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Review Article

Total Alloplastic Temporomandibular Joint: Proposal for a Total Titanium Condylar Prosthesis with UHMWPE Joint Fossa Design (DARSN TM Joint Prosthesis)

Darpan Bhargava[1]*, RS Neelakandan[2], V Dal Singh[3] and Yogesh Sharma[4]

[1]Associate Professor, Department of Oral and Maxillofacial Surgery, Peoples College of Dental Sciences and Research Centre, People's University, Bhopal, India

[2]Vice-Chancellor, MAHER Professor and Head of the Department, Department of Oral and Maxillofacial Surgery, Meenakshi Ammal Dental College and Hospital, Chennai, India

[3]Vice-Principal and Head of the Department, Department of Oral and Maxillofacial Surgery, Lenora Institute of Dental Sciences, Rajahmundry, India

[4]Professor, Department of Oral and Maxillofacial Surgery Peoples Dental Academy, Bhopal, India

***Corresponding Author:** Darpan Bhargava, Associate Professor, Department of Oral and Maxillofacial Surgery, Peoples College of Dental Sciences and Research Centre, People's University, Bhopal, India.

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Abstract

After the reports of successful orthopaedic total joint replacement surgeries, total alloplastic temporomandibular joint (TMJ) replacement holds promise for patients with end-stage temporomandibular joint disorder, temporomandibular joint ankylosis or any other disorder/anomaly mandating joint reconstruction/replacement. Although currently available, alloplastic temporomandibular joint designs cannot simulate a natural joint completely, it manages to provide a reasonable answer to the patients' problems with evidence of improvement in the post replacement quality of life in a majority of these patients. The concern remains the affordability of such joint replacement surgeries. We propose stock total titanium condylar prosthesis with ultra-high molecular weight polyethylene (UHMWPE) joint fossa design that could provide an acceptable and affordable solution for the masses needing total alloplastic temporomandibular joint replacement in the developing countries.

Keywords: Temporomandibular Joint Ankylosis; Total Alloplastic Temporomandibular Joint; Prosthesis; TMJ

Introduction

It is proposed by various authors that 'temporomandibular disorders related pain' has a significant psychosocial impact on patients. It affects 12% of general population with strong female predilection [1]. With the increasing evidence of success of alloplastic prosthesis in orthopaedic literature and the growing need to provide a definitive treatment for temporomandibular joint (TMJ) disorders, the various artificial temporomandibular are being investigated and some of them are in use. The possible challenges faced to replace a natural temporomandibular joint with total alloplastic temporomandibular prosthesis include:

1. Financial aspect involved, especially for patients in developing country like ours (India).
2. It has bilateral synovial articulation between the mandible and temporal bone which works in synchrony.
3. Ginglymoarthrodial joint - only joint in the body that has rotation and translator movements.
4. Presence of intervening disc.
5. Intervening fibrocartilaginous disc is dynamic with its movements controlled by lateral pterygoid muscle.
6. Temporomandibular joint and its function is influenced by the stomatognathic system (Occlusion, surrounding muscles) and requires harmony for its function.
7. Important joint for vital functions like speech, mastication.
8. Local surgical anatomy for surgical access to the temporomandibular joint involves vital structures like facial nerve, which require special training for open joint surgeries.
9. Acts as a growth centre and demonstrates structural changes in the joint per se with age.
10. Harmony in function between the intervening disc, osseous joint and the muscles controlling the movement.

Considering the challenges, a total alloplastic temporomandibular joint should be economical for the masses that need the replacement and provide reasonable functionality so as to improve the quality of life in patients suffering with either end-stage temporomandibular joint disorder, temporomandibular joint ankylosis or any other disorder/anomaly mandating joint reconstruction/replacement. We propose an alloplastic temporomandibular joint design based on sound principles of biomechanical engineering with the advantage of being acceptable financially, considering the availability of the raw materials used for its designing and manufacturing.

