Temporomandibular Joint Surgery

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1 Introduction

The history of temporomandibular joint (TMJ) surgery encompasses a list of many successful and unsuccessful attempts at re-establishing form and function and decreasing pain in the orofacial region. The first TMJ surgeries were thought to be performed in BC, primarily for treatment of pathologies such TMJ ankylosis and dislocation (Indresano and Mobati 2006). The first documentation of an intra-articular TMJ procedure is by Annandale in 1887, during which he performed a disc repositioning procedure for treatment of closed lock (Annandale 1887). Over the next several hundreds of years, the pendulum of surgical tenets, approaches, and options offered to patients with TMJ disease swung widely. This included a strong movement that promoted nonsurgical treatments after many catastrophic outcomes, followed by the use of alloplastic implants which had previously been shown to have poor biocompatibility. More recently, oral and maxillofacial surgeons (OMS) have played a major role in innovating devices and techniques in TMJ surgery through appropriately designed clinical trials, demonstrating highly effective surgical options for patients. Some of these procedures include TMJ disc excision with or without autogenous replacement, TMJ disc repositioning, autogenous costochondral TMJ reconstruction, stock and custom prosthetic TMJ replacement, as well as minimally invasive procedures such as arthrocentesis and arthroscopy. In this chapter, we will explore the history of different TMJ surgical techniques, as well as highlight landmark articles that resulted in the field of contemporary TMJ surgery that continues to evolve today with the advent of advanced technology. While we

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attempt to arrange this chapter in chronological order in regard to when the techniques were developed, the history of TMJ surgery is convoluted, and thus organization is quite challenging.

2 Gap Arthroplasty/Discectomy/Disc Repositioning

While ancient cultures were familiar with certain TMJ pathologies such as ankylosis of joints and jaw dislocation, there was no documentation of surgical treatment of these disease processes until the late 1800s. TMJ ankylosis was first treated via simple gap arthroplasty, but this procedure was often complicated by re-ankylosis (Topazian 1966). John Murray Carnochan, a prominent New York surgeon, is praised for his ideology of inter-posing a material (a block of wood) between the bony surfaces of the mandible and temporal bone after gap arthroplasty for treatment of TMJ ankylosis (Carnochan 1860). Soon thereafter, many different surgeons used this same principle of gap arthroplasty with inter-positional grafting for treatment of TMJ ankylosis.

While Gluck first made use of an Ivory prosthetic stabilized with cement to bridge the gap in 1891 (Gluck 1891), Murphy was the first to use temporalis fascia as an inter-positional graft for gap arthroplasty (Murphy 1913). In 1914, he published a case series in which he described his use of an axial rotational inter-positional flap of temporal fat and fascia to line the TMJ with the goal of restoring joint function and preventing re-ankylosis (Murphy 1914). Since then, surgeons have attempted to use many different types of inter-positional materials to restore function and range of motion, including temporalis muscle (Risdon 1933), gold foil (Risdon 1933), tantalum foil (Eggers 1946), stainless steel (Smith and Robinson 1952), dermis (Georgiade et al. 1957), full thickness skin (Popescu and Vasiliu 1977), and in the modern era, silastic and polytetrafluoroethylene (PTFE) a.k.a. Teflon materials.

Perhaps one of the darkest ages of TMJ surgery lies in the years during which silastic and Teflon implants began to be placed within the joint in the 1960s. At the time, silastic materials were known for their high thermal stability as well as their relative inertness within the human body (Mercuri 2016). Silicone was first used as an inter-positional material in 1968 during reconstructive hand surgery (Swanson 1997). Subsequently, Brown et al. reported on the use of silicone material to serve as a barrier in preventing TMJ ankylosis after gap arthroplasty (Brown et al. 1963), and others reported similar techniques (Robinson 1968). Short-term studies revealed that the silicone implants would incite formation of a reactive fibrous capsule that could possibly serve as a new disc while helping to prevent re-ankylosis (Brown et al. 1963; Spagnoli and Kent 1992).

Unfortunately, by the 1980s, studies began to describe significant complications related to silastic materials placed within the TMJ. Severe inflammatory foreign body reactions with associated regional lymphadenopathy as well as erosion of condylar heads were described in multiple reports (Dolwick and Aufdemorte 1985;

Eriksson and Westesson 1986; Hartman et al. 1988). Further studies even revealed that fragmented silicone particles had migrated within the regional lymphatics (Hartman et al. 1988). Additional follow-up studies were published conveying poor results associated with silastic implants within the TMJ (Eriksson and Westesson 1992). After review of a multitude of studies demonstrating the negative consequences of the implantation of silicone materials into the joint space, the American Association of Oral and Maxillofacial Surgeons (AAOMS) published a consensus paper recommending that the use of permanent silastic implants be discontinued (American Association of Oral and Maxillofacial Surgeons 1993a). The publication of these results was preceded by a workshop in 1992, during which AAOMS organized a meeting consisting of OMS experts, nonsurgical clinician experts in managing TMJ disorders, and biomaterial experts tasked with developing a consensus on the use of alloplastic inter-positional materials within the TMJ. The experts developed a consensus stating that silastic implants should no longer be *permanently* placed in the TMJ as an inter-positional material (American Association of Oral and Maxillofacial Surgeons 1993a). However, silastic implants have continued to be used as temporary spacers after arthroplasty and disc excision. The workshop also made detailed recommendations regarding the need for removal of implants and follow-up intervals (American Association of Oral and Maxillofacial Surgeons 1993a).

Around the same time that silastic materials began to be used for reconstruction of the TMJ, surgeons such as Small also began to report on their use of PTFE as a material for joint reconstruction after large mandibular resections (Small et al. 1964). PTFE was found to have a high density as well as a self-lubricating property, which was believed to be suitable for a ginglymoarthrodial joint such as the TMJ. Despite prior studies demonstrating Teflon fragmentation under loading that resulted in significant foreign body reactions (Charnley 1963), Cook proceeded to use Teflon as an alloplastic inter-positional material in the TMJ in 1972 (Cook 1972).

Later in that decade, Vitek Inc. (Houston, TX) began to fabricate implants in which Teflon was combined with other materials. In the 1960s, a chemical engineer by the name of Charles Homsy designed a material named Proplast, which was originally intended for use in orthopedic surgery. Given its porous nature and thus potential for tissue ingrowth and implant stabilization, it was thought to be suitable for use as an inter-positional material in TMJ surgery (Homsy 1970; Homsy et al. 1972). Proplast I (PTFE + carbon/graphite) was first developed, followed by Proplast II (PTFE + aluminum oxide) to allow for more neutral coloration of implants placed superficially (Westfall et al. 1982). Again, despite several studies demonstrating the presence of giant cells and macrophages around these intra-joint materials (Homsy et al. 1973), others continued to use Proplast implants within the TMJ and reported short-term successful outcomes (Kirsch 1984; Wade et al. 1986; Bee and Zeitler 1986). However, it was not long until there were widespread studies reporting on the deleterious effects of Teflon-based materials placed within the TMJ.

The most notable complications included severe condylar degeneration (Florine et al. 1986; Bronstein 1987), remodeling/erosion of condylar and glenoid fossa bony structures (Heffez et al. 1987), implant fragmentation (Heffez et al. 1987), and

foreign body giant cell reactions in regional lymph nodes (Lagrotteria et al. 1986). Additional longer-term studies demonstrated similar negative clinical and radiographic outcomes in patients with prior implantation of Teflon materials within the TMJ (Morgan 1988; Kaplan et al. 1988; Schellhas et al. 1988). As clinical symptoms were delayed compared to radiographic signs, patients soon began reporting symptoms including preauricular pain and swelling, limited mouth opening, occlusal changes, lymphadenopathy (Wagner and Mosby 1990), and even perforation into the middle cranial fossa (Fig. 1) (Berarducci et al. 1990).

Eventually, studies published by El-Deeb et al. and Valentine et al. demonstrated evidence of fragmentation of the Proplast implants with associated significant

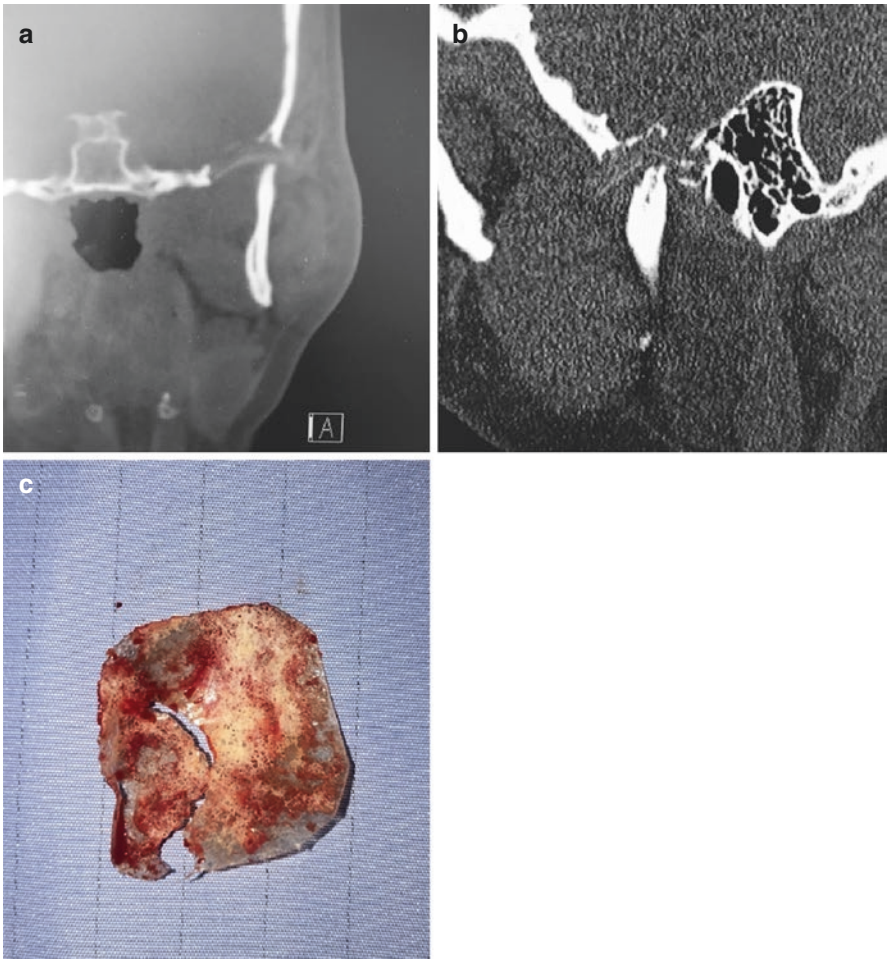

Fig. 1 (**a**) Coronal and (**b**) sagittal view of a CT scan demonstrating a Proplast implant within the TMJ resulting in erosion into the middle cranial fossa. (**c**) Explanted Proplast with evidence of significant wear leading to material perforation and implant fragmentation

