devices are removed. The treatment protocol varies with the patient's age. The principles used at various stages are described in the following.

14.8 DO in Preadolescence Combined with Orthopaedics

The surgical procedure of DO is relatively gentle and can be performed at all ages. Thus, if the disorder of TMJ pathology and growth disturbance is identified at a young age and the condition of the TMJ is stable, it is possible to undertake early elongation of the mandibular ramus and thereby "catch up" with the insufficient growth. Early intervention is indicated if the severity of growth restriction does not allow for correction solely with orthopaedic measures. The DO procedure is followed by an orthopaedic treatment to support the position of the mandible and secure the development of a normal occlusion (Fig. 14.5). A valid evaluation of the patient's growth stage is important because sufficient dentoalveolar growth is required after DO. In unilateral distractions, there is still remaining growth in the healthy side, and overcorrection by the DO procedure is therefore recommended. If

DO is performed before growth has ceased, further growth and development can be normalised owing to the continuous growth in the dentoalveolar area [44]. Orthodontic treatment may be required for final occlusal settling. Early surgical treatment with DO is indicated in two categories of patients with impaired growth of the mandibular ramus: (1) where it is expected that bone lengthening followed by orthodontic and orthopaedic treatment may suffice and no further surgery is required and (2) in patients where the severity of the deformity is expected to require repeated surgery and early improvement of the facial morphology is desired.

14.9 DO in Preadolescence Combined with Later Orthognathic Surgery

In patients with unilateral involvement, early DO is rarely indicated unless it is expected that no further surgery is required. However, if micrognathia develops as a consequence of both TMJs being restricted in growth, the deficiency is likely to require definite surgery when growth has ended. Nevertheless, early elongation of the mandibular rami using DO is an option to obtain functional improvement and improved aesthetics at a young age. Later, orthopaedic and orthodontic treatment will have to be undertaken to maintain the position of the mandible, stimulate further growth and establish good occlusion. It must be anticipated that a second surgical treatment may be indicated at a later stage. However, it will be less extensive than if no primary treatment had been done.

14.10 DO in Adolescence Combined with Orthodontics and Orthopaedics

For patients in late adolescence in whom orthopaedic treatment turns out to be insufficient, DO followed by orthodontic adjustment may be an option. Treatment can be finalised by orthodontics provided that the malocclusion arising after completion of DO is mainly of dentoalveolar origin (Fig. 14.11). If a skeletal component is present, the option described in the following section is usually chosen.

14.11 DO in Adolescents or Adults Combined with Le Fort 1 and/or Genioplasty

If the mandibular position is corrected by DO, the remaining maxillary deviation usually requires surgical correction to ensure stable occlusion. Maxillary osteotomy can be used to correct deviations in all three dimensions, and it is planned to be performed either at the surgical procedure during which the distraction device is removed or at a later stage (Fig. 14.12). Additionally, the chin projection is often compromised in bilateral cases and can be improved by a chin augmentation when removing the distraction devices.

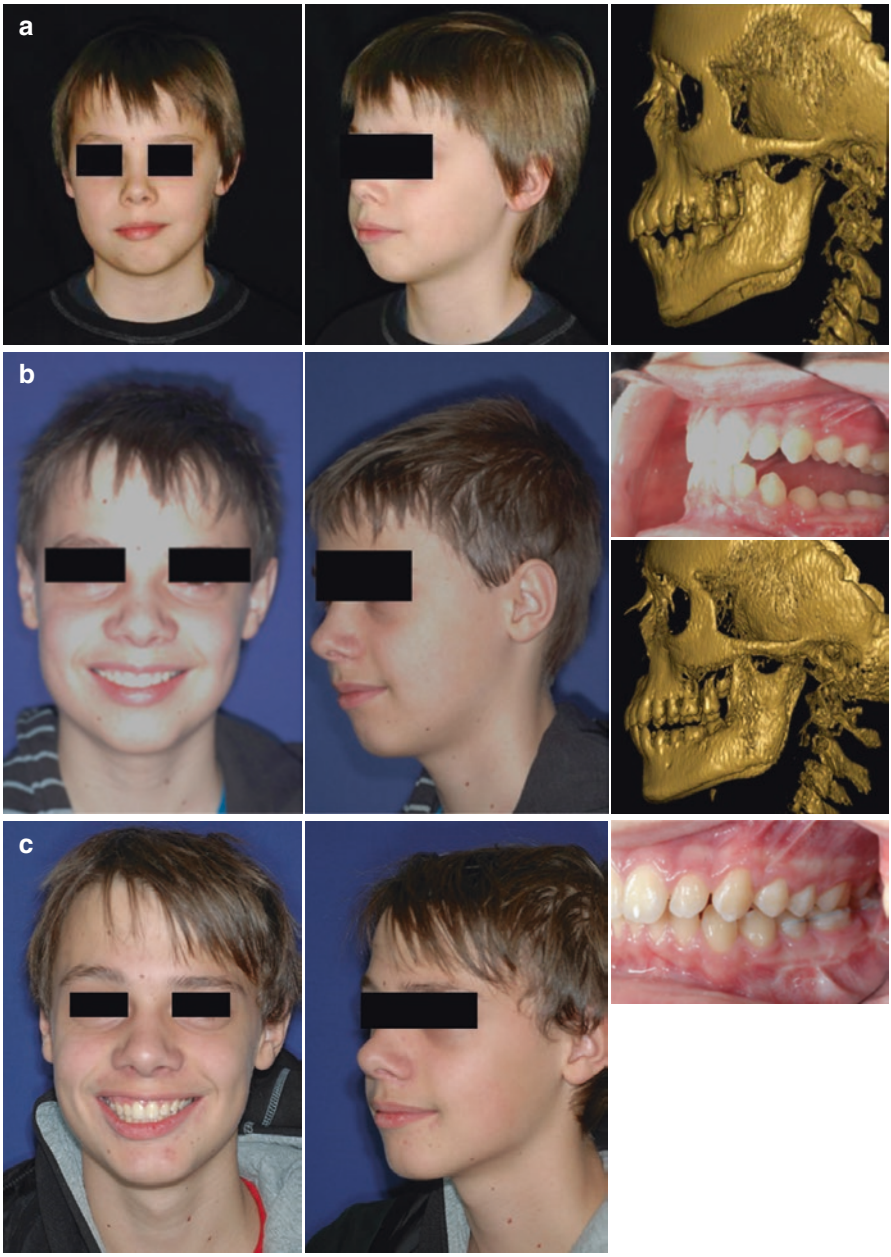

Fig. 14.11 (**a**) A 12-year-old boy with previous JIA in the left TMJ. Asymmetry of mandible. (**b**) Situation 6 months after DO of left ramus (15 mm) at the age of 14. (**c**) Appearance and occlusion 1½ year after DO. No fixed orthodontic appliances have been used

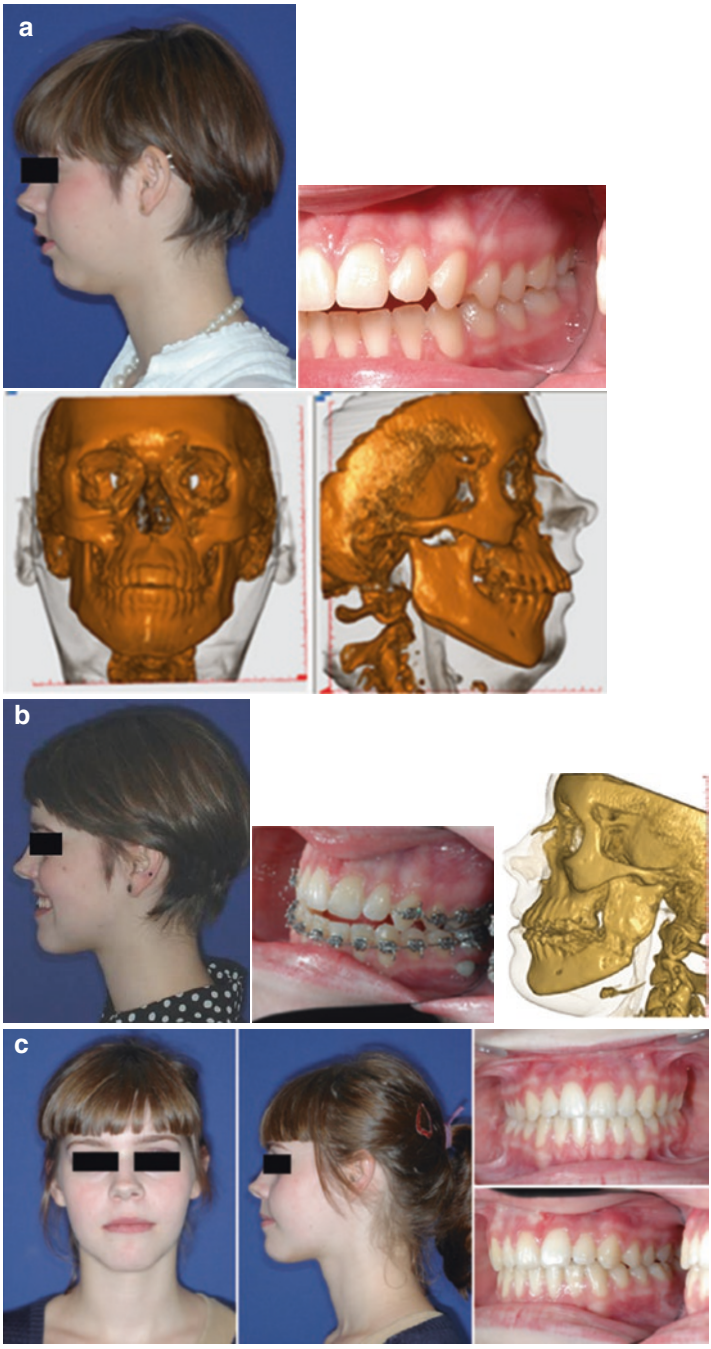

Fig. 14.12 (**a**) Female 17 years with previous JIA. Bilateral involvement of TMJ. (**b**) Clinical situation 2 months after DO. CBCT after 6 months. (**c**) 18 months after DO and 6 months after Le Fort 1 osteotomy

14.12 Stability, Risks and Complications

Patients with sequelae related to degenerative diseases of the TMJ may have an increased risk of relapse and joint symptoms following jaw surgery. Relapse from orthognathic surgery is known to be more frequent in these patients (Fig. 14.3) than in patients with normal, healthy joints, and it should therefore be considered if it would be safer to divide the treatment of severe malformations into several smaller and more predictable procedures, e.g. treatment with DO. Relapse after mandibular osteotomy in JIA patients has been reported to be 0–8 mm [43]. This may be caused by continuous arthritic activity in the TMJs or by the tendency to relapse after orthognathic surgery in general [45, 46]. Relapse is mainly due to two factors: Firstly, extensive surgical movements of the bone segments in patients with micrognathia may challenge the soft tissue limits, resulting in partial reversion to the former morphology. Secondly, instability of the TMJ, i.e. the condyle, can result in further mandibular displacement leading to recurrence of the sagittal and vertical malformations. DO will also result in histogenesis of the soft tissue and thereby improve soft tissue extension.