Total titanium condylar prosthesis with ultra-high molcular weight polyethylene (UHMWPE) joint fossa design (DARSN TM Joint Prosthesis) - General Description

Proposed joint design will be a stock prosthesis, which may require on table surgical adjustments on the bone before fixation or may require minor mechanical modifications of the prosthesis before fixation. The advantage of stock prosthesis of being relatively economical when compared to custom prostheses has been considered for the presented design. The initial simulation design considering the biomechanical principles was done with computer-aided design (CAD) software - solid works premium 2012 SP0.0. The components of the joint include:

1. Titanium alloy condylar head with a lateral ramal attachment plate.
2. UHMWPE joint fossa.
3. 2.5 mm X 6 mm titanium alloy screws for fixation of cranial end of the ramal attachment plate (4 Nos).
4. 2.5 mm X 8 mm titanium alloy screws for fixation of caudal end of the ramal attachment plate (4 Nos).
5. 1.5 mm X 10 mm titanium alloy screws for fixation of the fossa component (4 Nos).

Description of total titanium condylar prosthesis (Figure 1)

This part of the joint prosthesis is made of Grade 5 titanium alloy (Ti_6Al_4V alloy). Ti-6Al-4V has long been favoured for biomedical applications considering its biocompatibility [2]. The composition of the alloy is summarised in table 1 [3]. The physical and mechanical properties of Grade 5 Ti alloy used are summarized in table 2 [4].

Figure 1: Total titanium condylar prosthesis. Note the tripod screw fixture points for better prosthesis retention.

Grade 5 Titanium Alloy	
Component	**Weight %**
Al	6
Fe	Max 0.25
O	Max 0.2
TI	90
V	4

Table 1: Composition of Grade-5 titanium alloy.

The total titanium condylar prosthesis is divided into three parts - the condylar head, neck and a lateral ramal plate. The condylar head is a solid titanium (G-5) medial extension, the cranial end of which is rounded, and caudal end is flattened. The medial extension has a rounded finished with flattened lateral aspect of the head that flushes with the neck of the prosthesis.

Physical Properties	
Parameter	**Values in Metric**
Density	4.43 g/cc
Mechanical Properties	
Parameter	**Values in Metric**
Hardness, Brinell	334
Hardness, Knoop	363
Hardness, Rockwell C	36
Hardness, Vickers	349
Tensile Strength, Ultimate	950 MPa
Tensile Strength, Yield	880 MPa
Elongation at Break	14 %
Reduction of Area	36 %
Modulus of Elasticity	113.8 GPa
Compressive Yield Strength	970 MPa
Notched Tensile Strength	1450 MPa
Ultimate Bearing Strength	1860 MPa
Bearing Yield Strength	1480 MPa
Poisson's Ratio	0.342
Charpy Impact	17 J
Fatigue Strength	240 MPa
Fatigue Strength	510 MPa
Fracture Toughness	75 MPa-m½
Shear Modulus	44 GPa
Shear Strength	550 MPa

Table 2: Physical and mechanical properties of the Grade-5 titanium alloy.

The neck of the prosthesis is a connector between the condylar head and the lateral ramal attachment plate. The neck is designed to incorporate a slight distal off-set, which places the condylar head distal to the long axis of the ramal fixation plate. This particular biomechanical design utilizes the advantage of "swan neck design" which evades the problem of implant-bone interface obstruction faced with right angled designs [5]. The rounded head design aids in the rotation of the joint when in function. Total alloplastic temporomandibular joint has the ability to produce pure rotation with minimal or no translator movement. During the fixation of the joint prosthesis if placement of the point of rotation of the prosthesis is kept inferior to the middle of the natural condyle, a pseudo translation may be observed when the joint is out to function during mouth opening. (Fulkenstrom CA) [5].

The lateral ramal fixation plate is 2 mm in thickness and 10 mm broad antero-posteriorly. It is made of titanium (G-5) which is a continuation of the neck portion of the prosthesis. The caudal end of the plate is rounded. The body of the plate bears 8 counter sink holes arranged in a tripod fashion for fixation of the prosthesis on the lateral surface of the ramus of the mandible. The counters inked fixation holes can incorporate 2.5 mm screws. It is preferable to fix 2.5 mm x 6 mm screws in the cranial four holes and 2.5 mm x 8mm screws in the caudal four holes. At times it may be required to shave off the anti-lingula on the lateral ramal surface for proper adaptation of the fixation plate, which may easily be done using a rose head shaped bur at the time of operation. The dimension of the condylar prosthesis is summarized in figures 2 to 4. The length of the lateral ramal plate may be adjusted at the inferior end for individual patient customization.