foreign body reactions composed of active giant cells/osteoclasts that resulted in severe degeneration of adjacent bony structures (El Deeb and Holmes 1989; Valentine Jr. et al. 1989). Wagner and Mosby also published a long-term study revealing 95% of patients with Proplast implants reporting severe pain, along with 100% of cases with condylar degeneration (Wagner and Mosby 1990). In light of the plethora of studies revealing potential negative consequences associated with implantation of Teflon substances in the TMJ, the FDA and Center for Devices and Radiological Health issued a Public Health Advisory in September 1991 regarding the recall and close monitoring of patients with previously placed Teflon implants within the joint (Johnson 1991). In 1992, this was followed by the release of a TMJ Implant Advisory sent to all OMS regarding the published data revealing the negative outcomes seen in patients implanted with Proplast-Teflon materials (American Association of Oral and Maxillofacial Surgeons 1992). Further evaluation of published studies on the topic resulted in an AAOMS-sponsored workshop that published recommendations for discontinuation of Proplast-Teflon as an inter-positional implant for the TMJ, as well as either removal of the implant with reconstruction using autogenous tissue or close monitoring with yearly CT and/or MRI evaluation (American Association of Oral and Maxillofacial Surgeons 1993b). As a result of these devastating results associated with Teflon-Proplast implants, very strict measures have appropriately been put in place to rigorously investigate the use of any further materials to treat pathologies of the TMJ. Furthermore, these failed materials were shown to having lasting consequences, as it has been shown that TMJR outcomes are less likely to be successful after Proplast-Teflon implant failure (Henry and Wolford 1993).

In addition to treatment of ankylosis, surgical methods and approaches began to focus on treatment to improve symptoms of internal derangement of the TMJ. As such, discectomy became one surgical treatment modality, originally described by Lanz in 1909 (Lanz 1909) and further popularized by Pringle (1918) and Ashhurst (1921). Although the discectomy procedure was found to have favorable results in follow-up studies (Boman 1947; Dingman and Moorman 1951), there was a significant amount of controversy over its use given the uncertainty regarding the pathophysiology of disease within the TMJ. It wasn't until Bowman published his dissertation (Bowman 1947), and other long-term follow-up studies were published (Eriksson and Westesson 1985; Holmlund et al. 1993; Silver 1984) that discectomy became a broadly accepted, effective treatment modality for TMJ pathologies.

Although the discectomy became standard of care by the 1970s (Dingman and Moorman 1951; Kiehn and Desprez 1962), there was still controversy regarding the necessity of replacing the disc with autogenous versus alloplastic materials to prevent recurrent disease/ankylosis. Several long-term follow-up studies have shown success with discectomy without replacement of the disc (Holmlund et al. 1993; McKenna 2001). However, surgeons continued to search for a disc replacement material due to concerns regarding persistent joint noise, crepitus, and condylar resorption seen in patients who had underwent discectomy without replacement (Dimitroulis 2011a). In 1958, Gordon had described his technique of replacing the intra-articular disc with polyethylene caps to prevent re-ankylosis and collapse of

vertical dimension (Gordon 1958). In addition to their use as inter-positional materials for gap arthroplasty, alloplastic materials such as silastic and Teflon were also used to replace discs. In light of the disastrous complications resulting from inserting these materials within the TMJ, surgeons began to search for autogenous grafts to serve as an articular disc replacement (Dimitroulis 2011a). Expanding upon Murphy's use of the temporalis fat-fascia axial flap for management of TMJ ankylosis (Murphy 1913, 1914), Dimitroulis introduced the use of abdominal dermis-fat as an inter-positional graft for use in ankylotic patients (Dimitroulis 2004). Given its relative success, Dimitroulis also introduced the concept of using abdominal dermis-fat grafting after TMJ discectomy and demonstrated its ability to survive and withstand the intra-articular forces (Dimitroulis et al. 2008). Fat grafting alone after discectomy was not shown to prevent additional bony morphological changes in the mandibular condyle (Dimitroulis 2011b), and it has been found to significantly decrease in size over time in orthopedic studies (Kanamori et al. 2001). While dermis-fat grafting has been shown to resist the reduction in size of the grafting as seen with fat alone (Dimitroulis et al. 2008), prevent ankylosis (Dimitroulis et al. 2008), and result in overall improvement in quality of life (Dimitroulis et al. 2010), severe condylar changes after its placement in the joint have prevented its regular use (Dimitroulis 2011b).

Additional autogenous materials used as a disc replacement include temporalis muscle flaps (Feinberg and Larsen 1989; Pogrel and Kaban 1990), auricular cartilage (Matukas and Lachner 1990), and dermis grafts (Meyer 1988; Dimitroulis 2005). Given studies that have shown fragmentation of the grafts, low survivability, and inability to prevent condylar changes, there has not been a graft that has shown adequate strength or biologic compatibility in serving as a replacement for the TMJ articular disc (Dimitroulis 2005; Yih et al. 1992; Sandler et al. 1997). Animal studies comparing meniscectomy alone versus different disc replacement grafts have largely demonstrated similar clinical outcomes in regard to pain relief, improvement in mouth opening, and osteoarthritic changes of the condyle with or without replacement. Histologic studies revealed that discectomy alone does not result in regeneration of the disc, but rather arthritic condylar changes along with replacement of the articular surfaces by infiltration of adjacent fibrovascular tissue (a pseudo-disc) (Tong and Tideman 2000). Discectomy with replacement using autogenous grafting demonstrated an extensive fibrotic response without survival of the graft. Given these results and similar clinical outcomes in human studies comparing discectomy alone versus discectomy plus replacement with graft, the decision whether or not to replace the disc remains controversial (Dimitroulis 2011a).

In addition to complete removal of the disc, other approaches including repositioning of the disc were attempted. While Annandale performed the first disc repositioning procedure in 1887, the concept of this surgical method for the treatment of internal derangement was not well-supported until Wilkes described the form and function of the TMJ in his arthrographic studies (Mehra and Wolford 2001; Wilkes 1978a, b). McCarty described the classic disc repositioning method of performing a high condylar shave with disc release and repositioning by suturing to the posterior

attachments (McCarty and Farrar 1979). Leopard described posterior repositioning of the disc via suturing of the disc to the inferior aspect of the temporalis fascia (Leopard 1984). Walker and Kalamchi recommended condyloplasty with freeing of the articular disc, which allowed for suturing of the disc to the lateral capsule in a new position atop the condylar head (Walker and Kalamchi 1987). Eventually, Weinberg demonstrated successful outcomes in meniscocondylar plication for disc repositioning, which provided the foundation for the idea of the Mitek mini anchor (Weinberg and Cousens 1987). In 1993, Wolford et al. developed a technique in which a bone anchor, named a Mitek mini anchor (DePuy Synthes Mitek Anchor, Raynham, MA, USA), is implanted into the posterior condylar head and subsequently sutured to reposition and stabilize the articular disc (Fig. 2) (Cottrell and Wolford 1993). Since this time, the FDA has approved its use in patients for the treatment of internal derangement of the TMJ. Additional bone anchors, including the JuggerKnot Mini Soft anchor (Zimmer BioMet, Warsaw, IN, USA) (Hanley et al. 2015) and the Arthrex Corkscrew anchor (Arthrex Inc., Naples, USA) (Ryba et al. 2015), have also been developed for use in TMJ disc repositioning surgery.

TMJ ankylosis, along with internal derangement, served as the primary pathologies that led to the development of partial and total reconstruction of the joint. Although gap arthroplasty with inter-positional grafting for TMJ ankylosis has been shown to promote improved joint range of motion compared to gap arthroplasty alone (Ma et al. 2015), many studies have shown variable results in regard to re-ankylosis and restoration of function (Topazian 1966) (Ramezanian and Yavary 2006; Zhi et al. 2009). This, along with incomplete resolution of symptoms after

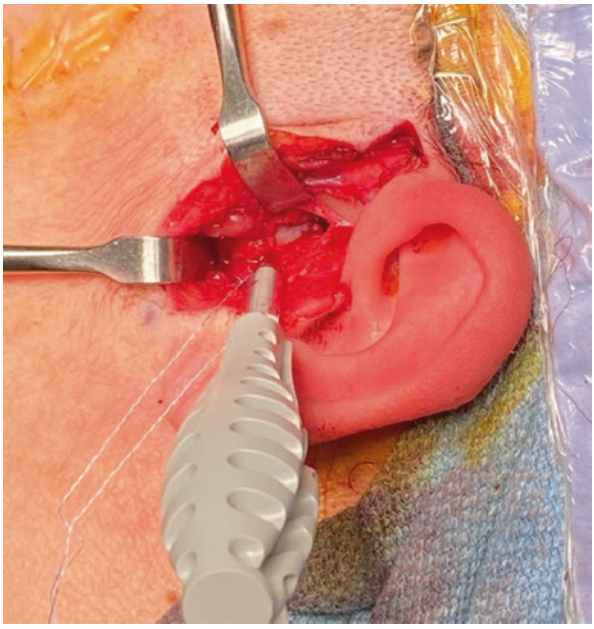

Fig. 2 Insertion of JuggerKnot Mini Soft anchor into the condylar head for the purpose of TMJ disc repositioning

discectomy/disc repositioning in the case of internal derangement, inspired surgeons to develop techniques for excision with TMJ reconstruction of joint articulation with both autogenous and alloplastic materials.