Patient satisfaction is very high after advancement of the chin by genioplasty, both with and without bilateral sagittal split osteotomy (BSSO) [43]; and 15 out of 16 patients reported that their surgery had a positive impact on their lives. The complication rate is usually low, but neurosensory disturbance of the mental nerves was reported as the most uncomfortable complication after surgery. Following mandibular DO, permanent neurosensory impairment was seen in 1.5% in a series of 131 patients [46], and a review comparing BSSO and MDO reported impairment in 2.9% of DO patients compared with 27.8% of patients following BSSO [47].

The effect of DO on the TMJ has been evaluated histologically in animal experimental studies of arthritic joints. In these studies, no increase in inflammation was observed [48]. In clinical follow-up of patients treated with vertical ramus DO, mild reactions from the TMJ were frequently found, but the number of severe complications related to the TMJ was low; temporary pain and sound from the joints were reported in approximately 40% of all patients, whereas degenerative changes occurred in 1.5% of the patients [46]. In a group of patients with JIA and unilateral TMJ involvement treated with DO, a temporary decrease in mandibular mobility was observed, but at long-term follow-up, the initial mobility was regained [34]. The anterior rotational mandibular movement during the DO occasionally causes the coronoid process to move in a cranial direction. This can result in interference with the zygomatic body or arch during mandibular movement. This problem is usually solved by reduction osteotomy of the coronoid process at the time the distraction device is removed.

14.13 Conclusion

Although only a small group of patients with TMJ pathological sequelae will need orthognathic surgical correction, it must be acknowledged that their orofacial function is severely reduced. Surgical treatment is challenging in patients with

compromised TMJs due to the specific limitations and the risk of relapse associated with their primary disease. It is therefore recommendable to design individual treatment plans that take into account disease activity, joint stability, risk of relapse and treatment burden. Additionally, dividing procedures into smaller and more predictable steps should be considered. Research in this field should focus on the efficacy, risk and stability of the treatment regime chosen.

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Part IV

The Future of Temporomandibular Joint Surgery and Training the Next Generation

Bioengineered Constructs of the Ramus/Condyle Unit

15

Sidney B. Eisig, Michael Forman, and Gordana Vunjak-Novakovic

Abstract

One of the most challenging reconstructions in maxillofacial surgery is that involving the condyle and ramus. Common reconstructive techniques involve either autogenous bone grafting such as costochondral rib grafting, a sliding posterior ramus border osteotomy, microvascular free fibula graft, or alloplastic reconstruction involving either stock or custom total joint replacement. None of these techniques specifically address the articular disc and some address only bone and not soft tissue. Bioengineering, which uses cells, molecules, chemistry, and scaffolds with engineering principles, is now providing novel solutions to complex biological problems.

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15.1 Introduction

In the United States alone, temporomandibular joint (TMJ) disorders (TMDs) are reported to affect close to ten million Americans annually. TMJ disorders requiring reconstruction of the ramus/condyle unit (RCU) can be the result of genetic disorders such as hemifacial microsomia and Treacher Collins syndrome; inflammatory disorders resulting in chondromalacia, arthritis, and condylar resorption; and acquired defects secondary to trauma, infection, failed surgery, and neoplasms. The underlying pathology, the anatomic defect, and the effect on function will dictate whether nonsurgical or surgical treatment is required. One of the most challenging reconstructions in maxillofacial surgery is that involving the condyle and ramus. Common reconstructive techniques involve either autogenous bone grafting such as costochondral rib grafting, a sliding posterior ramus border osteotomy, microvascular free fibula graft, or alloplastic reconstruction involving either stock or custom total joint replacement. None of these techniques specifically address the articular disc and some address only bone and not soft tissue. Bioengineering, which uses cells, molecules, chemistry, and scaffolds with engineering principles, is now providing novel solutions to complex biological problems.

15.2 Anatomy and Function

A brief review of the anatomy and function (although presented elsewhere in the text) is essential to understand the challenges inherent in designing an engineered graft that precisely replicates the defect. The temporomandibular joint is one of the most intricate functional joints in the human body. It is a ginglymoarthrodial joint, with both the ability for hinging movement (*ginglymoid*) in one plane and at the same time gliding movement (*arthrodial*) in another plane. Adding to its functional and reconstruction complexity is that it is the only joint in the body in which movement of one joint is always synchronous with the contralateral joint. Interestingly, unlike most other human joints that are composed of hyaline cartilage, the TMJ's articulating zone is made of dense fibrous connective tissue and fibrocartilage. The only other regions of the body that have similar fibrocartilage is the meniscus of the knee and annulus fibrosis of intervertebral discs. The articular surfaces of both the temporal bone and condyle are lined with the fibrous connective tissue. The head of the condyle is composed of four distinct layers—the most superficial is the *articular zone* composed of dense fibrous connective tissue; the next is the *proliferative zone*, which is mostly cellular and reparative and housing the stem cell niche; the third layer is the *fibrocartilaginous zone* providing support and resistance; and the deepest zone is the c*alcified cartilage zone*, comprised of chondrocytes and chrondroblasts [1].

The condyle is separated from the roof of the glenoid fossa of the squamous portion of the temporal bone by a thin articular disc, thereby creating two joint spaces. The articular disc functionally serves as a non-ossified bone and is composed of

dense fibrous connective tissue [1]. The disc enables the joint to do its complicated movements and also contributes to the reconstructive challenge of this anatomic structure. The articular surface of the condylar head abuts the thinnest and most central portion of the disc. The disc is attached via the main three functional ligaments of the TMJ, the capsular ligament, collateral ligaments, and temporomandibular ligament, and it maintains its position circumferentially around the entire condyle. Endothelial cells producing synovial fluid line the superior and inferior joint spaces—hence the TMJ is also a synovial joint.

Lastly, it is important to understand the muscle attachments in this area. The superior lateral pterygoid inserts on the articular capsule, disc, and neck of condyle. The inferior lateral pterygoid inserts primarily onto the neck of the condyle. Currently, muscle attachments are not addressed with any of the reconstruction options following condylectomy.

The normal range of motion of the mandible includes rotation within the inferior joint space to approximately 25 mm and then translation within the superior joint space to approximately 40–45 mm of opening. As the condyle slides anteriorly and posteriorly, moving in and out of the fossa, the articular disc rotates around the attachments of the discal collateral ligaments to maintain its position. Lateral and protrusive excursions through contraction of the lateral pterygoid muscles also occur. Movement should be smooth without any joint noises. At the end of the range of motion, the condyle should rest under the articular eminence with the biconcave portion of the disc sitting between the two. During function the loose synovium provides nutrition and lubrication to the articulating surfaces. It is the intimate and intricate anatomic relationship of the articular disc to the mandibular condyle via the main supportive ligaments in addition to the external pterygoid attachments that are vital to healthy and normal TMJ function.

15.3 Current Treatment Modalities

While **autogenous** reconstruction is the current gold standard, it is almost impossible to recreate the precise three-dimensional geometric shape, structure, and supporting tissues that are being replaced. Autogenous reconstruction also requires additional surgical sites to harvest tissues and carries the risk of donor site morbidity. There is still no gold standard for replacement of the disc, but options include dermis fat graft, auricular cartilage, or rotating a temporalis fascia or temporalis muscle flap to line the joint and separate the new condyle from the glenoid fossa roof [2]. Further, the literature supports that disc resection without replacement has predictable long-term success [2]. Previous attempts to use alloplasts such as silastic sheets or Teflon-proplast were dismal failures [2–4].

Alloplastic reconstruction is very technique sensitive, which will result in no excursive movements off of the ipsilateral side, and although failure rate is low, an infection of the joint would require its removal resulting in a significant postoperative deformity [5].

Bioengineering solutions such as the injection of growth and repair factors to serve as homing agents, the direct injection of stem cells to permit repair of diseased tissue, and the combination of scaffolds and stem cells engineered to precisely reconstruct the anatomic defect will play an increasingly important role in repair and regeneration. Recent advances in bioengineering employing stem cell technologies have brought us closer to an autologous graft (derived from recipient cells ± scaffold) that precisely reconstructs the anatomy of the bone and articulating cartilaginous surfaces. Bioengineered constructs would also limit donor site morbidity and decrease the length of stay; both of which would improve patient care and potentially decrease cost of care.

Osteochondral grafts to replace articulating surfaces like the RCU have an increased degree of complexity. We will explore here the components required for tissue engineering and its impact for reconstructive oral and maxillofacial surgery. Successful bioengineering would allow reconstructive surgeons to design scaffolds for each patient and their specific defect being treated (Fig. 15.1). We will discuss the process required for bioengineering a RCU including scaffold selection and fabrication, cell selection, seeding of scaffold with cells (±growth factors), viable tissue growth, surgical implantation into chosen animal model, and postimplantation evaluation of remodeling and breakdown (Table 15.1).