Figure 2: CAD showing total condylar prosthesis height in mm.

Figure 3: CAD showing lateral dimensions of the prosthesis (mm).

Figure 4: Antero-posterior dimensions of the prosthetic condylar head (mm).

Description of UHMWPE joint fossa (Figure 5 and 6)

The fossa attachment of this prosthesis is made of Ultra high molecular weight polyethylene (UHMWPE). UHMWPE is a semi crystalline polymer that has been used for over four decades as a bearing surface in total joint replacements [6]. It acts as an intervening material between the metallic condylar head and the temporal bone to prevent any mechanical damage to the bone during function. The fossa component is screw retained, consisting of a horizontal and a vertical plate. The vertical plate has holes to accommodate 1.5 x 10 mm Ti-alloy screws for fixation of the fossa component to the zygomatic arch. The horizontal plate bears a crater like depression to house the Ti-alloy condylar head. The cranial surface of the horizontal plate is flat and rests on temporal bone. The bone on which the horizontal plate rests may need prefixation modification during the surgery to provide a near flat surface for the plate to rest without rocking. The computer aided design (CAD) of the stock UHMWPE fossa component is summarized in figures 7. The stock design has the medial extension of the horizontal plate of 28 mm with 5 mm thickness.

Figure 5: Lateral view of the prosthetic UHMWPE fossa.

Figure 6: Medial extension of the prosthetic UHMWPE fossa.

Figure 7: Computer aided design of the UHMWPE fossa.

Although UHMWPE is being currently used for the presented joint design, future trends and research may direct us to replace this material with highly cross-linked ultrahigh-molecular weight polyethylene which is reported to have better wear properties and improved mechanical and fatigue properties [7]. Future research would also direct alpha-tocopherol stabilization of ultrahigh-molecular weight polyethylene to improve oxidation resistance of the material [8]. Long term conclusive in-vivo follow-up studies would direct these future trends on modification/replacing UHMWPE material used for the fossa design of this prosthesis.

Description of the fixation screws

The fixation screws are made from Grade 5 titanium alloy. Screws are round headed with a single slot meant to seat on the counter sink design of the fixation hole after reaching the desired depth in the bone for anchorage. The surgeon should aim at achieving good primary stability during fixation of the device. The dimensions of the screws needed to stabilize the device include- 2.5 mm X 6 mm screws for fixation of cranial end of the ramal attachment plate (4 Nos); 2.5 mm X 8 mm screws for fixation of caudal end of the ramal attachment plate (4 Nos) and 1.5 mm X 10 mm screws for fixation of the fossa component (4 Nos). The need for the number of screws to be used may vary with individual case for achieving appropriable primary stability.

Recommended sterilization protocol for the prosthesis and its components

These are the recommendations from the authors and can/may be modified as per the local/regional/institutional guidelines on sterilization. The metal condylar component including screws can be sterilized using standard moist heat sterilization method just before use. UHMWPE material can undergo Gamma/EtO sterilization [9]. All the sterilized components should be stored in a broad-spectrum antibiotic solution and not exposed to air in the operation theatre from the time of unpacking to *in vivo* fixation.

Conclusion

As highlighted, currently available alloplastic temporomandibular joint designs cannot simulate a natural joint completely, it manages to provide a reasonable answer to the patients' problems with evidence of improvement in the post replacement quality of life in a majority of these patients. Proposed stock total titanium condylar prosthesis with UHMWPE joint fossa design can provide an acceptable and affordable solution for the masses needing total alloplastic temporomandibular joint replacements.

Declaration

- This manuscript is a part of the work undertaken to wards Ph. D registered under MAHER University, Chennai, India.
- There is no financial aid availed for this project.
- Authors declare no conflict of interest.
- IEC Clearance: Obtained.
- Design Patent: Filed 2541/MUM/2015.

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