Temporomandibular Joint Replacement—Past, Present and Future: A Bioengineering Perspective

I. Islam, J.S.P. Loh, and R.C.W. Wong

Abstract

Temporomandibular Joint disorders are a major cause of non-dental pain in the maxillofacial region. Total replacement of the TMJ is indicated for patients with severe degenerative or inflammatory diseases as well as for losses due to trauma or tumor. and morbidity. Alloplastic replacement has been successful but problems continue to exist. This paper will address some of the historical perspectives and advances in the field of TMJ total reconstruction as well as prospects and implications for future designs.

Keywords

TMJ reconstruction • Alloplastic reconstruction • Prosthesis • Bioengineering • Tissue engineering

1 Introduction

Temporomandibular disorders (TMD) is a collective term used to describe a number of related disorders and clinical problems involving the masticatory muscles and/or the temporomandibular joints (TMJ) [1]. They are a major cause of non-dental pain in the orofacial region. The most common reason for treatment seeking is pain, usually localized in the muscles of mastication, the preauricular area, and/or the TMJ. Most of the patients can be adequately treated by a combination of conservative techniques including rest, reassurance, analgesics and physiotherapy [2]. However, patients who are not responsive to conservative therapy or who have advanced degenerative diseases require surgical intervention and often joint replacement.

Total replacement of the TMJ is indicated for patients with severe degenerative or inflammatory joint diseases as well as for ankyloses and traumatic bone loss [3]. The reconstruction of the Temporomandibular joint can be a very complex and challenging problem. The reconstruction must take into account both the anatomical complexity of the joint and its proximity to the base of the skull as well as the biomechanics modulating the function of the joint. Over the last few years, total replacement of the TMJ has gained more and more popularity as favorable treatment outcomes have been reported with total joint replacements [4–6]. This paper will review the historical development of TMJ prosthesis and look at the treatment options available today. Future prospects and implications for future designs will be discussed.

2 Historical Overview

The first report of an alloplastic material in a joint was in 1946 by Eggers who placed a tantalum foil over the mandibular stump as well as the base of skull to prevent re-ankylosis [7]. A stainless steel plate was used by Smith and Robinson in 1957 for the same purpose [8]. In 1960 Robinson went on to describe a pseudo stainless steel prosthesis by placing a stainless steel box against the fossa and eminence and in 1968, he used a silastic sponge for the

I. Islam (✉) · R.C.W. Wong
Disciple of Oral and Maxillofacial Surgery, Faculty of Dentistry, National University of Singapore, 11 Lower Kent Ridge Road, Singapore, Singapore
e-mail: denii@nus.edu.sg

J.S.P. Loh
Disciple of Oral and Maxillofacial Surgery, National University Hospital, Singapore, Singapore

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same purpose [9]. In 1972, a pilot study of a proplast coated chrome-cobalt condylar prosthesis was published [10]. The prosthesis was fixed to the mandibular ramus by three or four screws. Spiessl in 1976 used a spherical head articulated against the condylar fossa fixed to the mandibular ramus by five to seven screws. They incorporated V shaped notches between the screws to allow the surgeon to bend the plate to fit the ramus. This was known as the AO/ASIF prosthesis [11]. However subsequent studies showed a lot of resorption of the fossa and it was concluded that a glenoid fossa implant is also necessary [12].

In 1965 Christensen had already introduced a TMJ condylar prosthesis along with a fossa-eminence prosthesis to form a total joint prosthesis. It comprised of an acrylic head fixed to a vitallium plate. Kent et al. in 1983 added a fossa prosthesis to the condylar process and was known as the vitek-Kent TMJ total joint prosthesis [13]. They designed the fossa in a S shape based on tracings from lateral radiographs and the fossa had a laminated construction of Proplast and Teflon. However, in vivo wear rates later showed a lifespan of only three years and a large amount of polymer debris causing foreign body reaction [14]. Proplast was unable to bear compressive loads and collapsed and proplast fragments caused bone resorption and excessive foreign body reaction [15, 16] The Vitek-Kent prosthesis was withdrawn in 1990. This led to a major setback in research involving TMJ prosthesis and the field did not progress for a while. In the early 1990s a number of stock TMJ devices were introduced. These included the Morgan prosthesis, the Christensen prosthesis, the Osteomed and the Delrin-Timesh prosthesis. Most of these suffered from mechanical failure including particle wear, mechanical loosening and fracture of the metal components. A major breakthrough in the field occurred when the reports of a patient fitted total temporomandibular joint system (Techmedica) was published by Mercuri et al. [17]. In 1995, Biomet introduced a stock TMJ total joint reconstruction device called the Lorenz Total Temporomandibular Joint Implant. It was later renamed as the Biomet Microfixation TMJ replacement system.