3 TMJ Reconstruction: Autologous and Alloplastic

The history of TMJ reconstruction includes unfortunate catastrophic failures and recent success. The goal of TMJ reconstruction is to restore form and function. In addition, the primary goal should focus on improving quality of life for the patient. Loss of TMJ functionality most often results from ankylosis, internally deranged joints/osteoarthritis, high inflammatory arthritides, as well as less common etiologies such as congenital abnormalities and neoplastic processes. The constant daily use of the TMJ, as well as the complex physiology of a joint that is capable of both rotational and translational movements, creates a significant hardship in effectively restoring form and function via reconstruction. A plethora of both autologous and alloplastic materials have been used to partially and totally reconstruct the TMJ.

3.1 Autogenous

Several different autologous grafts have been used to attempt to reconstruct the TMJ (Lindqvist et al. 1986; MacIntosh and Henny 1977). In 1909, Lexer was the first to describe the use of "joint allotransplantation," during which he used a costochondral graft to reconstruct a proximal tibia after excision of a sarcoma (Lexer 1909; Nikolaou and Giannoudis 2017). Bardenheur is then credited as the first surgeon to replace the mandibular condyle with an autograft (fourth metatarsal) in 1909 (Lexer 1925), while Gillies is well-known for being the first to reconstruct the TMJ with a costochondral allograft (MacIntosh and Henny 1977; Gillies 1920). The use of an osteochondral allograft was promising, as it allowed for the use of an avascular tissue to replace both hyaline cartilage and a significant bony deficiency.

Since this time, surgeons have attempted to use many different types of autografts for TMJ reconstruction, including iliac, metatarsal, tibial, fibula, and sternoclavicular tissues (Smith and Robinson 1952; Entin 1958; Dingman and Grabb 1964; Plotnikov 1965; Ware and Taylor 1966; Snyder et al. 1971). The uses of these autografts have had variable results, specifically given their inconsistent adaptability and lack of growth potential (Poswillo 1974). Most surgeons have collectively agreed that the costochondral graft functions best as a replacement of the mandibular condyle given its biological and physiological similarities, along with low donor site morbidity (Lindqvist et al. 1986; Freihofer and Perko 1976; Kennett 1973). Furthermore, biologic studies were carried out to prove superiority of the costochondral graft compared to other autografts, given its proliferative nature as well as its remodeling and growth properties (Poswillo 1974; Blackwood 1966; Durkin

et al. 1973). Long-term follow-up studies have also confirmed the efficacy of costochondral grafts for TMJ reconstruction (Lindqvist et al. 1988; Perrott et al. 1994; Figueroa et al. 1984). Resnick et al. also recently developed a consensus regarding the use of costochondral grafts and other surgical modalities in the specific treatment of patients with juvenile idiopathic arthritis (JIA) (Resnick et al. 2019).

3.2 Alloplastic

The safety and efficacy of alloplastic joints in the orthopedic literature encouraged the OMS community to seek alloplastic implant options for their patients with severe TMJ disease (Charnley 1961). While alloplastic TMJ replacement is now a widely accepted procedure within the scope of OMS today, the history of placing alloplastic implants within the TMJ is fraught with publications describing drastic failures of materials such as the Kent-Vitek prosthesis (Vitek, Houston, TX, USA) as well as the Christensen, Osteomed, and Delrin-Timesh prostheses (Mercuri 2016; Driemel et al. 2009). One of the major advantages of alloplastic joint reconstruction is that it afforded the surgeon the ability to efficiently and predictably restore form and function to the TMJ without any donor site morbidity or need for maxillomandibular fixation (Donlon 2000).

Eggers was the first to describe placement of an alloplastic material between the mandible and cranium when he placed tantalum foil in the intra-joint space for the treatment of ankylosis (Eggers 1946). Subsequently, Smith and Robinson published on the use of a stainless steel fossa (Robinson 1960; Smith and Robinson 1957), while Henry published on the use of stainless steel as a means of replacing the mandibular condyle (Henry 1960). Ward, who also popularized the modified condylotomy approach for the treatment of TMJ internal derangement, published on the use of cobalt-chrome alloy to reconstruct the TMJ (Ward 1961). Notably in 1963, based on Robinson's method of creating a fossa prosthesis, Christensen designed a 0.5-mm Vitallium-based glenoid fossa eminence prosthesis to reconstruct the TMJ as well as provide a mechanical barrier for prevention of re-ankylosis (Christensen 1963, 1964). With this method, Christensen fabricated castings of 20 different-sized glenoid fossae prostheses made of rigid, polishable Vitallium that can be sized intraoperatively and anchored to the zygoma. Eventually, he expanded the stock of casted prostheses to 33 per side and then 44 to broaden the surgeons' reconstructive options for anatomic variations (Fig. 3) (Christensen 1964). Eventually, Christensen went on to describe the first total joint replacement device for the TMJ. The device consisted of his previously described Vitallium fossa prosthesis along with a condylar component made of cobalt-chrome (Co-Cr) alloy and a molded polymethylmethacrylate (PMMA) condylar head (Driemel et al. 2009; Christensen 1971). In 1996, he eventually discontinued the use of the PMMA head given reports of material resorption under function (Mercuri 1996). Almost 5000 Christensen prostheses had been implanted between 1993 and 2003, and their use continued until the FDA ordered a cease and desist order in 2015 due to non-compliance with 522

Fig. 3 Original set of Christensen set containing 33 variations of stock prostheses for reconstruction of the TMJ

post-market surveillance studies (Christensen 1971; TMJ 2021). Christensen also eventually developed an all-cast-Vitallium custom total joint prosthesis using CAD/CAM technology to treat more surgically and anatomically complex patients (Garrett et al. 1997).

In 1971, Morgan described alternative fossa eminence prostheses that consisted of a Vitallium eminence and eventually added a silastic articulating component given the degenerative changes seen within the condylar head (Morgan 1971; Morgan and Hall 1985). Eventually, the use of permanent silastic implants for TMJ surgery was discontinued given the significant foreign body reaction observed in patients (Eriksson and Westesson 1986; American Association of Oral and Maxillofacial Surgeons 1993a). Soon thereafter, Morgan went on to develop his own ramus-condyle replacement that consisted of an acrylic condylar head (House et al. 1984; Morgan 1992). Kiehn is also credited for the development of a Vitallium condylar-fossa prosthesis reinforced with PMMA (Kiehn et al. 1974).

Others had also reported on the idea of hemiarthroplasty, in which an alloplastic condylar component functions against a natural disc/fossa without an alloplastic fossa component. Authors have reported on the use of custom cast gold ramus-condyle units (Tauras et al. 1972), methyl methacrylate (Kameros and Himmelfarb 1975), Delrin (polyoxymethylene)-titanium (Boyne et al. 1987), Vitallium (Kiehn et al. 1974; Silver et al. 1977; Hahn 1964), Vitallium with PMMA cement (Silver et al. 1977), as well as the controversial Proplast-coated Ticonium condylar prosthesis (Hinds et al. 1974). Despite studies on TMJ hemiarthroplasty demonstrating successful outcomes with low complication rates (Marx et al. 2008), other studies have discredited its use given the potential dreadful complication of severe bony erosion into the cranial base (Lindqvist et al. 1992; Westermark et al. 2006).

In 1976, Spiessl attempted to decrease the risk of glenoid fossa resorption by altering the condylar head design in his AO/ASIF system (Spiessl 1976). He designed both short and long models of a condylar reconstruction plate (Prein 2002), although reports were still made describing erosions into the glenoid fossa (Lindqvist et al. 2002). Attempts were made to make use of the AO/ASIF system

while preserving the articular disc or in conjunction with lining the glenoid fossa with a pedicled flap (Prein 2002; Klotch et al. 1998).

In 1972, Kent et al. published a pilot study describing the use of a condylar prosthesis with its head coated with Teflon-Proplast (Kent et al. 1972). Accordingly, Kent added a Teflon-Proplast fossa prosthesis consisting of a Proplast superior layer with a Teflon inferior layer (Kent et al. 1983), which collectively with the condylar unit became known as the Vitek-Kent I (VK-I) total joint prosthesis. The Vitek-Kent II (VK-II) was then subsequently described, which also included PTFE within the fossa component (Kent et al. 1986).

Throughout the 1980s the Vitek-Kent prosthesis was commonly used as a means for alloplastic joint reconstruction. During this time, Rooney et al. published a study with concerning findings of significant foreign body reaction to PTFE resulting in condylar degeneration (Rooney et al. 1988). Given the concerns for fracturing of the Teflon-Proplast fossae resulting in significant foreign body reactions, the Teflon portion of the Vitek-Kent prosthesis was eventually replaced with polyethylene. Kent subsequently reported an update on the follow-up of the VK-I and VK-II prostheses, which had 80% success rate at 6 years and 20% success rate at 10 years (Kent et al. 1993). Given the material failure of the Proplast-Teflon with associated foreign body giant cell reaction, patients who had undergone reconstruction with these devices underwent frequent imaging and follow-up to evaluate for the need for device removal (Spagnoli and Kent 1992; Feinerman and Piecuch 1993). These complications resulted in millions of dollars in claims and the official revoking of prior FDA approval (Speculand et al. 2000). As such, TMJ devices were reclassified as class III devices, suggesting the high risk posed to the patient and thus necessitating stringent pre- and post-market approval processes (FDA 2021).