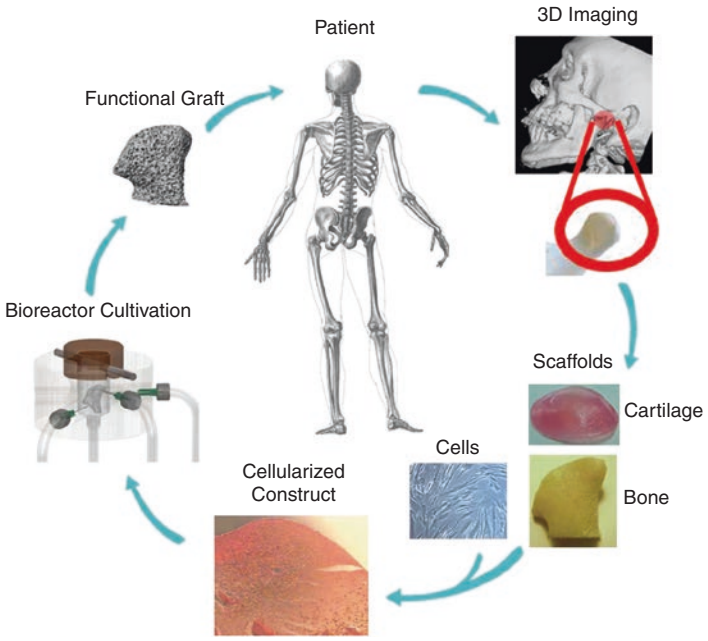


Fig. 15.1 Engineering of cartilage/bone grafts. The process begins with 3D imaging of the defects for manufacturing an anatomical shape scaffold, consisting of strong mineralized region for the formation of bone and hydrogel region for the formation of cartilage. Both regions are seeded with cells and cultured in a bioreactor (also manufactured with the aid of imaging) that provides environmental control and physical stimulation, perfusion for bone, dynamic mechanical loading for cartilage

Table 15.1 Required armamentarium and steps for bioengineering

1. Fabrication of scaffold
– Precise anatomical shape
– Material selection: sufficient mechanical strength, appropriately sized and positioned pore, non-immunogenic, biocompatible, biodegradable
2. Selection of appropriate cells
– Mesenchymal stem cells: bone marrow, adipose, umbilical cord, peripheral blood, dental pulp, exfoliated deciduous teeth, dermis, amniotic fluid, tumors
3. Seeding of cells
– Lineage-specific media ± growth factors
4. Bioreactor
– Dynamic tissue growth
5. Implantation into host
6. Assimilation, maintenance
– Rejection, biodegradation, de novo synthesis

15.4 Scaffold Selection

A scaffold is a mechanical template that supports cell attachment, growth, and differentiation, and its main purpose is to provide the compositional, structural, and mechanical properties of native extracellular matrix (ECM) [6]. Intrinsic or external growth factors can assist the scaffold in performing its function. Scaffolds have been in use for decades in reconstructive surgery, such as for placing allogeneic bone grafts into a defect, as templates for endogenous bone formation with eventual replacement of the graft with host tissues. However, when bioengineering anatomic structures with cells, the success of such a construct naturally becomes more complex and unpredictable. Ideally, the engineered construct would simulate both the ECM and local microenvironment to support or induce tissue formation [7].

Appropriate selection of the correct material is critical to the success of any biologic scaffold. The ideal qualities of such a construct are (1) sufficient mechanical strength; (2) appropriately sized and positioned pores to allow for cell seeding, transport, and interconnectivity; (3) being non-immunogenic and biocompatible, and (4) being biodegradable to allow for future proliferation and differentiation of the cells into the desired tissue phenotype (*see* Table 15.1). These features allow for crucial biologic functions such as vascular infiltration and waste management, while also maintaining enough structural integrity to withstand the load-bearing function of the RCU. Equally important is finding a material that degrades and/or resorbs at a similar rate to replacement tissue formation by the recipient. For mandibular reconstruction, the scaffold must be able to withstand compressive forces during the healing phase when the graft is being replaced by host bone and remodeled. While many believe being non-immunogenic is still an important principle in material selection, some research has shown that finding a material able to produce a controlled immune response may actually enhance integration [8]. Finding the appropriate materials for craniofacial tissue engineering has been a vibrant area of research over the past decade.

15.5 Scaffold Types

The craniofacial engineering material armamentarium consists of natural and synthetic polymers, decellularized bone, ceramics, composite materials, silk, and electrospun nanofibers [9].

Research started with natural polymers such as polypeptides (e.g., collagen) polysaccharides (e.g., hyaluronic acid, chitosan), and silk. Collagen was a popular material as it is a predominant organic component of bone ECM and total bone protein. The benefits of natural polymeric materials include the proven ability to support the attachment, proliferation, and differentiation of cells [10, 11]. However, investigations into the material showed utility was limited by natural polymeric mechanical strength, unpredictable degradation and breakdown rates, and risk of infection [7].

Silk fibroin, derived from silkworms, has shown excellent biocompatibility, mechanical properties, and degradation patterns. Silk sponges, tubes, and fibers have been used for cartilage [12], blood vessels [13], and ligaments [14], respectively. Until recently, silk was never investigated as a scaffold for bone regeneration. However, the porosity of silk sponges behaves quite favorably as a bone scaffold allowing for cell attachment and nutrient and waste transport [15]. Further, the silk's pore size and geometry, as well as material stiffness were important factors for bone formation with adipose derived stem cells [15]. Silks remain a viable option as a dependable scaffold in the future.

Synthetic polymers such as poly (lactic acid), poly (glycolic acid), and poly (methyl methacrylate) demonstrate greater structural stability than their natural counterparts and provide support for bone tissue formation [16]. Synthetic polymers compared to their natural counter parts are more convenient because they can be reproduced easily with targeted mechanical properties and degradation kinetics [17]. Natural bone is composed of collagen and hydroxyapatite. Bioceramics such as hydroxyapatite (HA) and tricalcium phosphate (TCP) have been used for bone regeneration. Hyaluronic acid alone has also been used in CAD-CAM designs for TMJ replacement with promising results in sheep [18]. When a polymer matrix is incorporated with TCP or HA, the material then becomes a hybrid/composite. The fillers enable the tissue engineer to alter the degradation and resorption kinetics of the planned complex tissue [19]. It is important to understand the degradation of the synthetic product in vivo; i.e., if acid products are produced by scaffold degradation, a prolonged inflammatory response may result.

Hydrogels such as agarose, alginate, and chitosan are important polymers for tissue engineering purposes. Cartilage matrices consist of a highly hydrated proteoglycan hydrogel embedded into a type II collagen network [20]. Hydrogels have been very successful as the material of choice for cartilage scaffolding since they support the spherical shape and normal phenotype of chondrocytes [21].

The process of electrospinning allows scientists to accurately recapitulate the bone extracellular matrix. The natural network that makes up bone is intricately interspersed with nanocrystallites such as hydroxyapatite, which allows it to function as a nanocomposite organized on the nanoscale [22]. Nanofibrous matrices

have high porosity and a favorable surface area to volume ratio, which allow the material to maximize protein adsorption, cell adhesion, nutrient exchange, angiogenesis, and other critical cellular tissue functions. Further, different materials can be cross-linked to polymers by electrospinning, which would enhance the weak mechanical strength of certain polymers.

The authors' own research focuses primarily on using decellularized bovine trabecular bone as the scaffold for RCU bioengineering with promising translational successes [23–25]. We use an already FDA-approved decellularized bovine trabecular bone and utilize image-guided micromilling to craft a scaffold into an anatomically correct shape for the target host defect [24]. The xenograft has intrinsic adhesion molecules for the cells. However, care must be taken to ensure no antigenic proteins remain after decellularization.

15.6 Scaffold Fabrication

Scaffolds can be fabricated via fiber bonding, solvent casting, freeze-drying, salt leaching, and phase separation among other more traditional mechanisms. Both computer-aided design (CAD) and computer-aided manufacturing (CAM) provided an important progressive step in scaffold fabrication. CAD-CAM 3D printing or micromilling from existing materials and electrospinning now allow engineers the precision to craft most infrastructures they require.

When preparing autologous derived grafts (grafts made for hosts using their own stem cells), the TMJ can be imaged via a computed tomography (CT) scanner similar to a patient preparing for virtual surgical planning for orthognathic surgery. Subsequently, depending on the clinician's and engineer's material of choice, one option is to either 3D print the scaffold with a synthetic polymer or micromill it from an existing block. We recently reported successful use of micromilling a large decellularized cancellous bone block from bovine femurs. The scaffold was milled to the custom geometric specifications based on the CT images of each study animal (Fig. 15.1) [24]. This can hopefully be done clinically as well, by imaging a patient defect or mirror-imaging their "healthy TMJ" if applicable and preparing a unique autologous graft for that patient. Regardless of what technique is being used, the geometry, pore size, and dispersal are critical for cell seeding. CAD technology has allowed groups to precisely fabricate a scaffold to mimic exact bone defects needed to be reconstructed with improved internal architecture.

Following the fabrication of the construct, it must be cultivated with the cells of choice for adhesion and future development of the desired tissue. This step is critical and frequently a problem for research laboratories. The bioreactor must maintain appropriate conditions for tissue growth and maturation prior to implantation. The provision of precise interstitial flows and physiologic functions during this culture period is highly technique sensitive, and laboratory dependent, yet ultimately crucial for biologic success. Ideally, a bioreactor should be capable of coordinating biological, mechanical, and physiological stimuli in a spatially and temporally controlled manner to support a desired cell and tissue growth [20].

15.7 Stem Cells and Growth Factors

There are two basic types of stem cells: embryonic and adult. Embryonic stem cells are harvested from embryos in the blastocyst stage of development and are capable of dividing indefinitely and, under appropriate stimulation and/or culture medium, can differentiate into all cell types of all three germ layers (termed pluripotent) [26, 27]. However, due to ethical concerns, the use of embryonic stem cells in the United States has been controversial and therefore limited.

Scientists have been forced to focus their efforts on harvesting other cell lineages that would be of similar pluripotent and multipotent utility. Adult stem cells are undifferentiated cells that reside in a stem cell niche among differentiated cells until they are called upon to initiate repair. Most human tissues have delineated reservoirs of stem cells used for repair—neural, hematopoietic, gastrointestinal, and mesenchymal [27]. For example, transcription cofactor YAP activates mesenchymal stem cells (MSCs) residing in the synovium to initiate repair of damaged cartilage [28]. Future therapy may be directed to providing the appropriate cues to initiate this mechanism of repair in damaged joints and elsewhere.

MSCs are multipotent cells that give rise to a variety of tissue types: bone, cartilage, vascular, and adipose tissues [29]. Multipotent cells are more limited than pluripotent cells because they are not able to produce cells of all three germ layers. For completeness, it is worth mentioning that some researchers have demonstrated MSCs to have pluripotential when reprogrammed [30–32]. Regardless, this cell line is the one of most interest to bioengineers and clinicians alike focusing on craniofacial reconstruction [30, 33]. MSCs have been the cell line of choice due to little or no ethical limitations, availability, minimal immunogenicity, and ability to produce the relevant tissues. During the harvest of either a cancellous or corticocancellous autogenous bone graft, MSCs are naturally harvested.