The three recent TMJ prosthetic systems (Techmedica/TMJ Concepts, Christensen/TMJ Implants, Biomet/Lorenz) are compared in Table 1 (Figs. 1, 2 and 3). All the three systems present a ball and socket type prosthetic joint similar to the hip implant. The condylar component is made of metal (cobalt chrome alloy or titanium). The fossa is made of either a ultra high molecular weight polyethylene or titanium or cobalt chrome alloy. The Christensen/TMJ Implants used a cobalt chromium fossa and a cobalt chromium condylar head. The original condylar head was covered by a methyl methacrylate head. This original system was associated with fracture of the condylar component. The current system is an all metal on metal prosthesis. Speculand et al. reported results with the Vitek VK II and the Christensen systems in 68 patients. Four vitek prosthesis were replaced by the Christensen system and the overall success rate was 94% [18]. The Biomet system is a metal on polyethylene design. The TMJ Concepts system consist of a customized titanium shell lined with a UHMWPE surface with a posterior stop to allow a centric relation position for the condylar head [4]. The mandibular component is manufactured from a titanium, aluminium, vanadium alloy.

The custom prosthesis design involves manufacturing customized TMJ reconstruction devices from CT scans from which a stereolithic acrylic model is developed. The TMJ ramus and fossa components are designed and manufactured from this model taking into account the surgical resection, the location of the inferior alveolar nerve, the blood supply in the region and the bone architecture. Favorable treatment outcomes have been reported with both the stock and the custom prosthesis. Giannakopoulos in 2012 reported successful treatment of 228 patients with 442 Biomet implants and showed significant improvement in mouth opening, pain scores and jaw function [19]. Subsequent literature has shown that total alloplastic TMJ replacement is a reliable and effective method of reconstruction [6, 20, 21].

Similar to the Biomet system, the long term data for success with the TMJ concepts system is also very promising. Wolford published data outlining twenty year follow up on the Techmedica/TMJ concepts prosthesis [4]. They evaluated 111 patients with a median follow up of 21 years. No joints were removed owing to material wear and all patients showed significant improvement in jaw function, pain and mouth opening. O'connor in a prospective study showed successful reconstruction of the joint in 26 patients (46 joints) suffering from rheumatoid or psoriatic arthritis [22].

However, the surgical technique required to perform reconstruction of the joint is difficult to master and it has

Table 1 Comparison of the commercially available TMJ prosthesis

Prosthesis	Fossa	Condyle	Ranus
Biomet	UHMWPE	Cobalt chrome/Titanium	Cobal chrome/Titanium
TMJ concepts	Titanium (surface UHMWPE)	Cobalt chrome	Titanium
TMJ implants	Cobalt chrome	Cobalt chrome	Cobalt chrome

Fig. 1 Biomet Prosthesis

Fig. 2 TMJ Concepts Prosthesis

been suggested that all maxillofacial surgeons should not attempt to undertake this surgery [3]. The surgery has considerable risks ranging from facial paralysis resulting from damage to the facial nerve to life threatening hemorrhage during resection of the diseased joint.

Hence efforts are being made to modify the prosthesis to minimize these risks.

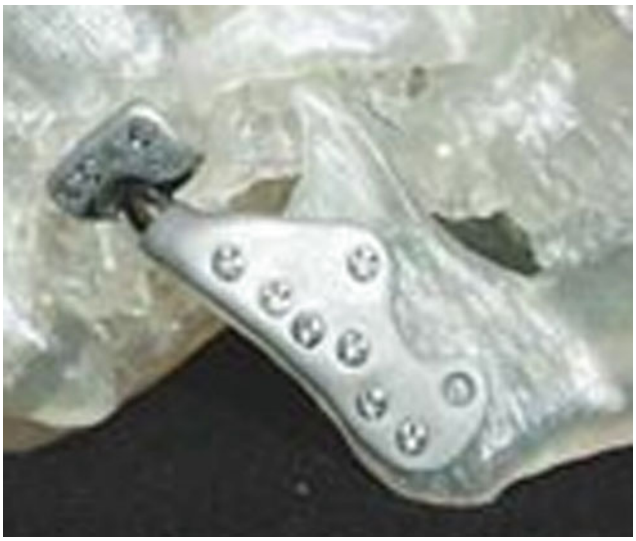

Fig. 3 Christensen Prosthesis

3 Biomechanical Perspective

There have been a lot of studies looking at the biomechanical functioning of the TMJ including study of mandibular forces during simulated tooth movements [23] biomechanical loading [24] and finite and rigid body analysis [25].