After the devastating material failure of the Teflon-Proplast system, several other surgeons set out to develop other materials for alloplastic reconstruction, including ceramic implants (Szabo et al. 1990), titanium-based implants (Raveh et al. 1984; MacAfee and Quinn 1992; Butow et al. 2001), and titanium-polyethylene combinations (Sonnenburg et al. 1984; Sonnenburg and Sonnenburg 1990). Van Loon reported biomechanical studies demonstrating the acceptable wear resistance of metal-on-UHMWPE total TMJ prostheses (Van Loon et al. 1999, 2000). Others attempted to expand upon the AO/ASIF with adjustable/add-on condylar prostheses, but placement and positioning of the device proved to be quite technically difficult (Driemel et al. 2007; Raveh et al. 1980; Vuillemin et al. 1989).

In the early 1990s, Mercuri made use of the emerging advanced technology by developing the TMJ Concepts Prosthesis (Techmedica model) (Mercuri et al. 1995). This model made use of pre-operative CT scanning and CAD/CAM technology to fabricate custom condylar and fossa prostheses designed to fit the specific anatomy of each patient. Its condylar component consisted of a titanium alloy mandibular shaft with a cobalt-chromium-molybdenum (Co-Cr-Mo) condylar head, while its fossa component consisted of a titanium mesh with an articulating surface composed of ultra-high-molecular-weight polyethylene (UHMWPE) that is designed to maximize contact with the condylar head (Fig. 4) (Mercuri 2000). Given the

extensive pre-operative surgical planning resulting in precise device fitting, the TMJ Concepts facilitated the reconstruction of TMJs that have been undergone multiple operations resulting in distorted anatomy (Mercuri et al. 2002; Wolford et al. 1994). After long-term follow-up studies demonstrating successful results, the TMJ Concepts prosthesis obtained FDA approval in 1999 (Driemel et al. 2009; Mercuri et al. 2002). Others such as Butow (Butow et al. 2001) and Hoffman and Pappas (Fig. 5) (Hoffman and Pappas 2000) had prostheses in development at the same time, but ultimately did not receive FDA clearance. These devices had titanium nitride at the condylar and fossa contacting surfaces to produce more wear-resistant components.

Also in the 1990s, Quinn and Van Loon built upon the ideology of a stock metal-on-polyethylene prosthesis to produce a more cost-effective, wear-resistant stock prosthesis (van Loon et al. 2000, 2002; Quinn 2000). In 1995, Quinn introduced the Biomet-Lorenz total joint stock prosthesis, which consisted of Co-Cr condylar heads with titanium plasma spray coating of different lengths and widths and a UHMWPE fossa of multiple flange sizes (Figs. 6 and 7) (Quinn 2000). This led to

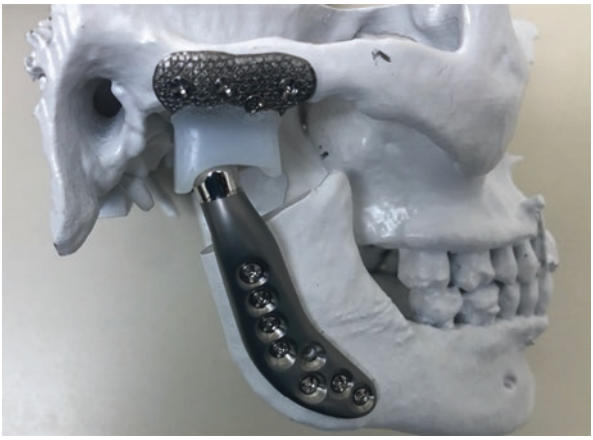

Fig. 4 Custom TMJ Concepts prosthesis with Co-Cr-Mo condylar head and titanium mesh + UHMWPE fossa component

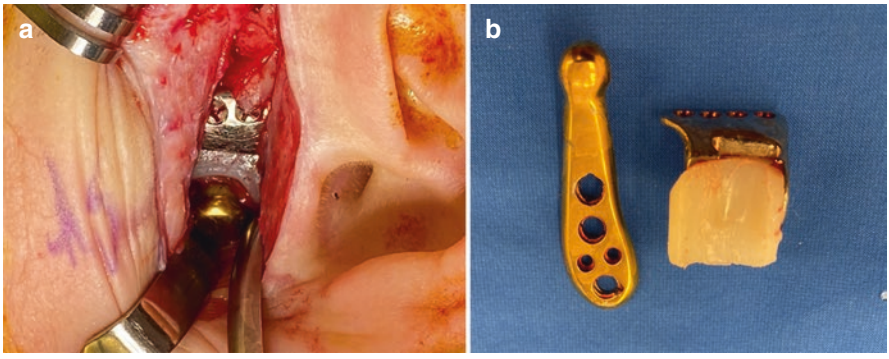

Fig. 5 Hoffman-Pappas device (**a**) implanted within the patient and (**b**) explanted

Fig. 6 Original Biomet-Lorenz TMJ replacement set

an investigational device exemption study published in 2012 demonstrating the safety and efficacy of the Biomet-Lorenz stock prosthesis (Giannakopoulos et al. 2012), and the device was approved by the FDA in 2010. A recent FDA post-market study by Granquist et al. revealed a similar survivorship rate and subsequent surgical intervention rate to that of other orthopedic joint replacements (Granquist et al. 2020).

4 Arthroscopy

As TMJ surgery continued to evolve throughout the 1900s with many successes and failures, OMS began to take notice of the orthopedic surgery literature and their minimally invasive techniques of treating diseased joints. A long history of endoscopic procedures exists in the orthopedic literature, dating back to the first use of an endoscope 1853. A French surgeon named Antoine Jean Desormeaux, now known as the "Father of Endoscopy," first demonstrated the use of an endoscope (named the Lichtleiter) in a patient for a urology procedure (Indresano and Mobati 2006; Figdor 2004). The endoscope primarily functioned as a cystoscope until 1918, when Japanese surgeon Kenji Takagi described the use of a 3.5-mm

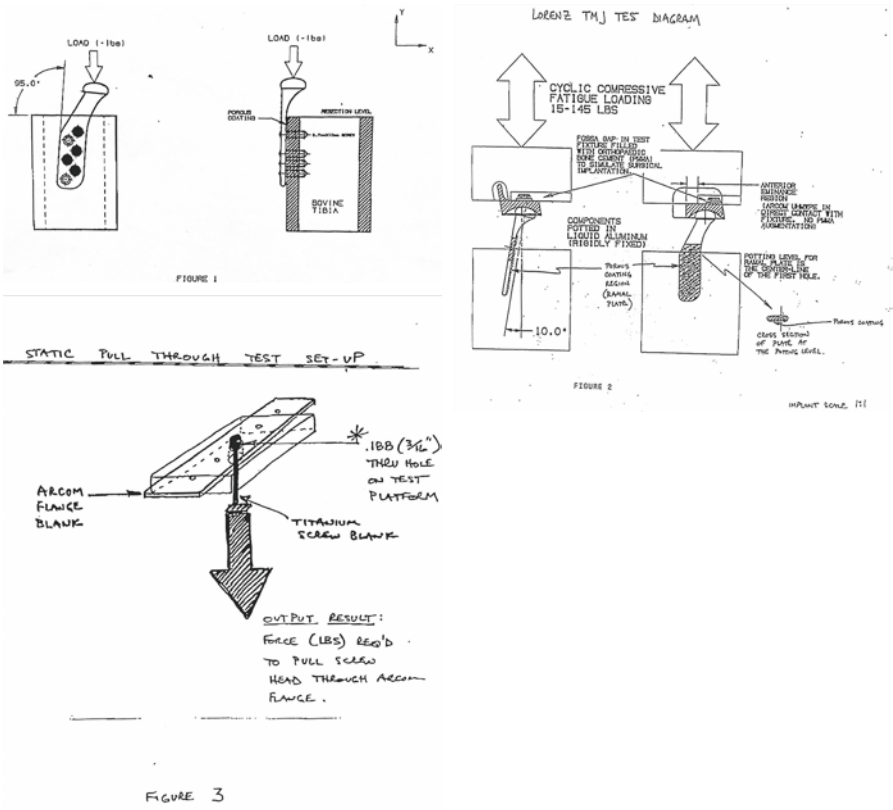

Fig. 7 Original design sketches by Dr. Peter Quinn demonstrating the biomechanical testing of the load and cyclic compressive fatigue for the Biomet-Lorenz TMJ prosthesis

cystoscope to perform diagnostic arthroscopies of cadaver knee joints (de Mello Granata Jr 2012). He subsequently helped design an arthroscope in 1920 and then published a case series including photos of his knee arthroscopies (Indresano and Mobati 2006; de Mello Granata Jr 2012). As additional studies were published describing diagnostic techniques using the arthroscope (Kreuscher 1925) and technologic advances allowed for the development of smaller arthroscopes with improved optics, TMJ surgeons took notice of this minimally invasive technique.

After the development of the small joint arthroscope by Watanabe in 1958 (Watanabe 1986; Watanabe and Takeda 1960) (Fig. 8), a Japanese surgeon by the name of Ohnishi was the first to describe its use for performing a TMJ arthroscopy in 1975 (Onishi 1975). As additional studies out of Japan by Murakami had described arthroscopy as a minimally invasive, useful adjunct in the treatment of patients with TMJ disorders (Murakami and Ono 1986; Murakami et al. 1986;

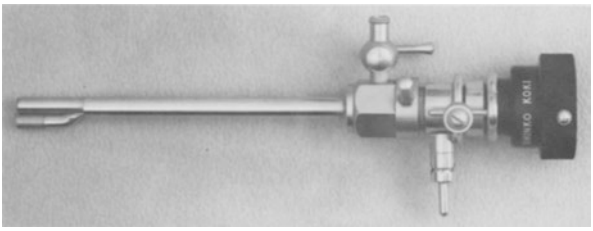

Fig. 8 The original no. 21 arthroscope developed by Watanabe in 1958 (Watanabe and Takeda 1960)

Murakami and Ito 1981, 1984), Sanders introduced the technique of TMJ arthroscopy in the United States (Sanders 1986).