Original cell-based bioengineered TMJ grafts used mature osteoblasts and chondrocytes to seed the constructs [34]. Now investigations have advanced to employing MSCs that can be harvested with ease from adipose or bone marrow tissues [24, 35]. Bone marrow tissues were the original source of MSCs and previously the "standard of care" for obtaining the multipotent cells [36]. Now MSCs can be isolated from adipose [37], umbilical cord blood [38], peripheral blood [39], dental pulp [40], exfoliated deciduous teeth [41], dermis [42], amniotic fluid [43], and tumors [44]

We have found success using both bone marrow MSCs and adipose derived stem cells (ASCs) for bioengineering of the RCU [23–25]. Despite bone marrow-derived MSCs having higher osteogenic potential, ASCs have sufficient osteogenic capacity and similar in vitro self-renewal and are widely available with easy harvest from any subcutaneous source of fat (sourced commonly from elective liposuction aspirates) when compared to traditional bone marrow harvests [45]. Thus, ASCs have come to the forefront of the bone regeneration research community.

There have been countless laboratory and clinical successes using ASCs for bone regeneration, which we will describe later in this chapter. Recently we reported a successfully tissue-engineered autologous facial bone reconstruction using recipient animal subcutaneous fat as a source for ASCs [24, 46]. ASCs have a vast amount

of differentiation capabilities and need to be cultured in lineage-specific media. They can be predictably cultured to differentiate toward chondrocytes and osteoblasts [45]. Osteogenic media may include 1,25-dihydroxyvitamin D3, ascorbate-2-phosphate, and bone morphogenetic protein (BMP)-2 (BMP-2) [47]. Also important for any bioengineered RCU would be the formation of a cartilage cap through the utilization of the chondrogenic potential of cells. ASCs demonstrate chondrogenic potential if its media contains other supplements such as transforming growth factor beta 1 (TGF-β1), insulin, dexamethasone, ascorbate-2-phosphate, BMP-6, and a high-density pellet culture [35].

The placement of some of the above osteogenic growth factors, molecules, or cells alone into defects can initiate cell homing for repair. The placement of human recombinant BMP-2 is the most obvious example of this. BMPs are able to initiate, promote, and support chondrogenesis and osteogenesis [48]. BMP-2 has been demonstrated to recruit mesenchymal stem cells that then differentiate into bone. It does this by stimulating transcription of core binding alpha-1 (Cbaf-1/RunX2) and Osterix, which are responsible for activating osteoblastic specific genes (e.g., alkaline phosphatase (ALP); osteopontin; osteonectin; bone sialoprotein, collagen type I) [49]. BMP-2 has been used to reconstruct both maxillary and mandibular defects such as alveolar clefts and continuity defects following ablative surgery for benign disease [50]. However, the use of BMP-2 for creation of a new condyle has not been reported. In maxillofacial surgery, BMP-2 is FDA approved only for sinus lifts and socket preservation and is not approved in children. Other uses of BMP-2 are necessarily off-label.

It is important to understand some of the genes and proteins involved with bone production because the osteogenic potential of the ASCs can be measured in frequent time points by measuring mRNA expression of the well-known bone markers. Early in the growth process proteins Runx-2, Osterix, or the gene ALP can be quantified, compared to more mature stages when collagen type I can be found. Some studies have found expression of Runx-2 in their culture media as early as 1 and 4 days [51, 52]. Researchers depend on the presence of these proteins to determine experimental efficacy and success (Fig. 15.2).

15.8 Clinical Investigations and Applications to the Maxillofacial Skeleton

Now that we have reviewed the scientific and engineering components of what is required for craniofacial bioengineering, we can now begin to discuss promising areas of translational investigation and preliminary research results. While much work remains for optimization of tissue engineering, the reconstructive surgeon is closer than ever to having this in their surgical armamentarium.

One of the earliest reports of using autologous stem cells for bone regeneration in a human was reported in 2004, when a 7-year-old girl suffered widespread calvarial defects after trauma and cranial surgeries. Due to limited autogenous cancellous bone, the team utilized autologous adipose stem cells and mixed them with

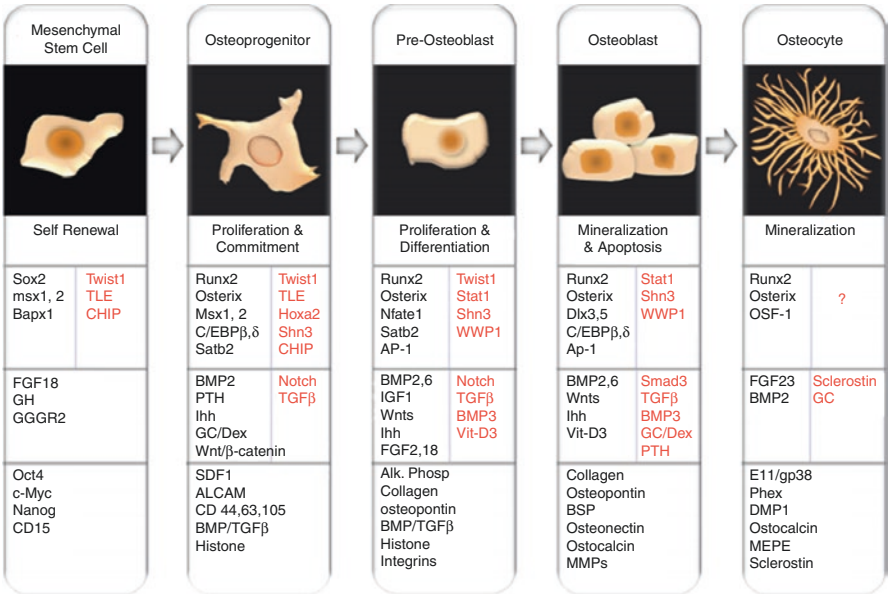


Fig. 15.2 Ontogeny of osteoblast and regulatory control of osteoblast lineage progression and phenotypic features. Sequence and stages of the osteoblast lineage from a self-renewing, pluripotent mesenchymal stem cell to terminally differentiated osteocyte is diagrammatically illustrated. The characteristic feature of each developmental stage is indicated below the cell morphology. Next row summarizes the key transcription factor and co-regulatory protein involved in genetic control of osteoblast differentiation. Factors that negatively regulate Runx2 activity and osteoblast differentiation are indicated in red. Several physiologic mediators influencing osteoblast development, including transforming growth factor β (TGFβ), the bone morphogenetic proteins (BMPs), and fibroblast growth factors (FGFs), Wnt/β-catenin signaling, and hormones, are also indicated. Secretory molecules, receptor, and signal transducer that inhibit osteoblast maturation are highlighted in red. Last row summarize phenotypic marker genes expressed at different developmental stages of osteoblast differentiation. The understanding of these markers allows scientists to evaluate the stage of MSC induction. Reprinted from Oral and Maxillofacial Surgery Clinics of North America, 22, Genetic and Transcriptional Control of Bone Formation, 283–293, (2010), with permission from Elsevier

milled cancellous bone and autologous fibrin glue manufactured from the patient's plasma. They reported a great yield of stem cells and marked ossification after 3 months but concede that it is impossible to determine to what degree the stem cells were responsible for regarding the regeneration [53]. Nonetheless, the results were promising and helped show proof of concept for ASCs use in a pediatric human subject who has limited autogenous bone sources.

Warnke PH et al. reported a successful outcome of a custom bone implant through a bone-muscle-flap technique [54]. A CT was taken of the patient's mandibular defect following a 7 cm, subtotal mandibulectomy. With the use of CAD technology, a Teflon construct was milled to the exact specifications of the planned reconstruction geometrical shape. Ultimately, they used pre-bent titanium mesh; filled it with bone mineral block grafts and particles, BMP-7, collagen type I, and autologous aspirate from iliac crest; and then implanted it into the patient's latissimus dorsi muscle as an in vivo bioreactor. They eventually implanted the graft into

the mandibular defect, and it proved viable for 15 months until the patient unfortunately died from an unrelated comorbidity [55]. These early human reports provide hope that bioengineered constructs can be translated to human application.

15.9 Ramus Condyle Unit

The earliest report investigating cell-based TMJ engineering was in 2001. Investigators used a polyglycolic and polylactic acid as a scaffold and seeded them with mature osteoblasts and chondrocytes [34]. Scaffolds were implanted subcutaneously for 12 weeks in a non-load-bearing region of nude mice. This study demonstrated not only trabecular bone formation but also a bone-cartilage interface representative of articulating joints.

Other proof-of-concept studies were published regarding MSCs and scaffolds for the mandible and RCU. Abukawa, H, et al. isolated porcine MSCs and cultured them with osteogenic supplements [56]. A porcine mandibular condyle was then used as a model to fabricate poly-DL-lactic-co-glycolic acid (PLGA) scaffolds. Once the osteoblasts were differentiated, they were transferred to the scaffold and cultured for 6 weeks in a rotational oxygen-permeable bioreactor. Evaluation of the constructs showed promising radiographic radiodensity, and histology proved that bone existed on the entire surface of the scaffold [56]. The same group then published the first report in our literature of using autologous MSCs from a Yucatan mini-pig and biodegradable scaffold for actual implantation into a mandible [57]. Porcine MSCs were isolated from the ilium and seeded onto poly-DL-lactic-co-glycolic acid (PLGA) scaffolds. Compared to controls, iatrogenic full thickness bony defects (2 × 2 cm) showed filling with hard tissue that were uniformly radiodense with indistinct interfaces between native bone and implanted constructs [57].

