Surgery of the Temporomandibular Joint: Surgical Arthroscopy

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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]

Stage	Clinical and radiologic findings according to Wilkes			Arthroscopic findings according to Bronstein and Merrill	
	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

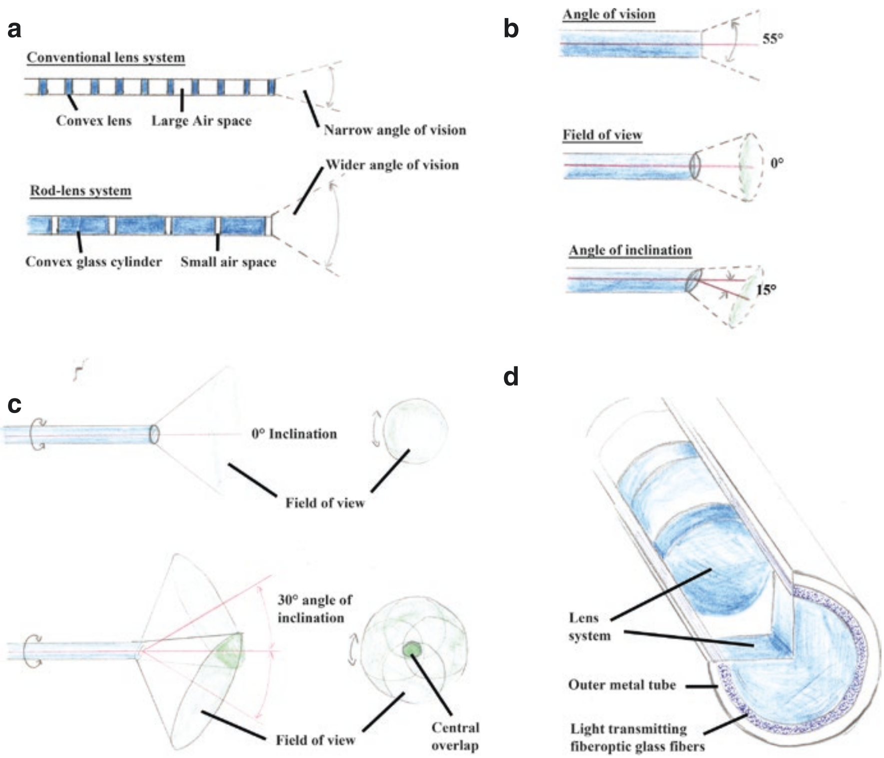

Fig. 4.1 (**a**) Comparison of the structure of the conventional endoscopic lens system showing a narrow angle of vision and the Rod-lens system showing a wider angle of vision. (**b**) The drawing illustrates the terms of ankle of vision, field of view, and angle of inclination. The 0° angle of inclination 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

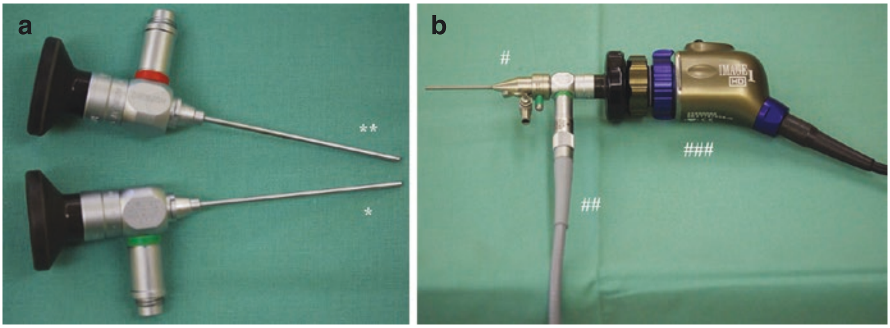

Fig. 4.2 (**a**) Comparison of the most frequently used straightforward 0° (asterisk) arthroscope and the 30°-angled arthroscope (doubel asterisk) (HOPKINS™, Storz, Tuttlingen, Germany) with a diameter of 1.9 mm and a length of 6.5 cm. (**b**) For clinical use, the arthroscope is connected with the working 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)