Subsequent clinical studies carried out by Sanders, Murakami, and McCain evaluated the efficacy of arthroscopy of the TMJ and solidified its diagnostic and therapeutic use in the United States (Murakami et al. 1986; Sanders and Buoncristiani 1987; McCain 1988; McCain et al. 1989). In particular, Murakami published on the use of arthroscopy to evaluate joint adhesions (Murakami and Segami 1993), and Bronstein demonstrated its use in determining disc position (Bronstein 1989). McCain also published on advanced operative techniques in which the disc could be manipulated and repositioned using arthroscopy (McCain et al. 1992a). McCain and Sanders subsequently published a study describing high success rate of arthroscopies of over 4800 TMJs in 1992 (McCain et al. 1992b), with additional studies demonstrating high efficacy (Sanders and Buoncristiani 1993). Additional advanced techniques including the use of sclerotherapy (Merrill 1993) and laser treatments (Indresano and Bradrick 1993) were also developed and described. Further significant technological advances have also been made to develop state-of-the-art arthroscopes specifically designed to improve upon visualization of the temporomandibular joint space (Fig. 9). In a controversial surgical field troubled by the recent failure of alloplastic materials in TMJ replacements, TMJ arthroscopy served as an initial, safe, inexpensive, effective means of treating TMJ disease via lysis and lavage and offered an option to patient to potentially spare an open procedure.

5 Arthrocentesis

Evidence of the first "arthrocentesis" as a treatment for intra-joint fluid accumulation dates to the sixteenth century, during which it was described in the Aztec literature. During this time, the technique of simple paracentesis was often performed to treat joint effusions (Emmart 1940; Rodnan et al. 1966). In 1792, a French surgeon by the name of Jean Gay described the successful outcomes associated with his technique of paracentesis along with injection of "medication" into a knee joint. With the intention of decreasing inflammation, Gay injected a mixture of wine, brandy, and rum into the knee joint of two separate patients, noting a significant post-operative improvement in symptoms (Rodnan et al. 1966).

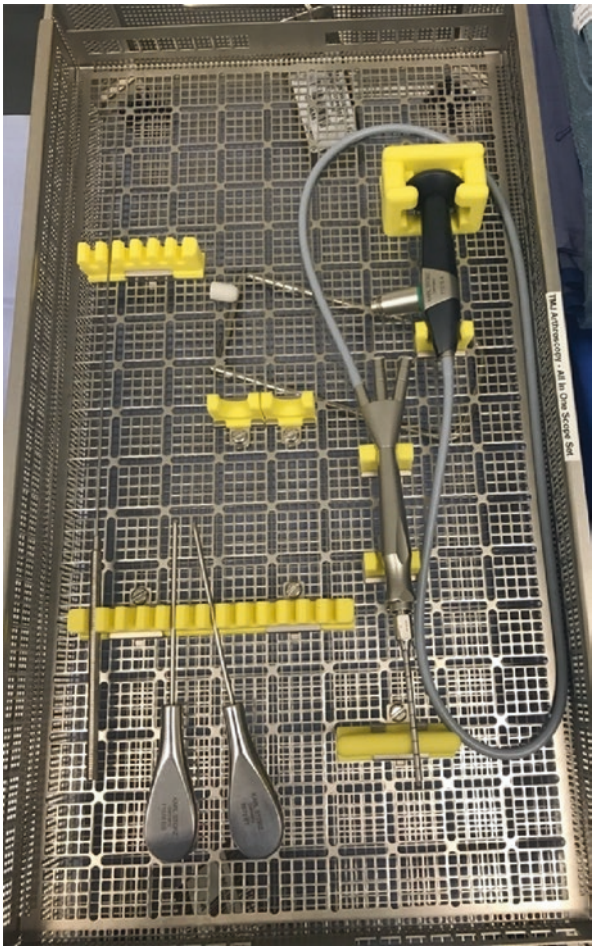

Fig. 9 Contemporary Karl Storz model all-in-one TMJ arthroscope system

In 1947, Schultz was the first to describe injection into the TMJ. He injected sodium psylliate into the periarticular region with the intent of stimulating a fibrotic response to limit condylar mobility in order to treat joint hypermobility (Schultz 1947). In 1950, McKelvey demonstrated successful patient outcomes of his own by injecting sclerosing solutions into the periarticular region of the TMJ to treat subluxation (McKelvey 1950). Later in 1987, Murakami et al. published on their use of arthrocentesis in the treatment of closed lock. Their team described a technique of readjusting the mandible while inducing hydraulic pressure with lidocaine in the upper joint space with a 21-gauage needle (Murakami et al. 1987). Nitzan, Dolwick, and colleagues then built upon Murakami's technique by describing the lavage of the TMJ with lactated ringers by placing two separate needles (one used for inflow, the other for outflow) into the superior joint space. They described successful results in patients with trismus, with lavage resulting in improvement in pain scores, improvement in maximal incisal opening, and lasting symptom relief (Nitzan et al.

1991). Although initially only used for acute closed lock, TMJ arthrocentesis is now used for a variety of conditions associated with the joint including disc displacement, synovitis, rheumatoid arthritis, disc adhesions, and hemarthrosis, with other medications such as steroids, anti-inflammatories, and lubricating agents commonly being injected.

References

American Association of Oral and Maxillofacial Surgeons. TMJ implant advisory. August 1992.
American Association of Oral and Maxillofacial Surgeons. Recommendations for management of patients with temporomandibular joint implants. Temporomandibular Joint Implant Surgery Workshop. J Oral Maxillofac Surg. 1993a;51(10):1164–72.
American Association of Oral and Maxillofacial Surgeons. Recommendations for management of patients with temporomandibular joint implants. Temporomandibular Joint Implant Surgery Workshop. J Oral Maxillofac Surg. 1993b;340:510–3.
Annandale T. Displacement of the interarticular cartilage of the lower jaw and its treatment by operation. Lancet. 1887;8:411.
Ashhurst AP. Recurrent unilateral subluxation of the mandible excision of the interarticular cartilage in cases of snapping jaw. Ann Surg. 1921;73(6):712–5.
Bee D, Zeitler D. The Proplast-Teflon implant in TMJ reconstruction following meniscectomy. 68th annual meeting of the American Association of Oral and Maxillofacial Surgeons New Orleans, LA. 1986.
Berarducci JP, Thompson DA, Scheffer RB. Perforation into middle cranial fossa as a sequel to use of a Proplast-Teflon implant for temporomandibular joint reconstruction. J Oral Maxillofac Surg. 1990;48(5):496–8.
Blackwood HJ. Growth of the mandibular condyle of the rat studied with tritiated thymidine. Arch Oral Biol. 1966;11(5):493–500.
Boman K. Temporomandibular joint arthrosis and its treatment by extirpation of the disc. Acta Chir Scand. 1947;95:1.
Bowman K. Temporomandibular joint arthrosis and its treatment by extirpation of the disk: a clinical study. Acta Chir Scand Suppl. 1947;118:225 p.
Boyne PJ, Mathews FR, Stringer DE. TMJ bone remodeling after polyoxymethylene condylar replacement. Int J Oral Maxillofac Implants. 1987;2(1):29–33.
Bronstein SL. Retained alloplastic temporomandibular joint disk implants: a retrospective study. Oral Surg Oral Med Oral Pathol. 1987;64(2):135–45.
Bronstein SL. Diagnostic and operative arthroscopy: historical perspectives and indications. Oral Maxillofac Surg Clin North Am. 1989;1:59–68.
Brown JB, Fryer MP, Kollias P, Ohlwiler DA, Templeton JB. Silicone and Teflon prostheses, including full jaw substitution: laboratory and clinical studies of Etheron. Ann Surg. 1963;157:932–43.
Butow KW, Blackbeard GA, van der Merwe AE. Titanium/titanium nitride temporomandibular joint prosthesis: historical background and a six-year clinical review. SADJ. 2001;56(8):370–6.
Carnochan J. Mobilizing a patient's ankylosed jaw by placing a block of wood between the raw bony surfaces after resection. Arch Med. 1860:284.
Charnley J. Arthroplasty of the hip. A new operation. Lancet. 1961;1(7187):1129–32.
Charnley J. Tissue reaction to the polytetrafluoroethylene. Lancet. 1963;2:1379.
Christensen RW. The correction of mandibular ankylosis by arthroplasty and the insertion of a cast Vitallium glenoid fossa. South Calif Dent Assoc. 1963;31:117–8.