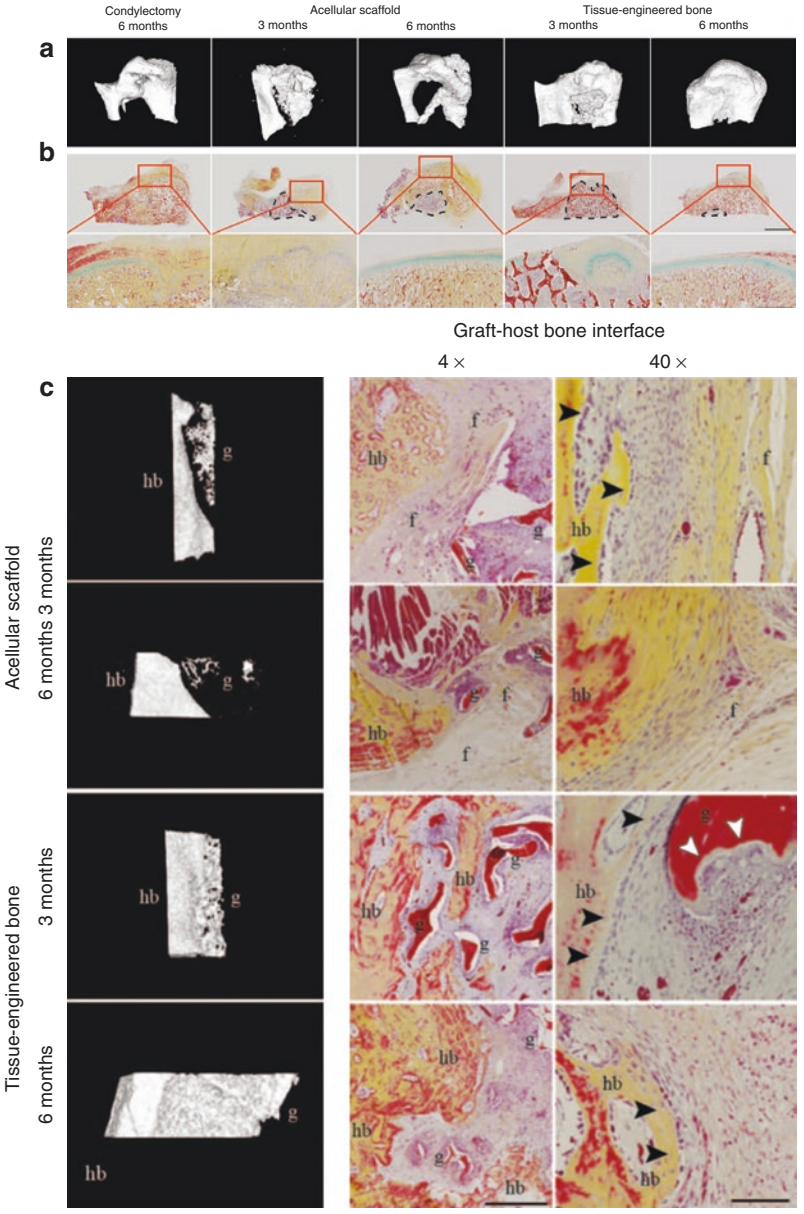
Additional studies aimed to engineer osteochondral grafts in the shape of human TMJs [58–62]. Since the synovial joint head has a combination of fibrocartilage and bone, this model may have high utility in not only reconstruction but also long-term success of any implanted scaffold. Groups have applied the principles that we have outlined throughout the chapter to achieve this—a bilayered hydrogel or scaffold, mixed with lineage-specific growth factors for chondrocytes and osteoblasts, seeded with MSCs and either evaluated in vitro or in vivo. As an example, Re'em et al. used a bilayered affinity binding alginate scaffold. TGF-β1 (for chondrocytes) and BMP-4 (for osteoblasts) were affinity bound to two distinct layers of the hydrogel, and the entire complex was subsequently seeded with MSCs isolated from human donors. After evaluation they determined that both cartilage and bone formed. Further, when implanting an acellular two-layer hydrogel in situ, they found tissue growth after 4 weeks [62]. However, this required the use of growth factors.

Sheehy et al. described a novel approach to osteochondral constructs [60]. They describe the difficulty investigators have in maintaining MSC-derived cartilage from resisting hypertrophy and ultimate endochondral ossification compared to fully differentiated chondrocytes [63, 64]. However, this limitation for MSC engineered cartilage formation can be employed for in vivo bone regeneration. This route may be

more advantageous because of the natural conditions that cells typically endure during endochondral ossification. For example, hypertrophic chondrocytes are already designed to withstand hypoxic conditions that occur during the early implantation stage of a tissue-engineered scaffold in vivo and also release natural angiogenic and mineralization factors that promote bone growth [65]. Farrell, E, et al used a bilayered hydrogel with chondrogenically primed cells, MSCs, in one layer and stable cartilage, chondrocytes, on top. They reported success in finding enhanced chondrogenesis in the cartilage layer and mineralization of the MSC-seeded layer when cultured in a hypertrophic medium with osteogenic supplements [65].

Recently Vunjak-Novakovic's lab successfully engineered autologous grafts for facial bone reconstruction. Bhumiratana et al. describe the process in which they grew an anatomically precise RCU and repaired a large defect in the jaw of a Yucatan mini-pig without using BMPs or other growth factors. Instead, they used the decellularized native bovine bone matrix to induce osteogenic differentiation of ASCs [24]. By utilizing computer-aided micromilling guided by three-dimensional reconstructions of CT images of each individual pig jaw, precise anatomically shaped scaffolds were customized to each animal. All scaffolds were cultured for 3 weeks with autologous porcine ASCs in an anatomically shaped, perfused bioreactor system with tight control of exchange of nutrients, metabolites, and oxygen [23]. Fourteen mini-pigs had their left condyle resected to create a standardized defect and were then either reconstructed with a tissue-engineered scaffold, cell-free scaffold, or not reconstructed. Ultimately, through sequential CT-imaging, sacrifice, and histological and bone marker assay analysis, the investigators demonstrated that over 6 months of implantation, the engineered grafts reestablished the entire RCU, integrated with host bone, and formed extensively vascularized bone-like tissue that was significantly different than both control groups (Fig. 15.3).

Fig. 15.3 Morphology and structure of regenerated RCU. (**a**) Condyle regeneration was assessed using μCT 3D reconstruction and (**b**) Movat's pentachrome staining at low magnification (top; 1-cm scale) and high magnification (bottom; 2-mm scale) of the condylectomy site. The dashed circumferences indicate the remaining graft regions, with the red trabecular structure representing the remaining scaffold material. (**c**) μCT 3D reconstruction of the graft-host interface and Movat's pentachrome staining were used to assess integration of the implanted graft with the host bone. For acellular grafts, the mineralized host bone (*hb*) and the graft structures (*g*) were separated by soft fibrous tissue (*f*). In contrast, host bone extended into the tissue-engineered bone graft. In the proximity of the new bone, osteoclastic resorption (*white arrowheads*) was detected on the implanted scaffold with the lining of osteoblasts (*black arrowheads*), indicating active ossification. Scale bars, 1 mm (4×) and 100 μm (40×). From Bhumiratana S, Bernhard JC, Alfi DM, et al. Tissue-engineered autologous grafts for facial bone reconstruction. Sci Transl Med. 2016;8(343):343–83. Reprinted with permission from AAAS


Condylectomy
6 months
Acellular scaffold
3 months
6 months
Tissue-engineered bone
3 months
6 months
a
b
Graft-host bone interface
4 ×
40 ×
c
Acellular scaffold
6 months 3 months
Tissue-engineered bone
3 months
6 months
hb
g
f

The bioengineered RCU successfully reconstructed a load-bearing joint. Multiple previously described proof-of-concept studies, such as those looking into scaffold material, bioreactor design, cell seeding, stem cell selection, and stem cell differentiation, were all combined and in one successful investigation. The investigation also mimicked the logistics of a future commercial process. Grafts were grown and implanted at two locations greater than 1200 miles apart. This would allow surgeons to send images and patient information to a centralized bioengineering center, which would then fabricate and return a custom bioengineered scaffold loaded with cells to the treating surgeon.

To summarize, as we focus on temporomandibular joint reconstruction, there are a few principles to highlight when reviewing replacement of the TMJ in the literature moving forward. First, it is important to create an osteochondral construct. Cartilage is believed to be necessary for maintaining a stable functional joint as it enables friction-free physiologic activity. Further, both cell layers—cartilaginous and bony—need to be able to repair themselves and have cells capable to regenerate as a healthy joint would. To complement the accurate cellular makeup of two tissues, correct geometry of the anatomy to allow for precise joint mechanics is of equal importance. This depends on anatomically shaped scaffolds, bioreactors, and the advent of CAD with either 3D printing or micromilling. For any future RCU construct to be successful, patients will have to be imaged using computed tomography and then have scaffolds fabricated via solid free-form fabrication (SFF) [66]. This technique simply uses the patient-specific imaging and allows engineers to design scaffolds with the specific internal architecture of the target, in our case, the TMJ. This helps optimize mechanical properties that are of most importance when fabricating load-bearing, stratified osteochondral joints [67].

15.10 Articular Disc

Although we have discussed briefly the principles of bioengineering cartilage as it pertains to osteochondral constructs, the process of engineering the disc itself is unique and worth reviewing. Cartilage responds poorly to injury due to its avascular and acellular makeup. Unfortunately, damage to cartilage is often progressive, leading to subchondral bone remodeling, and ultimately osteoarthritis. However, due to its avascular nature, the tissue is also immunoprivileged and therefore engineered cartilage replacements do not generate large immune responses [68, 69]. In addition, the ECM of cartilage is dense and does not enable cells from within the matrix to repair damage at a distant site, further adding to the reparative challenge of cartilaginous tissue.

Load-bearing joints and their cartilaginous tissues have received a great deal of attention primarily in the orthopedic community. It is important to remember that only the TMJ disc and the meniscus in the knee are composed of fibrocartilage. Fibrocartilage differs from hyaline cartilage by its histomorphology and the ratio and amounts of collagen type I and II, with the TMJ disc nearing a ratio close to one

(Col I/II), with hyaline cartilage close to zero (Col I/II) [70]. Nonetheless, many of the principles of cartilage reconstruction from orthopedics are still transferrable to the TMJ.

The cell choice for engineering cartilaginous tissues has proven to be more difficult than for engineering bone. MSC-derived chondrocytes have a tendency to hypertrophy, mineralize, and undergo endochondral ossification, which is not acceptable for cartilage replacement applications. For cartilage tissue alone, bone marrow, synovium, and periosteum are the best sources for MSC-induced chondrogenesis [71]. Synovium-derived MSCs, referred to as SDSCs, are believed to have the greatest potential to produce cartilaginous ECM when supplemented appropriately [72–75]. SDSCs can undergo chondrogenesis in vitro when combined with specific growth factors such as basic fibroblast growth factor (bFGF), and insulin-like growth factor I, TGF-β1 [72]. Until recently, MSCs were much more difficult to use in cartilage tissue engineering than juvenile chondrocytes, until a breakthrough finding revealed that a condensation step needed to be added, forming condensed mesenchymal bodies [76]. The key for TMJ-targeted tissue will be to find the best combination to produce in vivo conditions of collagen type I.