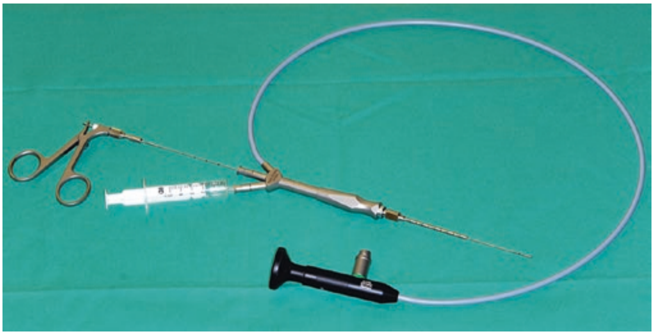

Fig. 4.3 The all-in-one arthroscope has an outer diameter of 2.2 mm and an integrated 1.4 mm working channel. It combines the telescope, the irrigation channel, and the working channel and thereby allows arthroscopic lavage as well as arthroscopic microsurgery. The palpation hook, scissors, and biopsy 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).

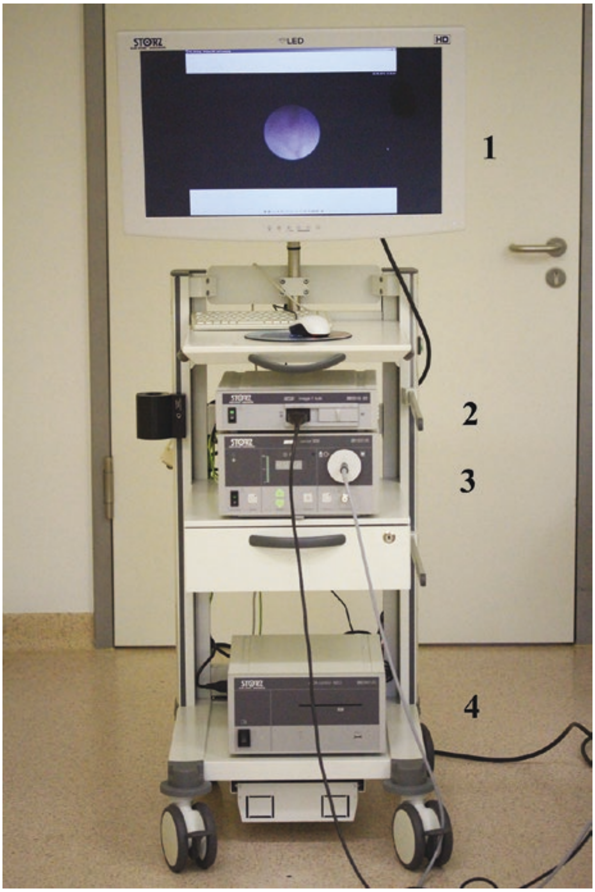

Fig. 4.4 The basic mobile video cart contains the monitor (1); the camera control unit, which converts optical images to digital (2); the cold light fountain with the light transmission cable (3); and the recording unit (4) (Storz, Tuttlingen, Germany)

