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Improving Articulating Surfaces for Temporomandibular Joint Implants

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Abstract

Our project focuses on developing and evaluating a novel design for a temporomandibular joint (TMJ) to treat those suffering from temporomandibular disease (TMD). Patients with life altering TMD often opt for surgical treatment via an implant to remove the affected bone and alleviate their pain. However, currently available implants are not the lifelong solutions that patients have hoped for.

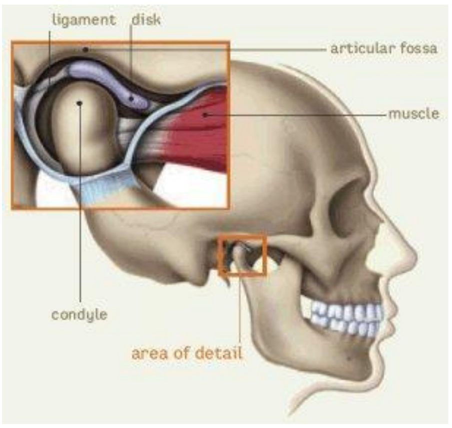
Our design utilizes Zirconium Oxide, a ceramic material, as the fossa and condyle of the joint. Hyaluronic acid soaked bovine pericardium acts as the articulating surface between the ceramic components to reduce friction and wear. Our original design was not able to accommodate the adherence of pericardium to the ceramic surface at high loads. This led us to consider both chemical adherence with mechanically stable endpoint for the tissue. These additions to our design made significant improvements in attachment and strength. There is still much to research in regards to the addition of hyaluronic acid and how it will affect the adhesion and strength.

Introduction

While the cause of TMD is often unclear, it may occur from disk erosion or misalignment, damaged cartilage, or trauma to the joint. The implants that are available currently are not able to sustain the joint long term. Inflammatory responses due to detrimental particle production lead to discomfort and implant weakening. We chose ceramic for the implant due to its biocompatibility and strength, and pericardium for its low coefficient of friction.

Objective

1. Adhering pericardium tissue to the ceramic using dental adhesives to serve as a cushion between the condyle and fossa
2. Measure tissue adhesion strength to the ceramic
3. Develop a novel mechanical system for holding the tissue in place
4. Model a condyle and fossa piece mimicking jaw anatomy



Original Design

Preliminary:
Working from previously modeled implants that eliminated the patient's native anatomy, this design utilized real data to create an anatomically correct model. Due to the complex nature of the joint, presenting both hinge and gliding articulations, it was decided to stay true to the biological joint design. Figure 1 demonstrates the modeling process from CT data. The TMJ was modeled from sample CT data from a free source CAD program: 3D Slicer.

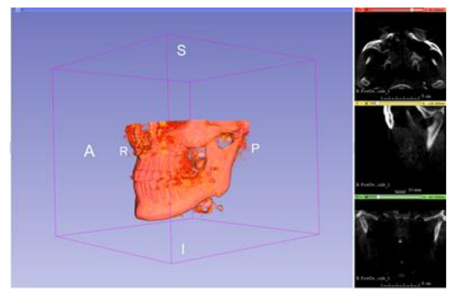


Figure 1. *Isolating the TMJ from CT data from a post surgical dental patient. This data was taken from and created by 3D Slicer.*

Secondary:
Based on the preliminary data and the difficulties presented in adhering the pericardium, a dual approach is considered, demonstrated in Figure 2.