In 1991 the first pilot study on TMJ disc growth was reported by using TMJ cartilage from New Zealand white rabbits and mixing them with collagen type I to inject into a collagen matrix in vitro [77]. A few years later, another group demonstrated true hyaline cartilage growth in the shape of a TMJ disc and biomaterial polymer success and explored the biomechanical nature of their constructs [78]. These early investigations frequently harvested mature chondrocytes from newborn calves as their cell source. However the TMJ disc is composed of fibrocartilage, not hyaline cartilage.

A decade after the first investigation of biomaterials for disc replacement, researchers found that, unlike other joint engineering success, TMJ chondrocytes (isolated from porcine discs) prefer PGA non-woven meshes when compared to alginate hydrogels [79]. There has been more recent success using an alternative material, poly (glycerol sebacate) (PGS) as a scaffold material in growing fibrocartilage through their experimental process, where they found both cell seeding time and density were important variables for success [80].

There is an alternative approach to cell-based, scaffold models for TMJ disc replacement. Brown BN, et al followed up on their original pilot study by more thoroughly investigating the use of an acellular, scaffold-based approach for disc replacement [81, 82]. They creatively used decellularized porcine urinary bladder tissue (urinary bladder matrix (UBM)) alone as a scaffold without any isolated chondrocytes, MSCs, or SDSCs, to serve as an interpositional graft and inductive template for reconstruction of the disc in vivo [81]. They prepared the UBM and layered it onto a hard plastic mold, which mimicked the approximate TMJ disc size. Following complete, bilateral disc removals on ten adult female mongrel dogs, each subject received one graft and had the contralateral side left alone. Animals were sacrificed at 6 months, and analysis indicated that multiple tissue types formed throughout the scaffold, and histology showed architecture highly

analogous to native disc tissues [82]. If reproducible, this approach to replacement would serve as a stock packaged option for replacement during TMJ surgery.

In recent years, multiple studies exploring in vitro fibrocartilage for the TMJ disc have been performed finding answers to important clinical questions. It is believed that either costal chondrocytes or articular chondrocytes are both superior cell sources for disc engineering than TMJ disc cells [83]. When comparing IGF, TGF-β1, and bFGF, TGF-β1 demonstrated the greatest ability to produce ECM, glycosaminoglycans (GAGs), and collagen [84, 85]. Scaffoldless constructs may be better than cell-seeded scaffold constructs [70]. Yet, all current methods are still inferior in strength and chemical makeup to native TMJ disc tissue [70, 85–87]. Perhaps a more focused stem cell approach may be the next wave of fibrocartilage research for TMJ disc investigators.

15.11 Future Directions and Challenges

Significant advances in the field of tissue engineering as it pertains to the RCU have been made. As with all translational research, there is still much to be done moving forward.

Ideally a standardized scaffold for the RCU could be developed. For example, either decellularized bovine bone or one synthetic option such as PGA would be optimized and available for all researchers to then proceed with further research focusing on other aspects. Also, many studies have done only in vitro or ex vivo synthesis on a small scale. Groups need to ensure they are able to not only scale up their tissues but to employ methods like CAD/CAM to ensure their constructs are anatomically precise and unique.

ASCs seem to be a promising cell type that is easily accessible and useful for hard tissue. As we have discussed, some groups use growth factors and others do not. A standard cocktail for media would help standardize experiments across all laboratories trying to answer the same clinical question. In view of the current controversies surrounding the use of growth factors, the ideal culture medium would be designed without them.

Creating an osteochondral construct with a bilayered system of bone and cartilage that would be able to repair itself and thrive in vivo still remains to be seen. Most studies that have done animal implantation have sacrificed the animals at around 6 months postimplantation. True long-term viability data is needed; can these grafts survive long term as a load-bearing joint?

Another challenge in maxillofacial reconstruction is the need to replace a large volume of soft tissue and bone. The workhorse of maxillary and mandibular reconstruction of cancer patients who have undergone ablative surgery is the microvascular free fibula graft. The use of an engineered bone construct without an adequate vascularized soft tissue bed will be unsuccessful. One technique that has been reported would be to implant the graft into a muscle bed and then bring the muscle with feeding and draining vessels and the graft to the recipient site. However, this requires two surgeries and a second surgical site at the time of tissue transfer.

Ultimately an engineered construct of bone enveloped into a soft tissue of appropriate size with blood vessels for anastomosis would be ideal and allow for wide applicability of engineering techniques for facial reconstruction in acquired and congenital disease.

An important question is if the disc and RCU engineering and implantation can be coupled together. There does not seem to be any investigations at this point that have resulted in implanting a bioengineered RCU and articular disc simultaneously. Using bioreactors for osteochondral constructs allowing for the formation of both tissues would be groundbreaking. Perhaps, fabrication of a dual-compartment bioreactor would allow precise control of two separate environments, one chondrogenic and one osteogenic.

Also, no current studies address muscle reattachment of the external pterygoids. Alloplastic total joint replacement does not allow for lateral or protrusive movement because of the inability of the lateral pterygoid muscle to attach to the alloplast. This is another important area of research for total ramus condyle reconstruction utilizing engineered biologic constructs.

A possible augmenting area of bioengineering is gene therapy. Gene therapy depends on the transfer of genetic material into living cells in order to regenerate tissue, treat a disease process, or silence the unwanted gene expression. Through viral transfection or non-viral physical and chemical means, manipulated genetic material is taken up by the host cells that begin to express the transfected proteins of the selected gene (e.g., BMP-2, bFGF, etc.). For example, if increased levels of BMP-2 in vivo help bone regeneration from TMJ osteoarthritis, transfected cells can be injected locally into the joint space or necessary area, BMP-2 will be upregulated in the local environment, and bone regeneration will occur. The possibilities of gene therapy, if controlled, can be endless. They do come with risk, however, as viral infection is one of the more common ways of transfecting target cells. The possibility of gene silencing and editing strategies with methylation and miRNA, respectively, will hopefully expand gene therapy utility in the future without the risk for infection.

Some investigations for bone regeneration have already demonstrated great promise with this modality. In rabbits, orbital bony defects were repaired with BMP-2- and VEGF- transfected rabbit BMSCs [88]. Maxillofacial-derived stem cells, when transfected with osteogenic gene *BMP-2* via adenoviral vector, also showed high utility in treating a mandibular bony defect with high expression levels of the desired growth factor [89]. This is an avenue worth exploring to repair bony defects throughout the cranio-maxillofacial skeleton and possibly pairing with RCU engineering.

15.12 Conclusion

Numerous studies over the past decade provided opportunities for what the future of TMJ bioengineering may hold. Anywhere from stock disc replacement to custom, anatomical autologous condylar reconstruction will broaden the reconstructive surgeon's armamentarium to help the patients in need. We look forward to an

integrated use of biomaterials, bioactive factors, and cells toward serving the patients' needs.

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Educating the Next Gen TMD Surgeons

16

Vincent E. DiFabio

Abstract

Where are we going in oral and maxillofacial surgery (OMS) with the education of our residents in the proper protocol and techniques for temporomandibular joint surgery? Do all programs have the bandwidth to teach the surgical correction of temporomandibular joint diseases, pathology, and trauma using minimally invasive surgery, microscopic surgery, and arthroscopic surgery? With mandatory reduced hours for teaching but increased knowledge and education demands on our OMS residents, how can this be beneficial to teach such complicated techniques? Where do we stand with predicting success and even diagnosis of these disease entities? Do we teach them in training programs? The answers to these questions thus form the basis for this chapter and on the future of training in OMS residency programs of TMJ disorders and surgical treatment via arthroscopic surgery.

16.1 Introduction

Where are we going in oral and maxillofacial surgery (OMS) with the education of our residents in the proper protocol and techniques for temporomandibular joint surgery? Do all programs have the bandwidth to teach the surgical correction of

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temporomandibular joint diseases, pathology, and trauma using minimally invasive surgery, microscopic surgery, and arthroscopic surgery? With the mandatory reduced hours for teaching but increased knowledge and education demands on our OMS residents, how can this be beneficial to teach such complicated techniques? Where do we stand with predicting success and even diagnosis of these disease entities? Do we teach them in training programs? The answers to these questions thus form the basis for this chapter and on the future of training in OMS residency programs of TMJ disorders and surgical treatment via arthroscopic surgery. The AAOMS and ADA are lagging in changing the parameters of what the OMS residents are to learn when it comes to TMJ surgery or anything relating to the TMJ. Some programs do not teach any TMJ surgical correction, surgeries, or techniques. Other programs teach minimal TMJ techniques and procedures as they do not have the instructors to teach these complicated techniques, or they are inadequately trained in treating TMJ pathology or dismiss TMJ as "psychological." How can one of the most prevalent problems in the USA, affecting millions of people (especially women), be ignored? Basic TMJ disorders, pathology, and treatment modalities are not taught except at the very basic level in dental schools. In OMS training programs, there are no numbers of case requirements for TMJ surgeries noted in the ADA/CODA papers. Discussions with AAOMS committees on OMS resident education relating to this impropriety have brought forth no resolution. Perhaps the AAOMS and ADA need to look at their criteria for what they teach and establish some numerical values to ensure that the next generation of OMSs are trained in diagnosing and treating surgical TMJ pathology as a specific entity. TMJ pathology and treatment should not be buried in the general pathology section which is mixed with other head and neck pathologies. Whatever reasons the AAOMS and ADA give, teaching the next generation of OMSs will certainly be a challenge and perhaps a lost art. As noted above, the thrust of this chapter is to enlighten the large population of people with TMJ maladies, aspiring OMSs and OMS residents that "help is on the way!"