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

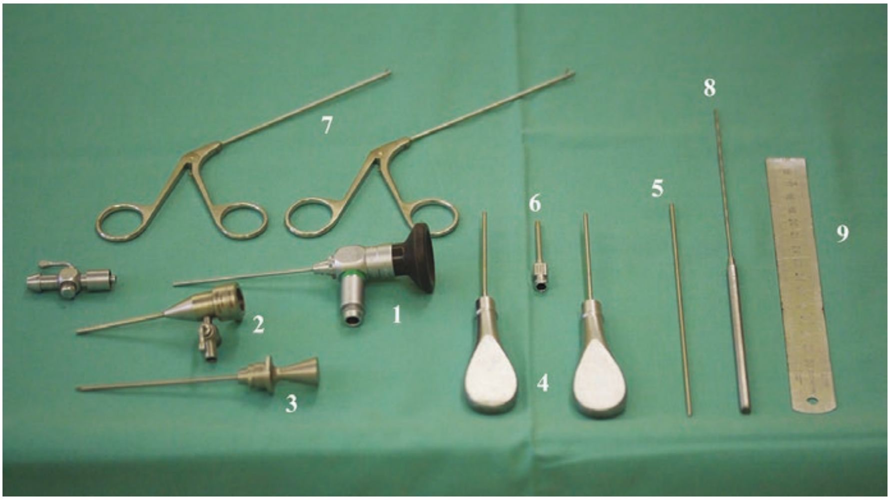

Fig. 4.5 The basic armamentarium for TMJ arthroscopy contains the (1) straightforward telescope 0°, diameter 1.9 mm, length 6.5 cm; (2) high-flow arthroscope sheath, diameter 2.5 mm, working length 4 cm, for use with the telescope 0°; (3) trocar, diameter 2.5 mm, length 3.5 cm; (4) sharp and a blunt 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 above-mentioned 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

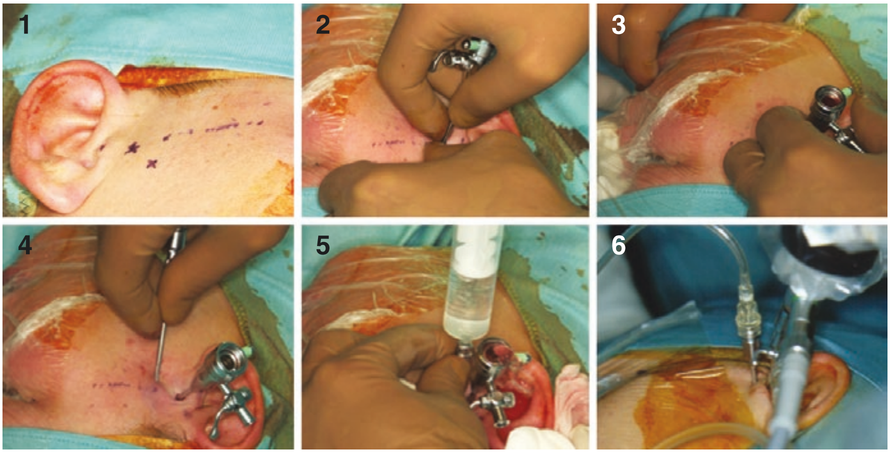

Fig. 4.7 The steps of the approaching procedure are shown: (1) The entry points are marked as described in Fig. 4.5. (2) After verification of correct place by palpating and moving the TMJ, the first sharp trocar is inserted into TMJ at the first landmark. (3) The trocar is replaced by the cannula. Moving 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.