Christensen RW. Mandibular joint arthrosis corrected by the insertion of a cast-Vitallium glenoid fossa prosthesis: a new technique. Report of a case. Oral Surg Oral Med Oral Pathol. 1964;17:712–22.
Christensen RW. The temporomandibular joint prosthesis eleven years later. Oral Implantol. 1971;2(2):125–33.
Cook HP. Teflon implantation in temporomandibular arthroplasty. Oral Surg Oral Med Oral Pathol. 1972;33(5):706–16.
Cottrell DA, Wolford LM. The Mitek mini anchor in maxillofacial surgery. J Oral Maxillofac Surg. 1993;57(3):150.
de Mello Granata GS Jr. A hundred years of knee arthroscopy. Rev Bras Ortop. 2012;47(6):684.
Dimitroulis G. The interpositional dermis-fat graft in the management of temporomandibular joint ankylosis. Int J Oral Maxillofac Surg. 2004;33(8):755–60.
Dimitroulis G. The use of dermis grafts after discectomy for internal derangement of the temporomandibular joint. J Oral Maxillofac Surg. 2005;63(2):173–8.
Dimitroulis G. A critical review of interpositional grafts following temporomandibular joint discectomy with an overview of the dermis-fat graft. Int J Oral Maxillofac Surg. 2011a;40(6):561–8.
Dimitroulis G. Condylar morphology after temporomandibular joint discectomy with interpositional abdominal dermis-fat graft. J Oral Maxillofac Surg. 2011b;69(2):439–46.
Dimitroulis G, Trost N, Morrison W. The radiological fate of dermis-fat grafts in the human temporomandibular joint using magnetic resonance imaging. Int J Oral Maxillofac Surg. 2008;37(3):249–54.
Dimitroulis G, McCullough M, Morrison W. Quality-of-life survey comparing patients before and after discectomy of the temporomandibular joint. J Oral Maxillofac Surg. 2010;68(1):101–6.
Dingman RO, Grabb WC. Reconstruction of both mandibular condyles with metatarsal bone grafts. Plast Reconstr Surg. 1964;34:441–51.
Dingman RO, Moorman WC. Meniscectomy in the treatment of lesions of the temporomandibular joint. J Oral Surg (Chic). 1951;9(3):214–24.
Dolwick MF, Aufdemorte TB. Silicone-induced foreign body reaction and lymphadenopathy after temporomandibular joint arthroplasty. Oral Surg Oral Med Oral Pathol. 1985;59(5):449–52.
Donlon WC. Total temporomandibular joint reconstruction. Philadelphia: W.B. Saunders Company; 2000.
Driemel O, Carlson ER, Muller-Richter U, Moralis A, Lienhard S, Wagener S, et al. New condylar head system for temporary condylar reconstruction in ablative tumour surgery. Mund Kiefer Gesichtschir. 2007;11(4):193–9.
Driemel O, Braun S, Muller-Richter UD, Behr M, Reichert TE, Kunkel M, et al. Historical development of alloplastic temporomandibular joint replacement after 1945 and state of the art. Int J Oral Maxillofac Surg. 2009;38(9):909–20.
Durkin JF, Heeley JD, Irving JT. The cartilage of the mandibular condyle. Oral Sci Rev. 1973;2:29–99.
Eggers GW. Arthroplasty of the temporomandibular joint in children with interposition of tantalum foil. J Bone Joint Surg Am. 1946;28:603–6.
El Deeb M, Holmes RE. Zygomatic and mandibular augmentation with Proplast and porous hydroxyapatite in Rhesus monkeys. J Oral Maxillofac Surg. 1989;47(5):480–8.
Emmart EW. The Badianus manuscript (Codex Barberini Latin 241). Baltimore: The Johns Hopkins Press; 1940.
Entin MA. Reconstruction in congenital deformity of the temporo-mandibular component. Plast Reconstr Surg Transplant Bull. 1958;21(6):461–9.
Eriksson L, Westesson PL. Long-term evaluation of meniscectomy of the temporomandibular joint. J Oral Maxillofac Surg. 1985;43(4):263–9.
Eriksson L, Westesson PL. Deterioration of temporary silicone implant in the temporomandibular joint: a clinical and arthroscopic follow-up study. Oral Surg Oral Med Oral Pathol. 1986;62(1):2–6.

Eriksson L, Westesson PL. Temporomandibular joint diskectomy. No positive effect of temporary silicone implant in a 5-year follow-up. Oral Surg Oral Med Oral Pathol. 1992;74(3):259–72.
FDA. Temporomandibular joint implants. Silver Spring: US Food and Drug Administration; 2021. Available from: https://www.fda.gov/medical-devices/temporomandibular-disorders-tmd-devices/temporomandibular-joint-tmj-implants#implants.
Feinberg SE, Larsen PE. The use of a pedicled temporalis muscle-pericranial flap for replacement of the TMJ disc: preliminary report. J Oral Maxillofac Surg. 1989;47(2):142–6.
Feinerman DM, Piecuch JF. Long-term retrospective analysis of twenty-three Proplast-Teflon temporomandibular joint interpositional implants. Int J Oral Maxillofac Surg. 1993;22(1):11–6.
Figdor PP. The development of endoscopy in the 19th century. Tuttlingen: Endo Press; 2004.
Figueroa AA, Gans BJ, Pruzansky S. Long-term follow-up of a mandibular costochondral graft. Oral Surg Oral Med Oral Pathol. 1984;58(3):257–68.
Florine B, Gatto D, Wade M. Pre- and post-surgical tomographic analysis of TMJ arthroplasties. J Oral Maxillofac Surg. 1986;44(11):M3.
Freihofer HP, Perko MA. Simultaneous reconstruction of the area of the temporo-mandibular joint including the ramus of the mandible in a posttraumatic case. A case report. J Maxillofac Surg. 1976;4(2):124–8.
Garrett WR, Abbey PA, Christensen R. Temporomandibular joint reconstruction with a custom total temporomandibular joint prosthesis: use in the multiply operated patient. Surg Technol Int. 1997;6:347–54.
Georgiade N, Altany F, Pickrell K. An experimental and clinical evaluation of autogenous dermal grafts used in the treatment of temporomandibular joint ankylosis. Plast Reconstr Surg (1946). 1957;19(4):321–36.
Giannakopoulos HE, Sinn DP, Quinn PD. Biomet Microfixation Temporomandibular Joint Replacement System: a 3-year follow-up study of patients treated during 1995 to 2005. J Oral Maxillofac Surg. 2012;70(4):787–94; discussion 95–6.
Gillies HD. Plastic surgery of the face. London: Oxford University Press; 1920.
Gluck T. Referat Uber die Durch das Moderne Chirurgische Expierment Gewonnenen Positven Resultate, Betreffenddie Naht und den Ersatz von Defecten Hoerer Gewebe, Sowie Uber die Verwerthung Resorbirbarer und Bebendiger Tampons in der Chirgurie. Arch Klin Chir. 1891;4:186.
Gordon SD. Surgery of the temporomandibular joint. Am J Surg. 1958;95(2):263–6.
Granquist EJ, Bouloux G, Dattilo D, Gonzalez O, Louis PJ, McCain J, et al. Outcomes and survivorship of Biomet microfixation total joint replacement system: results from an FDA postmarket study. J Oral Maxillofac Surg. 2020;78(9):1499–508.
Hahn G. Vitallium mesh mandibular prosthesis. J Prosthet Dent. 1964;14:777–84.
Hanley C, Martin SR, Sullivan S. Utilization of the all-suture Biomet Juggerknot Soft Anchor for disc repositioning in the surgical management of internal derangements of the temporomandibular joint. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015;119(5):e254.
Hartman LC, Bessette RW, Baier RE, Meyer AE, Wirth J. Silicone rubber temporomandibular joint (TMJ) meniscal replacements: postimplant histopathologic and material evaluation. J Biomed Mater Res. 1988;22(6):475–84.
Heffez L, Mafee MF, Rosenberg H, Langer B. CT evaluation of TMJ disc replacement with a Proplast-Teflon laminate. J Oral Maxillofac Surg. 1987;45(8):657–65.
Henry T. Prosthetic restoration of the left temporomandibular joint in a case of partial ankylosis. In: Transactions of the 2nd congress international society of plastic surgeons. London: Livingstone; 1960. 159 p.
Henry CH, Wolford LM. Treatment outcomes for temporomandibular joint reconstruction after Proplast-Teflon implant failure. J Oral Maxillofac Surg. 1993;51(4):352–8; discussion 9–60.
Hinds EC, Homsy CA, Kent JN. Use of a biocompatible interface for binding tissues and prostheses in temporomandibular joint surgery. Follow-up report. Oral Surg Oral Med Oral Pathol. 1974;38(4):512–9.

Hoffman D, Pappas M. Hoffman-Pappas prosthesis. Oral Maxillofac Surg Clin North Am. 2000;12(1):105–24.
Holmlund AB, Gynther G, Axelsson S. Diskectomy in treatment of internal derangement of the temporomandibular joint. Follow-up at 1, 3, and 5 years. Oral Surg Oral Med Oral Pathol. 1993;76(3):266–71.
Homsy CA. Bio-compatibility in selection of materials for implantation. J Biomed Mater Res. 1970;4(3):341–56.
Homsy CA, Cain TE, Kessler FB, Anderson MS, King JW. Porous implant systems for prosthesis stabilization. Clin Orthop Relat Res. 1972;89:220–35.
Homsy CA, Kent JN, Hinds EC. Materials for oral implantation--biological and functional criteria. J Am Dent Assoc. 1973;86(4):817–32.
House L, Morgan DH, Hall WP, Vamvas SJ. Temporomandibular joint surgery. Report of a 14 year joint implant study. Laryngoscope. 1984;94:537–8.
Indresano AT, Bradrick J. Arthroscopic laser procedures. Philadelphia: WB Saunders; 1993.
Indresano AT, Mobati DA. History of temporomandibular joint surgery. Oral Maxillofac Surg Clin North Am. 2006;18(3):283–9, v.
Johnson RM. Public health advisory on Vitek Proplast TMJ implants. 1991.
Kameros J, Himmelfarb R. Treatment of TMJ ankylosis with methyl methacrylate interpositional arthroplasty. J Oral Surg. 1975;33:282–91.
Kanamori M, Kawaguchi Y, Ohmori K, Kimura T, Md HT, Matsui H. The fate of autogenous free-fat grafts after posterior lumbar surgery: part 1. A postoperative serial magnetic resonance imaging study. Spine (Phila Pa 1976). 2001;26(20):2258–63.
Kaplan PA, Ruskin JD, Tu HK, Knibbe MA. Erosive arthritis of the temporomandibular joint caused by Teflon-Proplast implants: plain film features. AJR Am J Roentgenol. 1988;151(2):337–9.
Kennett S. Temporomandibular joint ankylosis: the rationale for grafting in the young patient. J Oral Surg. 1973;31(10):744–8.
Kent JN, Homsy CA, Gross BD, Hinds EC. Pilot studies of a porous implant in dentistry and oral surgery. J Oral Surg. 1972;30(8):608–15.
Kent JN, Misiek DJ, Akin RK, Hinds EC, Homsy CA. Temporomandibular joint condylar prosthesis: a ten-year report. J Oral Maxillofac Surg. 1983;41(4):245–54.
Kent JN, Block MS, Homsy CA, Prewitt JM 3rd, Reid R. Experience with a polymer glenoid fossa prosthesis for partial or total temporomandibular joint reconstruction. J Oral Maxillofac Surg. 1986;44(7):520–33.
Kent JN, Block MS, Halpern J, Fontenot MG. Update on the vitek partial and total temporomandibular joint systems. J Oral Maxillofac Surg. 1993;51(4):408–15; discussion 15–6.
Kiehn CL, Desprez JD. Meniscectomy for internal derangement of temporomandibular joint. Br J Plast Surg. 1962;15:199–204.
Kiehn CL, DesPrez JD, Converse CF. A new procedure for total temporomandibular joint replacement. Plast Reconstr Surg. 1974;53(2):221–6.
Kirsch T. The use of Protoplast-Teflon implants for meniscectomy and disc repair in the temporomandibular joint. Annual meeting of the American Association of Oral and Maxillofacial Surgeons. 1984.
Klotch DW, Lindqvist C, Schusterman MA, Prein J. Reconstructive tumor surgery in the mandible. Berlin: Springer; 1998.
Kreuscher P. Semilunar cartilage disease. A plea for early recognition by means of the arthroscope and early treatment of this condition. Ill Med J. 1925;47:290.
Lagrotteria L, Scapino R, Granston AS, Felgenhauer D. Patient with lymphadenopathy following temporomandibular joint arthroplasty with Proplast. Cranio. 1986;4(2):172–8.
Lanz A. Discitis mandibularis. Zentralbl Chir. 1909;36:289–91.
Leopard PJ. Anterior dislocation of the temporomandibular disc. Br J Oral Maxillofac Surg. 1984;22(1):9–17.
Lexer E. Uber Gelenktransplantation. Arch Klin Chir. 1909;90:263.
Lexer E. Joint transplantations and arthroplasty. Surg Gynecol Obstet. 1925;40:782.