16.2 The History of Virtual Reality Training in Medicine, Surgery, and Dentistry

Surgical training has followed the master-apprentice model for hundreds of years, and this way of producing a surgeon is currently undergoing a unique paradigm shift. The traditional model is inefficient, has no guarantee as to a varied case mix, has no proof of a quality product, and most important has not shown the numbers of patients treated, so that repetition becomes the norm and not the exception. There is a growing focus on competency-based medical education in response to restrictions on doctors' working hours, and the traditional mantra of "see one, do one, teach one" is being increasingly questioned. The medical profession is subject to more scrutiny than ever before and is facing mounting financial, clinical, insurance, and political pressures. Virtual reality simulation (VRS) is the means of addressing these challenges. It provides a way for trainees to practice technical tasks in a

protected environment without putting patients at risk and helps to shorten the learning curve. The evidence for simulation-based training in orthopedic surgery using synthetic models, cadavers, and virtual reality (VR) simulators is constantly developing, though further work is needed to ensure the transfer of skills to the operating theatre. The mentors will not be replaced but are needed for their guidance, supervision, knowledge, and experience to oversee those in training. The cost of using cadavers and patients as models and as a first step is now changing. This is a very inefficient and expensive model. OMS teaching of temporomandibular joint disorders and surgical corrections must change if we are to stay competitive in the marketplace. But more importantly, if we are to provide our residents with the excellence in education they deserve and the skills that our patients expect and demand.

It was almost two decades ago when general surgery training programs found that endoscopic or laparoscopic surgery could be used to the better treatment of abdominal pathologies; the search was on as to how to teach the residents this extremely different technique. Heretofore, the typical approach to a gallbladder surgery was opening the abdomen belly and going directly after the offending pathology. This was a total new and revolutionary set of training that needed to be taught to residents and to the older population of general surgeons. The use of virtual simulation and haptic or "touch technology" was born and now standard teaching in the simulation labs in all medical schools and hospitals with general surgery residents. But medicine and surgery did not stop there. Expansion to ob-gyn, urology, neurosurgery, and orthopedic surgery soon followed. Simulators for all these specialties were developed, researched, marketed, and sold to universities including "robotic" techniques as an additional branch. Thus the practice of these techniques was placed into the simulation labs, so the residents could develop skills prior to performing operations on live patients. And hence the days of "see one, do one, teach one" were over for these surgical specialties! As additional fodder, these specialties spun off hundreds and hundreds of professional papers and peer-reviewed articles. New technologies were discovered and new industries were born.

But wait, what happened in oral and maxillofacial surgery (OMS)? Nothing. This unique technology has not risen to the top in the teaching level of using minimally invasive surgery, microsurgery, and the use of endoscopic and arthroscopic techniques. Why? The use of VR simulators has become the norm for general trauma, for physical evaluation of the heart and lungs, for emergency room situations, for general anesthesia, for advanced airway management and medical emergencies, and for many other branches of medicine and surgery. VR simulator model is used for the teaching of all these different residents and for continued training and to keep up–to-date competence. There is now a large national society of healthcare simulation with an annual meeting and a peer-reviewed journal. The use of general dentistry then followed, and many dental schools are now using virtual reality simulation to teach students the proper technique in restorative dentistry. The VR simulators are joined with computers to assess the student's general progress in diagnosing pathology, learning over time, hand-eye coordination, skills of surgery progress, etc. The student is graded on his or her progress, and this is stored for future

reference. The training is stored and one is able to go back and practice until we obtain a passing grade. Some studies have noted that for knee surgery, an orthopedic resident must perform some 35 OR cases to become proficient and competent at this surgery. How many TMJ surgeries do our OMS residents do? Additionally, how can we let them out of training, untrained even in this basic concept of TMJ surgery?

16.3 Training Made Simple for All Other Areas of Medicine and Surgery So Why Not TMJ Surgery?

As noted, before an airline pilot can get into the cockpit of a commercial airliner, he or she must demonstrate on a simulator competence, and this takes hundreds of hours of training on that simulator. This has become commonplace and very advantageous to the passengers on a commercial airliner! From medical to surgical to dental to pilot, all have the same modus operandi: training before doing so on live customers. This simulation training benefits all concerned. Can this simulation be an assistance in teaching OMS residents and practitioners alike? Yes is the universal answer. We can develop a simulator to show all the possible pathology in the TMJ and clinically also to teach the necessary hand-eye coordination needed to perform such surgeries. Doing this before going to the operating room is not just a pipe dream, it has come to be seen as a necessity. In a paper written in 2008 by Howells et al., they showed that prior training of orthopedic residents, before an actual surgery and using a VRS model was superior to those orthopedic residents who just were given instructions, were allowed to watch one knee arthroscopic diagnostic surgery, and then were allowed to actually perform a knee arthroscopic surgery. The residents were graded on 9 separate parameters including handling of tissues, protecting articular cartilage, use of additional instruments, and others. See Figs. 16.1 and 16.2.

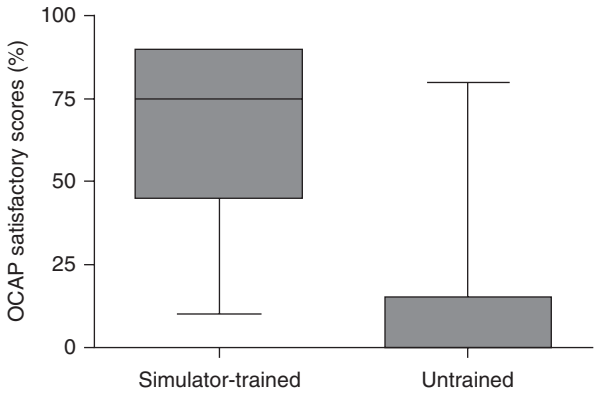

Fig. 16.1 (Howells et al.) Testing 9 separate parameters of surgery with a grade of satisfactory or unsatisfactory

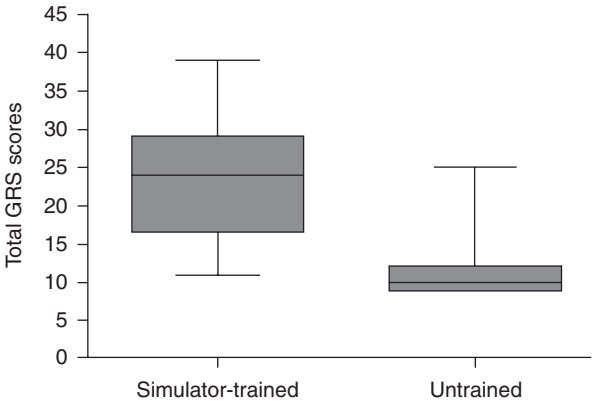

Fig. 16.2 (Howells et al.) Testing 9 separate parameters using a 1–5 scale from poor to excellent

16.4 The Future for Training the Next Generation of Oral and Maxillofacial Surgeons

The future for training the surgeons of tomorrow rests squarely in the hands of new and advancing technology. How we as OMSs leverage the technology will provide an avenue into the training our residents will have going forward. Minimally invasive surgery, microsurgery, and arthroscopic surgery are here to stay. As noted the "see one, do one, teach one" training methods of the past are history. Our current residents and future residents demand and expect more, and we should deliver this as a promise to teach them to a higher standard. This standard has been set by our medical and surgery fellows. For once OMS is behind the eight ball instead of leading the pack. We must advance into the next order. Being light-years behind means that a major shift in OMS education standards and this shift in education must come from AAOMS and ADA leadership at the top but can be influenced by the program directors and chairs but should be demanded by incoming and current residents. How can we graduate residents into the communities as trained to competence without ever having performed a single TMJ surgery? So far this siren call has been ignored.

Arthroscopic Surgery	
Training needs	Acquired knowledge and skill levels
1. Textbooks/videos/others	Theory, procedure, and pathology
2. Computer and textbooks	Anatomy and pathology of the procedure
3. Computer simulation with joysticks	Spatial orientation and hand-eye skills
4. Phantom joint	Camera, scope, light source, and orientation
5. VRS model, light, scope, camera	Haptic and/or direct feedback and pathology
6. Cadaver models (? number)	Camera, light, scope, and specimen handling
7. Operating room, patient, and mentor	Direct contact as assistant surgeon
8. Fully trained (~35 knee cases, # TMJs)	Performs the procedure to competence

For any resident the above flow chart shows how we get from learning about a "procedure" and how we achieve "competence" in performing the procedure. With VRS models and training, we can add 3, 4, and 5 and move to 6, 7, and 8 in a faster, more verifiable and more reliable fashion. How many cases are required to train a resident on OMS to competence will depend on the resident, mentor, and number of TMJ surgery cases in the residency program. Ideally with 4–6 years of training time, most residents should be competent in performing Level 1 (1 portal) and possibly Level 2 (2 portals) TMJ arthroscopic surgery.

16.5 Conclusion

The aviation industry, with similar demands for high levels of technical skill, small margins for error, and potential problems with significant consequences, has been using simulator-based training for decades. In all the areas of surgery, VRS as a potential training tool has only been considered for some 10–15 years. Thus the search for its usefulness and validity across the surgical and medical disciplines has been presented. It is not possible to show all the areas that VRS has entered into in the medical/surgical field. Note that this area is exploding and vigorous activity in research and development has taken off.

The name of the game is "change." OMS must find a way to get into this game of "change," and looking toward the future is the only way. The past can only give so much in terms of benefit ratio to the education process. Progression not stagnation in education must be advanced for all concerned. These VRS models help the OMS residents progress at their own pace to become competent in the skill sets needed to perform minimally invasive surgery, microsurgery, and arthroscopic surgery. Certainly the faculty in OMS programs will need training to train the residents, and this will come with VRS models at their institutions or shared VRS models with other local institutions. The patient will benefit from the OMS residents being well trained before they enter the OR, and thus there should be a decrease in OR time and therefore saving the hospitals and insurance companies' money. Additionally, there could be a plethora of new research projects (how do we test OMS residents in TMJ arthroscopy versus the orthopedic residents in knee surgery) and newer technologies (like total or partial joint replacements with MIS, smaller portable VRS models for home use, smart phone versions, etc.) in the future. Yes, the Future is VRS and "The Way." We must follow that lead into the future to improve outcomes for our patients and to educate our OMS residents to the highest level of training possible. In the 4–6 years of OMS training, there is a great need to teach minimally invasive surgery, microsurgery, and arthroscopic surgery. VRS is a must and with VRS "help will soon arrive!"