As more and more alloplastic joints are used and outcome measures are favorable, researchers have focused on looking at features of the mandibular and fossa components of the joint. Various studies have focused on the number and positions of the screws [26], the influence of implant geometry on mandibular behavior [27] and the influence of thickness and contact surface geometry on stability. There are also studies which have looked at thickness of the component where it is fixed to bone, the effect of stress on various portions of the mandible [28] as well as comparisons between custom and stock prosthesis. Comparisons have also been made between implants made of cobalt chrome and titanium [28]. The studies showed that maximum stresses occurred in the location of the first hole closest to the condyle in the implant and the highest micro strains were observed in the bone adjacent to the first screw hole. This can lead to screw loosening and implant failure under load. This concept can be utilized to design implants where screw holes are not placed near the condyle thus minimizing the risk of screw loosening and implant failure.

A recent study focused on the concept of a condylar support prosthesis where the condyle is resected just below the diseased bone and the prosthesis is matched to fit the condyle [29].

This transfers a lot of load to the mandible and there is less reliance on the screws. This condylar support prosthesis is customized to fit the resected jaw, and requires minimum bone removal. This allows the surgeon to minimize the surgical access leading to less chances of nerve injury and subsequent facial paralysis. There is also more residual bone in case revision surgery is required.

4 Tissue Engineering Perspective

Proponents of tissue engineering of the mandibular condyle have been trying to regenerate both bone and cartilage with distinct structural and functional differences. The scaffolds fabricated for this purpose must fulfil the biological and mechanical requirements for cartilage and bone regeneration. These requirements include surface chemistry, high porosity, mechanical compliance, biodegradability and biocompatibility for cell growth and extracellular matrix deposition [30, 31]. In order to achieve regeneration of both and cartilage, researchers have focused on biphasic scaffold strategies to create osteochondral constructs [32, 33]. The biphasic scaffold essentially entails fabricating two distinct compartments by using different materials such as alginate, chitosan, collagen and hyaluronic acid for the cartilage compartment, and calcium phosphate], hydroxyapatite and Bioglass® for the bone compartment. Alternatively, other studies have focused on scaffold design and culture conditions to construct stratified layers of cartilage and bone from a single source of MSCs [34]. They predifferentiated rat bone marrow-derived MSCs to chondrogenic and osteogenic cells before encapsulated in polyethylene glycol (PEG)-based hydrogel to create stratified cartilage and bone layers in the shape of a human condyle. After implantation in the ectopic site, they demonstrated distinct cartilaginous and osseous compartments of the mandibular condyle [34].

The fabrication of tissue engineered constructs is complicated by the complex three dimensional structure and functional load on the joint. In scaffold fabrication, several techniques including the solid free-form fabrication, electrospinning, and 3-D printing have been applied to not only control the overall shape, but also internal architecture [35] taking into account cues from CT/MRI images of the TMJ. In recent years, advances in material science have also enabled design of biomaterial scaffolds with incorporation of cues both biochemical cues (adhesive motifs and soluble factors) and biophysical cues (scaffold architecture, geometry and mechanical stiffness in the microenvironment to influence stem cell fate and functions [36, 37]. Engler et al. in a landmark study demonstrated the importance of matrix stiffness in guiding MSC fate [38]. They showed that MSCs cultured on 2-D collagen-coated polyacrylamide substrates of variable stiffness were found to commit to lineages based on the similarity to the committed cells' native matrix.

The use of composite materials offers the opportunity to combine biodegradable matrices and osteogenic inorganic phases such as hydroxyapatite. This can be used to created nanostructured scaffolds with tailored bioactivity and improved physical and mechanical properties [39].

5 Conclusions

There have been tremendous advancements in tissue engineering recently and the use of bioengineered implants for TMJ reconstruction is on the horizon. However, to date no method has provided a solution for all cases. While autogenous grafts remain the gold standard for juvenile cases, alloplastic replacement of the joint is commonly used for adults. The advances in composite materials offer an opportunity to develop materials to suit all patient populations.

The use of bioengineered devices would decrease donor site mobility in the case of autogenous grafts. They will also reduce the number of surgical sites, reduce risk of facial paralysis as well as simplify the procedure and reduce recovery time.

Although alloplastic joints have been used successfully, there have been few innovations in the design of the prosthesis in the last few years. Recent advances in Tissue Engineering, biomaterials and 3D printing technology should pave the way for advances in construction of these prosthesis and subsequent reconstruction of the temporomandibular joint.

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