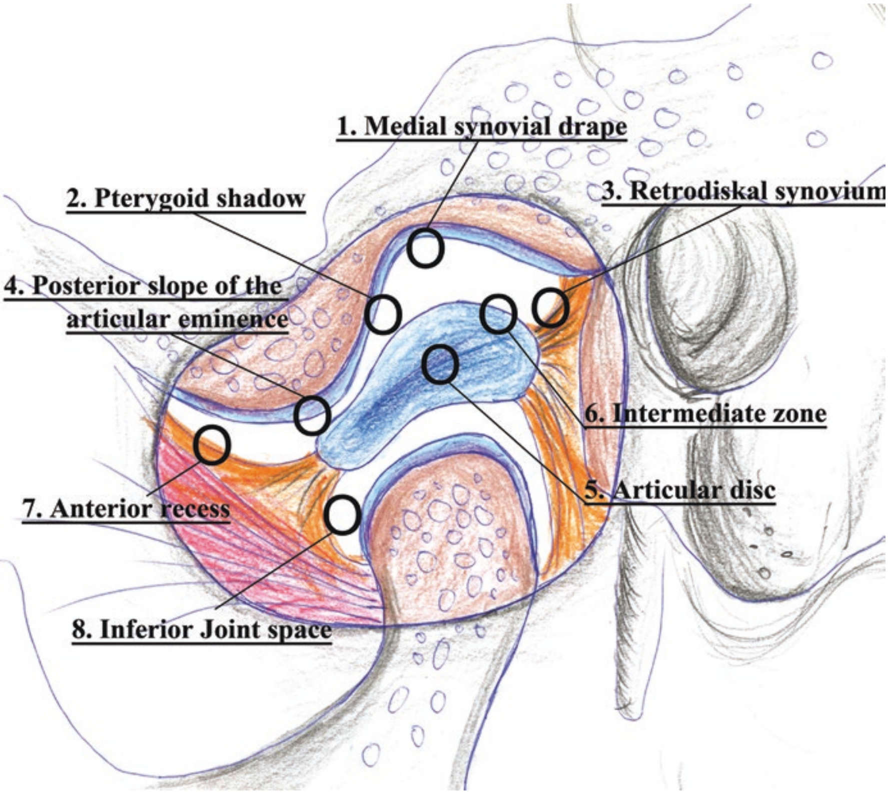

Fig. 4.8 During diagnostic TMJ arthroscopy, seven anatomic areas are to be examined: (1) the medial synovial drape, (2) the pterygoid shadow, (3) the retrodiscal synovium and the posterior ligament, (4) the posterior slope of the articular eminence and glenoid fossa, (5) the articular disc, (6) the intermediate 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

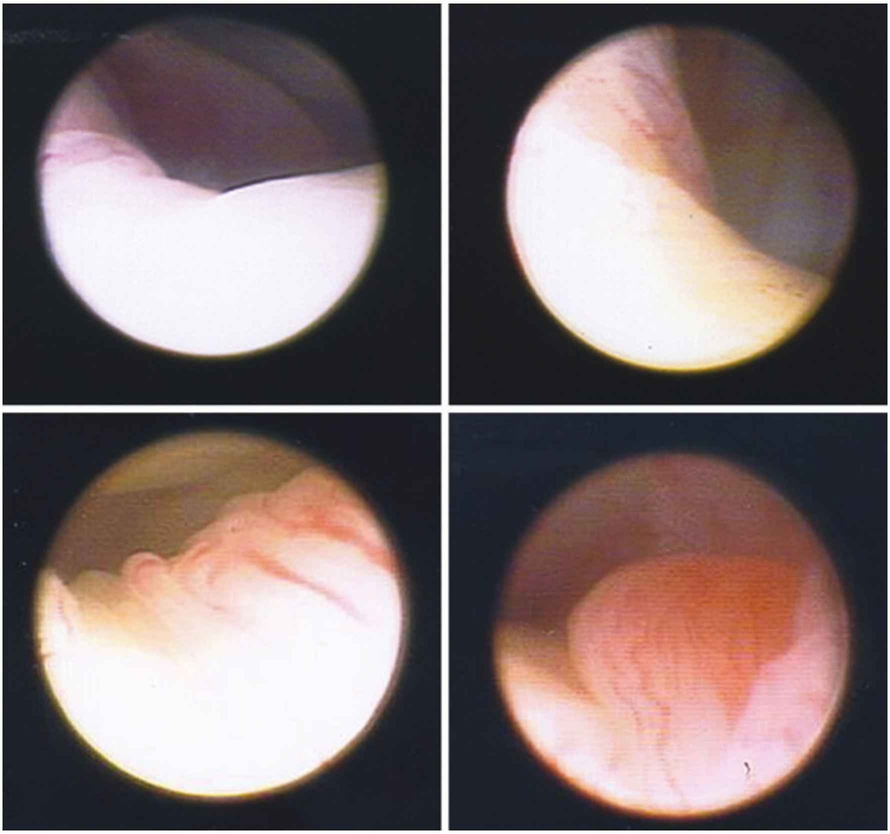

Fig. 4.9 Above: normal arthroscopic findings. View on the healthy dorsal ligament and the cross over the disc. Pathologic arthroscopic findings. View on the hyperplastic and elongated dorsal ligament

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].