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Correction to: Bioengineered Constructs of the Ramus/Condyle Unit

Sidney B. Eisig, Michael Forman, and Gordana Vunjak-Novakovic

Correction to:
S. T. Connelly et al. (eds.), *Contemporary Management of Temporomandibular Disorders*, https://doi.org/10.1007/978-3-319-99909-8_15

The original version of Chapter 15 was inadvertently published, so the following changes have been made to this updated version of the chapter:

- Bottom half of original figure 15.1 has been removed.
- Original figure 15.2 has been removed, and the remaining figures have been renumbered.
- Original figure 15.3 has been changed to figure 15.2 and the associated references in the texts are updated as well. At the end of this figure's legend the following text has been added, "Reprinted from Oral and Maxillofacial Surgery Clinics of North America, 22, Genetic and Transcriptional Control of Bone Formation, 283-293, (2010), with permission from Elsevier."
- Original figure 15.4 and its legend (now figure 15.3) has been replaced with a new figure and its legend. The associated references in the texts are updated as well.
- At the end of New Fig 15.3 (old 15.4) the following reference has been included:
- "From Bhumiratana S, Bernhard JC, Alfi DM, et al. Tissue-engineered autologous grafts for facial bone reconstruction. Sci Transl Med. 2016;8(343):343ra83. Reprinted with permission from AAAS."

The updated online version of this chapter can be found at
https://doi.org/10.1007/978-3-319-99909-8_15

S. T. Connelly et al. (eds.), *Contemporary Management of Temporomandibular Disorders*, https://doi.org/10.1007/978-3-319-99909-8_17

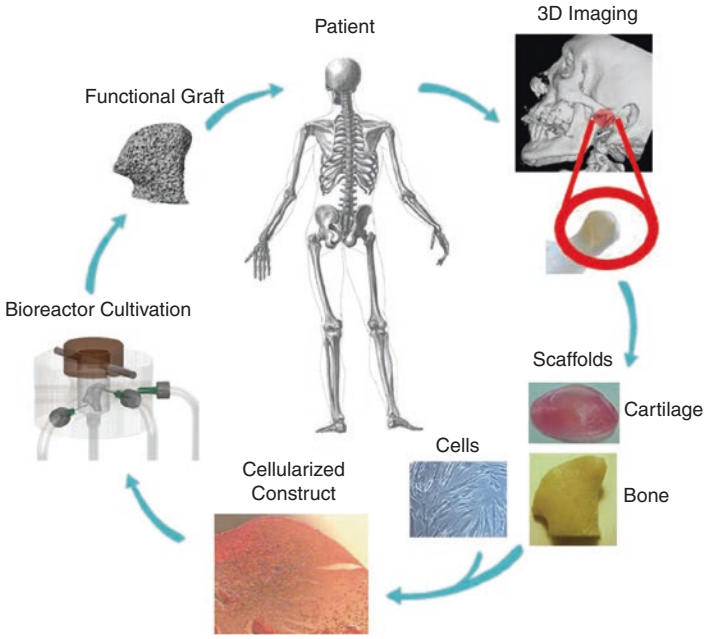

Fig. 15.1 Engineering of cartilage/bone grafts. The process begins with 3D imaging of the defects for manufacturing an anatomical shape scaffold, consisting of strong mineralized region for the formation of bone and hydrogel region for the formation of cartilage. Both regions are seeded with cells and cultured in a bioreactor (also manufactured with the aid of imaging) that provides environmental control and physical stimulation, perfusion for bone, dynamic mechanical loading for cartilage

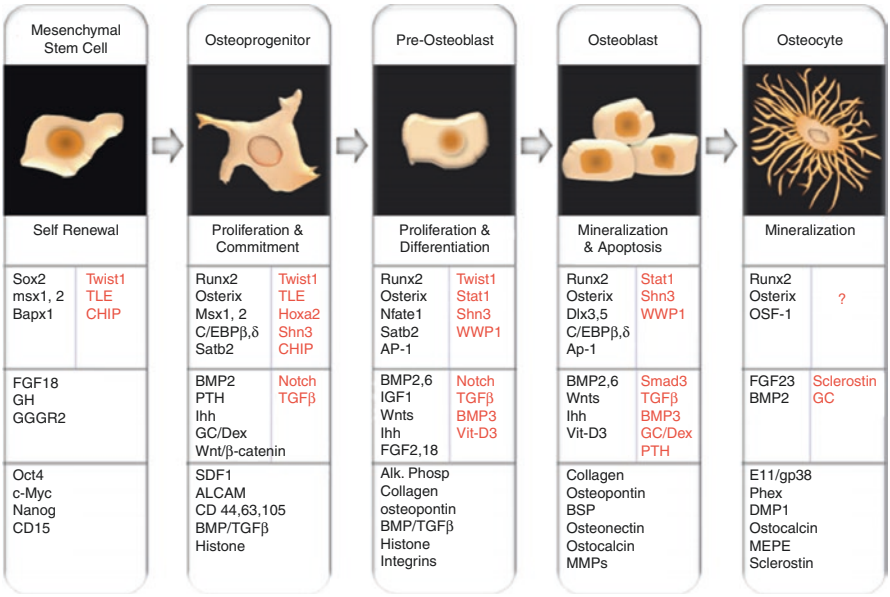

Fig. 15.2 Ontogeny of osteoblast and regulatory control of osteoblast lineage progression and phenotypic features. Sequence and stages of the osteoblast lineage from a self-renewing, pluripotent mesenchymal stem cell to terminally differentiated osteocyte is diagrammatically illustrated. The characteristic feature of each developmental stage is indicated below the cell morphology. Next row summarizes the key transcription factor and co-regulatory protein involved in genetic control of osteoblast differentiation. Factors that negatively regulate Runx2 activity and osteoblast differentiation are indicated in red. Several physiologic mediators influencing osteoblast development, including transforming growth factor β (TGFβ), the bone morphogenetic proteins (BMPs), and fibroblast growth factors (FGFs), Wnt/β-catenin signaling, and hormones, are also indicated. Secretory molecules, receptor, and signal transducer that inhibit osteoblast maturation are highlighted in red. Last row summarize phenotypic marker genes expressed at different developmental stages of osteoblast differentiation. The understanding of these markers allows scientists to evaluate the stage of MSC induction. "Reprinted from Oral and Maxillofacial Surgery Clinics of North America, 22, Genetic and Transcriptional Control of Bone Formation, 283–293, (2010), with permission from Elsevier"

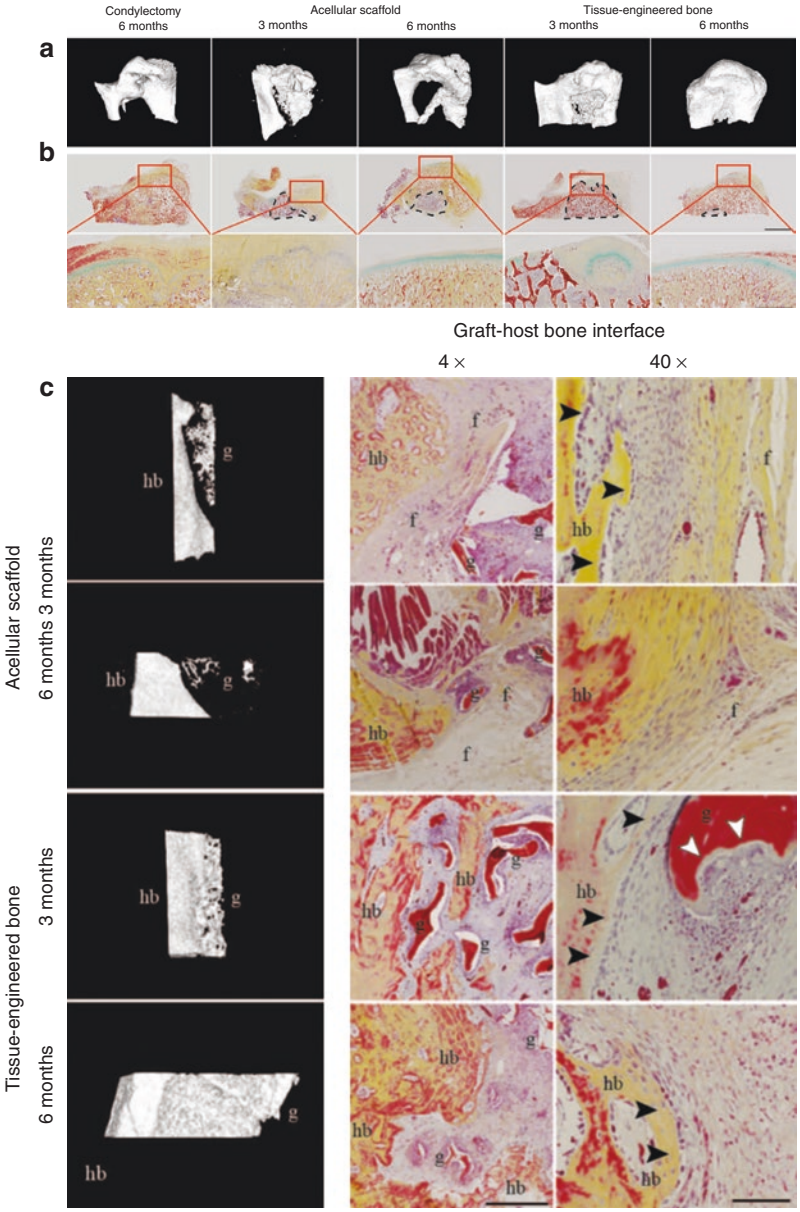
Condylectomy
6 months
Acellular scaffold
3 months
6 months
Tissue-engineered bone
3 months
6 months
a
b
Graft-host bone interface
4 ×
40 ×
c
Acellular scaffold
6 months 3 months
Tissue-engineered bone
3 months
6 months
hb
g
f

Fig. 15.3 Morphology and structure of regenerated RCU. (**a**) Condyle regeneration was assessed using μCT 3D reconstruction and (**b**) Movat's pentachrome staining at low magnification (top; 1-cm scale) and high magnification (bottom; 2-mm scale) of the condylectomy site. The dashed circumferences indicate the remaining graft regions, with the red trabecular structure representing the remaining scaffold material. (**c**) μCT 3D reconstruction of the graft-host interface and Movat's pentachrome staining were used to assess integration of the implanted graft with the host bone. For acellular grafts, the mineralized host bone (*hb*) and the graft structures (*g*) were separated by soft fibrous tissue (*f*). In contrast, host bone extended into the tissue-engineered bone graft. In the proximity of the new bone, osteoclastic resorption (*white arrowheads*) was detected on the implanted scaffold with the lining of osteoblasts (*black arrowheads*), indicating active ossification. Scale bars, 1 mm (4×) and 100 μm (40×). From Bhumiratana S, Bernhard JC, Alfi DM, et al. Tissue-engineered autologous grafts for facial bone reconstruction. Sci Transl Med. 2016;8(343):343–83. Reprinted with permission from AAAS