Lindqvist C, Pihakari A, Tasanen A, Hampf G. Autogenous costochondral grafts in temporomandibular joint arthroplasty. A survey of 66 arthroplasties in 60 patients. J Maxillofac Surg. 1986;14(3):143–9.
Lindqvist C, Jokinen J, Paukku P, Tasanen A. Adaptation of autogenous costochondral grafts used for temporomandibular joint reconstruction: a long-term clinical and radiologic follow-up. J Oral Maxillofac Surg. 1988;46(6):465–70.
Lindqvist C, Soderholm AL, Hallikainen D, Sjovall L. Erosion and heterotopic bone formation after alloplastic temporomandibular joint reconstruction. J Oral Maxillofac Surg. 1992;50(9):942–9; discussion 50.
Lindqvist C, Söderholm A-L, Hallikainen D. Problems related to mandibular condylar prosthesis. Berlin: Springer; 2002.
Ma J, Liang L, Jiang H, Gu B. Gap arthroplasty versus interpositional arthroplasty for temporomandibular joint ankylosis: a meta-analysis. PLoS One. 2015;10(5):e0127652.
MacAfee KA, Quinn PD. Total temporomandibular joint reconstruction with a Delrin titanium implant. J Craniofac Surg. 1992;3(3):160–9.
MacIntosh RB, Henny FA. A spectrum of application of autogenous costochondral grafts. J Maxillofac Surg. 1977;5(4):257–67.
Marx RE, Cillo JE Jr, Broumand V, Ulloa JJ. Outcome analysis of mandibular condylar replacements in tumor and trauma reconstruction: a prospective analysis of 131 cases with long-term follow-up. J Oral Maxillofac Surg. 2008;66(12):2515–23.
Matukas VJ, Lachner J. The use of autologous auricular cartilage for temporomandibular joint disc replacement: a preliminary report. J Oral Maxillofac Surg. 1990;48(4):348–53.
McCain JP. Arthroscopy of the human temporomandibular joint. J Oral Maxillofac Surg. 1988;46(8):648–55.
McCain JP, de la Rua H, Le Blanc WG. Correlation of clinical, radiographic, and arthroscopic findings in internal derangements of the TMJ. J Oral Maxillofac Surg. 1989;47(9):913–21.
McCain JP, Podrasky AE, Zabiegalski NA. Arthroscopic disc repositioning and suturing: a preliminary report. J Oral Maxillofac Surg. 1992a;50(6):568–79; discussion 79–80.
McCain JP, Sanders B, Koslin MG, Quinn JH, Peters PB, Indresano AT. Temporomandibular joint arthroscopy: a 6-year multicenter retrospective study of 4,831 joints. J Oral Maxillofac Surg. 1992b;50(9):926–30.
McCarty WL, Farrar WB. Surgery for internal derangements of the temporomandibular joint. J Prosthet Dent. 1979;42(2):191–6.
McKelvey L. Sclerosing solution in the treatment of chronic subluxation of the temporomandibular joint. J Oral Surg (Chic). 1950;8(3):225–36.
McKenna SJ. Discectomy for the treatment of internal derangements of the temporomandibular joint. J Oral Maxillofac Surg. 2001;59(9):1051–6.
Mehra P, Wolford LM. The Mitek mini anchor for TMJ disc repositioning: surgical technique and results. Int J Oral Maxillofac Surg. 2001;30(6):497–503.
Mercuri LG. The Christensen prosthesis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1996;81(2):134–5.
Mercuri LG. The TMJ concepts patient fitted total temporomandibular joint reconstruction prosthesis. Philadelphia: Saunders; 2000.
Mercuri LG. Temporomandibular joint total joint replacement – TMJ TJR. Cham: Springer; 2016.
Mercuri LG, Wolford LM, Sanders B, White RD, Hurder A, Henderson W. Custom CAD/CAM total temporomandibular joint reconstruction system: preliminary multicenter report. J Oral Maxillofac Surg. 1995;53(2):106–15; discussion 15–6.
Mercuri LG, Wolford LM, Sanders B, White RD, Giobbie-Hurder A. Long-term follow-up of the CAD/CAM patient fitted total temporomandibular joint reconstruction system. J Oral Maxillofac Surg. 2002;60(12):1440–8.
Merrill R. Arthroscopic temporomandibular joint lysis, lavage, and manipulation and chemical sclerotherapy for painful hypermobility and recurrent mandibular dislocation. Philadelphia: WB Saunders; 1993.

Meyer RA. The autogenous dermal graft in temporomandibular joint disc surgery. J Oral Maxillofac Surg. 1988;46(11):948–54.
Morgan D. Dysfunction, pain, tinnitus, vertigo corrected by mandibular joint surgery. J South Calif Dent Assoc. 1971;39:505–7.
Morgan DH. Evaluation of alloplastic TMJ implants. Cranio. 1988;6(3):224–38.
Morgan DH. Development of alloplastic materials for temporomandibular joint prosthesis: a historical perspective with clinical illustrations. Cranio. 1992;10(3):192–204.
Morgan DH, Hall WP. Addition of a Silastic and metal implant to a metallic condyle. Cranio. 1985;3:179–83.
Murakami K, Ito K. Arthroscopy of the temporomandibular joint: arthroscopic anatomy and arthroscopic approaches in the human cadaver. Arthoscopy. 1981;6:1–13.
Murakami K, Ito K. Arthroscopy of the temporomandibular joint third report; clinical experiences. Arthoscopy. 1984;9:49–59.
Murakami K, Ono T. Temporomandibular joint arthroscopy by inferolateral approach. Int J Oral Maxillofac Surg. 1986;15(4):410–7.
Murakami K, Segami N. Intra-articular adhesions of the temporomandibular joint: arthroscopic views and clinical perspectives. Philadelphia: WB Saunders; 1993.
Murakami KI, Lizuka T, Matsuki M, Ono T. Diagnostic arthroscopy of the TMJ: differential diagnoses in patients with limited jaw opening. Cranio. 1986;4(2):117–26.
Murakami KI, Iizuka T, Matsuki M, Ono T. Recapturing the persistent anteriorly displaced disk by mandibular manipulation after pumping and hydraulic pressure to the upper joint cavity of the temporomandibular joint. Cranio. 1987;5(1):17–24.
Murphy J. Bony ankylosis of jaw with interposition of flaps from temporal fascia. Surg Clin. 1913;2:659.
Murphy J. Arthroplasty for intra-articular bony and fibrous ankylosis of temporomandibular articulartion. J Am Med Assoc. 1914;62:1783–94.
Nikolaou VS, Giannoudis PV. History of osteochondral allograft transplantation. Injury. 2017;48(7):1283–6.
Nitzan DW, Dolwick MF, Martinez GA. Temporomandibular joint arthrocentesis: a simplified treatment for severe, limited mouth opening. J Oral Maxillofac Surg. 1991;49(11):1163–7; discussion 8–70.
Onishi M. Arthroscopy of the temporomandibular joint (author's transl). Kokubyo Gakkai Zasshi. 1975;42(2):207–13.
Perrott DH, Umeda H, Kaban LB. Costochondral graft construction/reconstruction of the ramus/condyle unit: long-term follow-up. Int J Oral Maxillofac Surg. 1994;23(6 Pt 1):321–8.
Plotnikov NA. Methoden der Aufbereitung und Konservierung lyophilisierter Knochen-Homotransplantatezur Substitution bei Unterkieferdefekte. Chir Plast. 1965;2:65.
Pogrel MA, Kaban LB. The role of a temporalis fascia and muscle flap in temporomandibular joint surgery. J Oral Maxillofac Surg. 1990;48(1):14–9.
Popescu V, Vasiliu D. Treatment of temporo-mandibular ankylosis with particular reference to the interposition of full-thickness skin autotransplant. J Maxillofac Surg. 1977;5(1):3–14.
Poswillo D. Experimental reconstruction of the mandibular joint. Int J Oral Surg. 1974;3(6):400–11.
Prein J. Condylar prosthesis for the replacement of the mandibular condyle. Berlin: Springer; 2002. p. 372–6.
Pringle J. Displacement of the mandibular meniscus and its treatment. Br J Surg. 1918;6(23):385–9.
Quinn P. Lorenz prosthesis. Oral Maxillofac Surg Clin North Am. 2000;12(1):93–104.
Ramezanian M, Yavary T. Comparison of gap arthroplasty and interpositional gap arthroplasty on the temporomandibular joint ankylosis. Acta Med Iran. 2006;44(6):391–4.
Raveh J, Stich H, Schawalder P, Sutter F, Straumann F. Conservative and surgical measures to restore temporomandibular joint function and new possibilities and methods for bridging defects in the mandible. SSO Schweiz Monatsschr Zahnheilkd. 1980;90(10):932–48.
Raveh J, Stich H, Sutter F, Greiner R. Use of the titanium-coated hollow screw and reconstruction plate system in bridging of lower jaw defects. J Oral Maxillofac Surg. 1984;42(5):281–94.