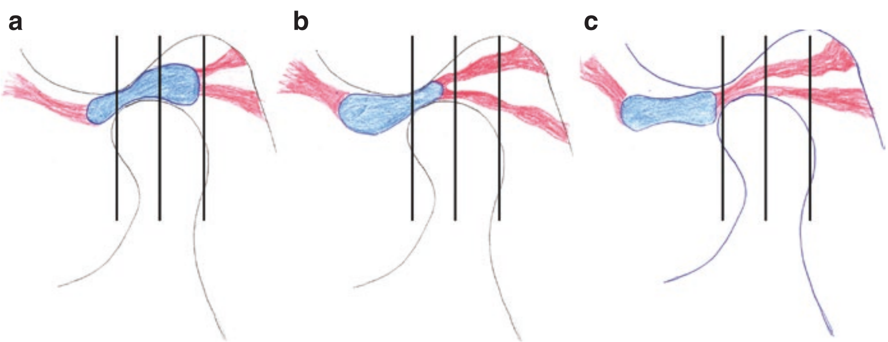

Fig. 4.10 Roofing describes the position of the posterior band of the articular disc relative to the articular eminence. (**a**) The disc is in a normal position and has a roofing of 100% if the posterior band of the disc is lying adjacent to the posterior slope of the articular eminence and abuts at 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%

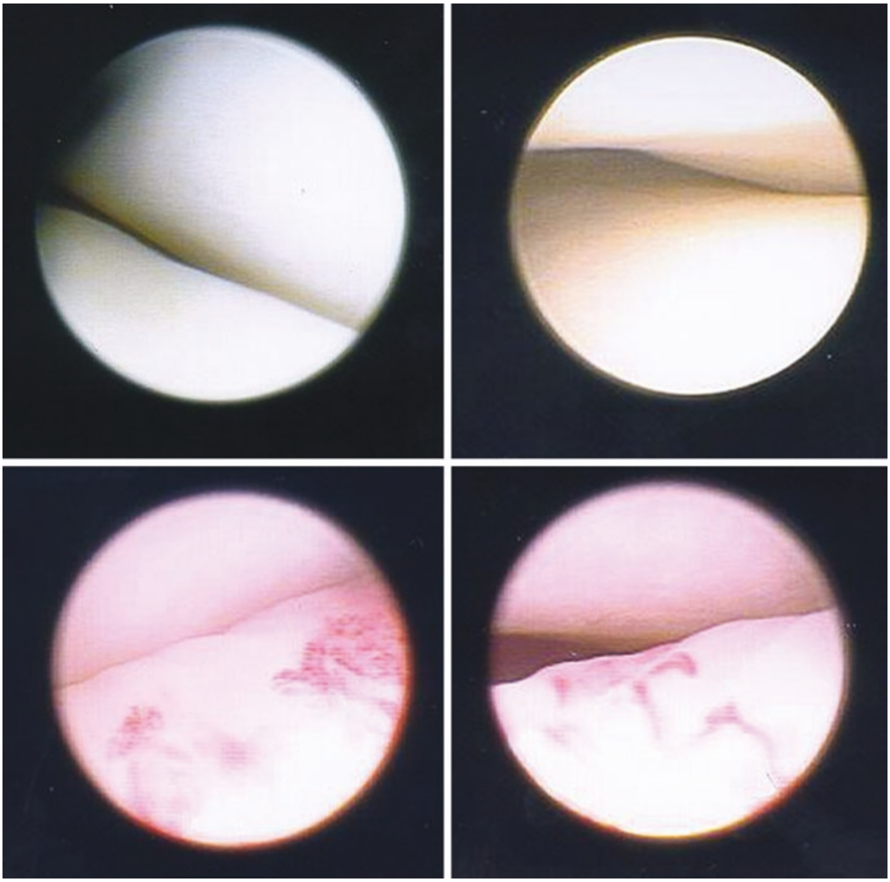

Fig. 4.11 Above: normal arthroscopic findings. View on the tuberculum articulare with regular positioned disc. Below: pathologic arthroscopic findings. View on the tuberculum articulare with the dorsal ligament underneath and anterior disc displacement

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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