Resnick CM, Frid P, Norholt SE, Stoustrup P, Peacock ZS, Kaban LB, et al. An algorithm for management of dentofacial deformity resulting from juvenile idiopathic arthritis: results of a multinational consensus conference. J Oral Maxillofac Surg. 2019;77(6):1152.e1–e33.
Risdon F. Ankylosis of the temporomandibular joint. J Am Dent Assoc. 1933;21:1933–7.
Robinson M. Temporomandibular ankylosis corrected by creating a false stainless steel fossa. J South Calif Dent Assoc. 1960;28:186–9.
Robinson M. Temporomandibular ankylosis corrected by creating a false silastic sponge fossa. J South Calif Dent Assoc. 1968;36(1):14–6.
Rodnan GP, Benedek TG, Panetta WC. The early history of synovia (joint fluid). Ann Intern Med. 1966;65(4):821–42.
Rooney TP, Haug RH, Toor AH, Indresano AT. Rapid condylar degeneration after glenoid fossa prosthesis insertion: report of three cases. J Oral Maxillofac Surg. 1988;46(3):240–6.
Ryba FM, Ali A, Matthews NS. Temporomandibular joint meniscopexy using the Arthrex Corkscrew(R) mini anchor system: technical note. Br J Oral Maxillofac Surg. 2015;53(3):299–300.
Sanders B. Arthroscopic surgery of the temporomandibular joint: treatment of internal derangement with persistent closed lock. Oral Surg Oral Med Oral Pathol. 1986;62(4):361–72.
Sanders B, Buoncristiani R. Diagnostic and surgical arthroscopy of the temporomandibular joint: clinical experience with 137 procedures over a 2-year period. J Craniomandib Disord. 1987;1(3):202–13.
Sanders B, Buoncristiani R. A 5-year experience with arthroscopic lysis and lavage for treatment of painful temporomandibular joint hypomobility. Philadelphia: WB Saunders; 1993. p. 21–4.
Sandler NA, Macmillan C, Buckley MJ, Barnes L. Histologic and histochemical changes in failed auricular cartilage grafts used for a temporomandibular joint disc replacement: a report of three cases and review of the literature. J Oral Maxillofac Surg. 1997;55(9):1014–9.
Schellhas KP, Wilkes CH, el Deeb M, Lagrotteria LB, Omlie MR. Permanent Proplast temporomandibular joint implants: MR imaging of destructive complications. AJR Am J Roentgenol. 1988;151(4):731–5.
Schultz LW. Report of ten years' experience in treating hypermobility of the temporomandibular joints. J Oral Surg (Chic). 1947;5(3):202–7.
Silver CM. Long-term results of meniscectomy of the temporomandibular joint. Cranio. 1984;3(1):46–57.
Silver CM, Motamed M, Carlotti AE Jr. Arthroplasty of the temporomandibular joint with use of a Vitallium condyle prosthesis: report of three cases. J Oral Surg. 1977;35(11):909–14.
Small IA, Brown S, Kobernick SD. Teflon and Silastic for mandibular replacement: experimental studies and reports of cases. J Oral Surg Anesth Hosp Dent Serv. 1964;22:377–90.
Smith AE, Robinson M. A new surgical procedure in bilateral reconstruction of condyles, utilizing iliac bone grafts and creation of new joints by means of non-electrolytic metal; a preliminary report. Plast Reconstr Surg (1946). 1952;9(5):393–409.
Smith AE, Robinson M. A new surgical procedure for the creation of a false temporomandibular joint in cases of ankylosis by means of non-electrolytic metal. Am J Surg. 1957;94(6):837–45.
Snyder CC, Levine GA, Dingman DL. Trial of a sternoclavicular whole joint graft as a substitute for the temporomandibular joint. Plast Reconstr Surg. 1971;48(5):447–52.
Sonnenburg M, Sonnenburg I. Development and clinical application of the total temporomandibular joint (T.M.J.) endoprosthesis. Rev Stomatol Chir Maxillofac. 1990;91(2):165–9.
Sonnenburg I, Fethke K, Sonnenburg M. Pressure load of the temporomandibular joint--an experimental study. Anat Anz. 1984;155(1–5):309–15.
Spagnoli D, Kent JN. Multicenter evaluation of temporomandibular joint Proplast-Teflon disk implant. Oral Surg Oral Med Oral Pathol. 1992;74(4):411–21.
Speculand B, Hensher R, Powell D. Total prosthetic replacement of the TMJ: experience with two systems 1988-1997. Br J Oral Maxillofac Surg. 2000;38(4):360–9.
Spiessl B. First experiences with a temporomandibular-joint prosthesis. Fortschr Kiefer Gesichtschir. 1976;21:119–21.

Swanson AB. Silicone rubber implants for replacement of arthritic or destroyed joints in the hand. 1968. Clin Orthop Relat Res. 1997;(342):4–10.
Szabo G, Barabas J, Matrai J, Gyorgy J, Miklos L. Application of compact aluminum oxide ceramic implants in maxillofacial surgery. J Oral Maxillofac Surg. 1990;48(4):354–61.
Tauras SP, Jordan JE, Keen RR. Temporomandibular joint ankylosis corrected with a gold prosthesis. J Oral Surg. 1972;30:767–73.
TMJ. TMJ device and regulatory history. Milwaukee: The TMJ Association; 2021. Available from: https://tmj.org/living-with-tmj/tmj-implants/tmj-device-and-regulatory-history/.
Tong AC, Tideman H. A comparative study on meniscectomy and autogenous graft replacement of the Rhesus monkey temporomandibular joint articular disc--Part I. Int J Oral Maxillofac Surg. 2000;29(2):140–5.
Topazian RG. Comparison of gap and interposition arthroplasty in the treatment of temporomandibular joint ankylosis. J Oral Surg. 1966;24(5):405–9.
Valentine JD Jr, Reiman BE, Beuttenmuller EA, Donovan MG. Light and electron microscopic evaluation of Proplast II TMJ disc implants. J Oral Maxillofac Surg. 1989;47(7):689–96.
Van Loon JP, Verkerke GJ, de Bont LG, Liem RS. Wear-testing of a temporomandibular joint prosthesis: UHMWPE and PTFE against a metal ball, in water and in serum. Biomaterials. 1999;20(16):1471–8.
van Loon JP, Verkerke GJ, de Vries MP, de Bont LG. Design and wear testing of a temporomandibular joint prosthesis articulation. J Dent Res. 2000;79(2):715–21.
van Loon JP, de Bont LG, Stegenga B, Spijkervet FK, Verkerke GJ. Groningen temporomandibular joint prosthesis. Development and first clinical application. Int J Oral Maxillofac Surg. 2002;31(1):44–52.
Vuillemin T, Raveh J, Sutter F. Mandibular reconstruction with the THORP condylar prosthesis after hemimandibulectomy. J Craniomaxillofac Surg. 1989;17(2):78–87.
Wade M, Gatto D, Florine B. Assessment of Proplast implants in meniscoplasties as temporomandibular joint surgical procedures. 68th annual meeting of the American Association of Oral and Maxillofacial Surgeons New Orleans, LA. 1986.
Wagner JD, Mosby EL. Assessment of Proplast-Teflon disc replacements. J Oral Maxillofac Surg. 1990;48(11):1140–4.
Walker RV, Kalamchi S. A surgical technique for management of internal derangement of the temporomandibular joint. J Oral Maxillofac Surg. 1987;45(4):299–305.
Ward TG. Surgery of the mandibular joint. Ann R Coll Surg Engl. 1961;28:139–52.
Ware WH, Taylor RC. Growth center transplantation to replace damaged mandibular condyles. J Am Dent Assoc. 1966;73(1):128–37.
Watanabe M. Memories of the early days of arthroscopy. Arthroscopy. 1986;2(4):209–14.
Watanabe M, Takeda S. The number 21 arthroscope. J Jpn Orthop Assoc. 1960;34:1041.
Weinberg S, Cousens G. Meniscocondylar plication: a modified operation for surgical repositioning of the ectopic temporomandibular joint meniscus. Rationale and operative technique. Oral Surg Oral Med Oral Pathol. 1987;63(4):393–402.
Westermark A, Koppel D, Leiggener C. Condylar replacement alone is not sufficient for prosthetic reconstruction of the temporomandibular joint. Int J Oral Maxillofac Surg. 2006;35(6):488–92.
Westfall RL, Homsy CA, Kent JN. A comparison of porous composite PTFE/graphite and PTFE/aluminum oxide facial implants in primates. J Oral Maxillofac Surg. 1982;40(12):771–5.
Wilkes CH. Structural and functional alterations of the temporomandibular joint. Northwest Dent. 1978a;57(5):287–94.
Wilkes CH. Arthrography of the temporomandibular joint in patients with the TMJ pain-dysfunction syndrome. Minn Med. 1978b;61(11):645–52.
Wolford LM, Cottrell DA, Henry CH. Temporomandibular joint reconstruction of the complex patient with the Techmedica custom-made total joint prosthesis. J Oral Maxillofac Surg. 1994;52(1):2–10; discussion 1.

Yih WY, Zysset M, Merrill RG. Histologic study of the fate of autogenous auricular cartilage grafts in the human temporomandibular joint. J Oral Maxillofac Surg. 1992;50(9):964–7; discussion 8.

Zhi K, Ren W, Zhou H, Gao L, Zhao L, Hou C, et al. Management of temporomandibular joint ankylosis: 11 years' clinical experience. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(5):687–92.