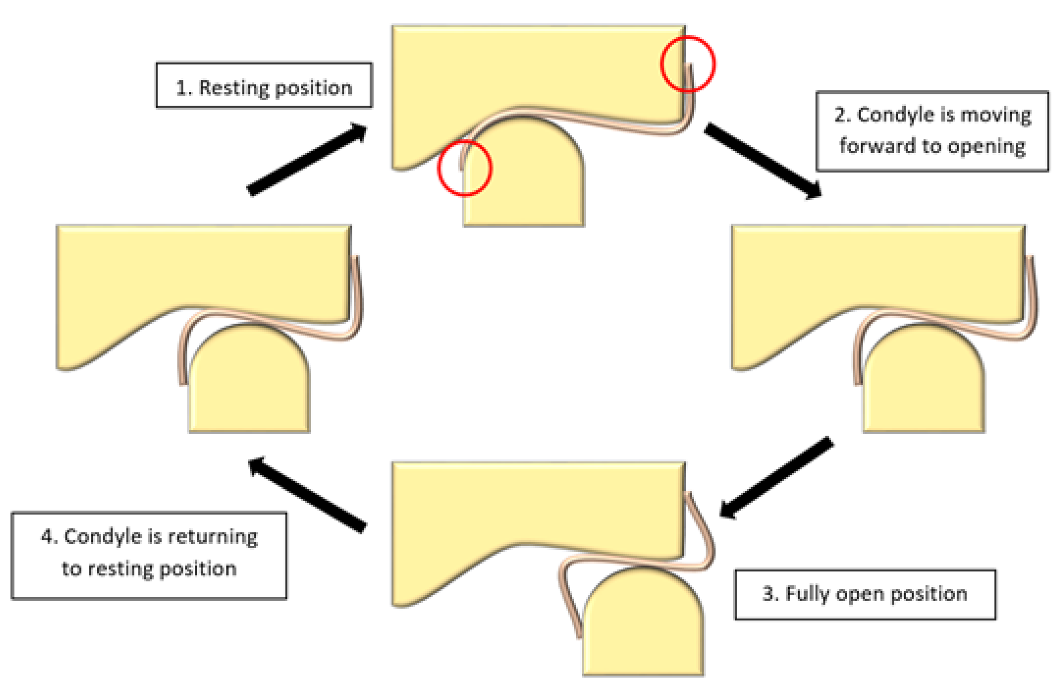


Figure 2. *Diagram of the open and close articulation cycle of the proposed "double attachment technique" between the ceramic condyle and fossa components. The red circles indicate the place of attachment of the pericardium to each ceramic component. The red area is also where the proposed "notches" will physically anchor the PC.*

Project Build

I. Procedure Development of Tissue-Ceramic Adherence

A secure attachment of the pericardium tissue to ceramic ingot is needed in order to achieve long lasting articulations between implant components. Research in tissue binding strength has shown that a maximum shear force of 40lbs is needed of the bond. The Shimpo MF Gauge, shown in Figure 3, performs the push-off test.

The ceramic pieces are polished and prepared for attachment using many different materials including

- Ceramic etching gel
- Adhese Universal
- Chronoflex
- Monobond Plus

During this procedure the tissue is fully dried in an incubator at 80°C for approximately 60 minutes between two plates.

The tissue and ceramic pieces are then pressed together for 24h to allow for adhesive to cure and develop a bond.

Figure 3. *Performing a push-off test using the Shimpo Mechanical Force Gauge*

II. Prototype Build

For demonstration purposes and to develop our prototype, measurements of an acquired human female skull were taken. This enabled us to quickly 3D model the TMJ components for testing without having to use CT and MRI data.

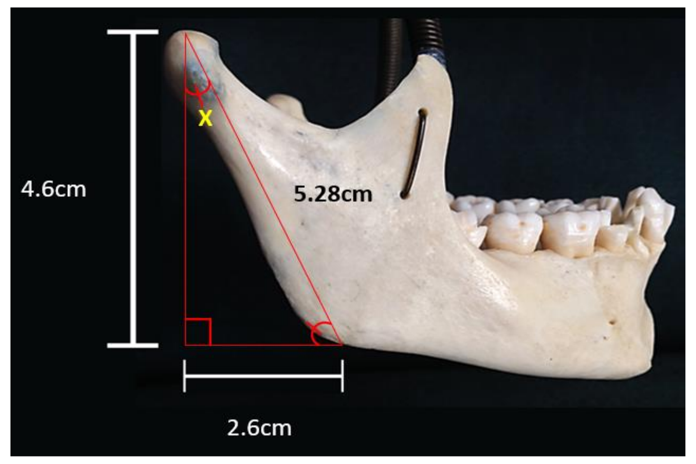


Figure 4. *Measurements of a procured female mandible. The angle X was calculated: Sin(X) = (2.6/5.28) therefor X = 29.50 degrees. The angles were not used in the original design but can be implemented for future testing*

Figure 5 represents a stress analysis simulation used on a CAD design model of the ceramic condyle component. The stress analysis is used to determine where the highest stress and strain are in the model. The notch in this design will provide a more secure attachment for the pericardium rather than just adhering it to the flat surface. Other notch designs include a slit 45 degrees to the surface.

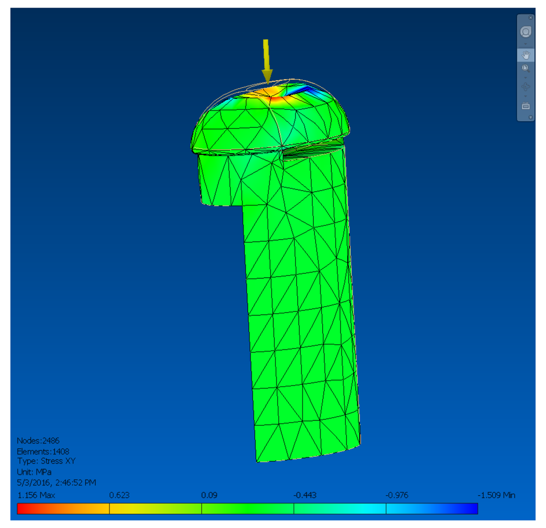


Figure 5. *Stress analysis done on a 3D model of a ceramic implants with a notches*

Tests and Results

Initial tests used Adhese Universal for studying adhesion in a wet environment. The mass of wet and dry pericardium was taken to measure the moisture level. The first procedure developed is as follows:

1) Sanitize all equipment
2) Dry pericardium on blotting paper & weigh (results in Table 1)
3) Soak pericardium in HA for 15 minutes
4) Weigh again
5) Apply 2 clicks each of Universal Adhesive on 6 ceramic samples
6) Place 3 of these ceramics in a petri dish with HA and the remaining 3 in a petri dish with water. Water serves as control, and HA is to provide the optimum lubricity.

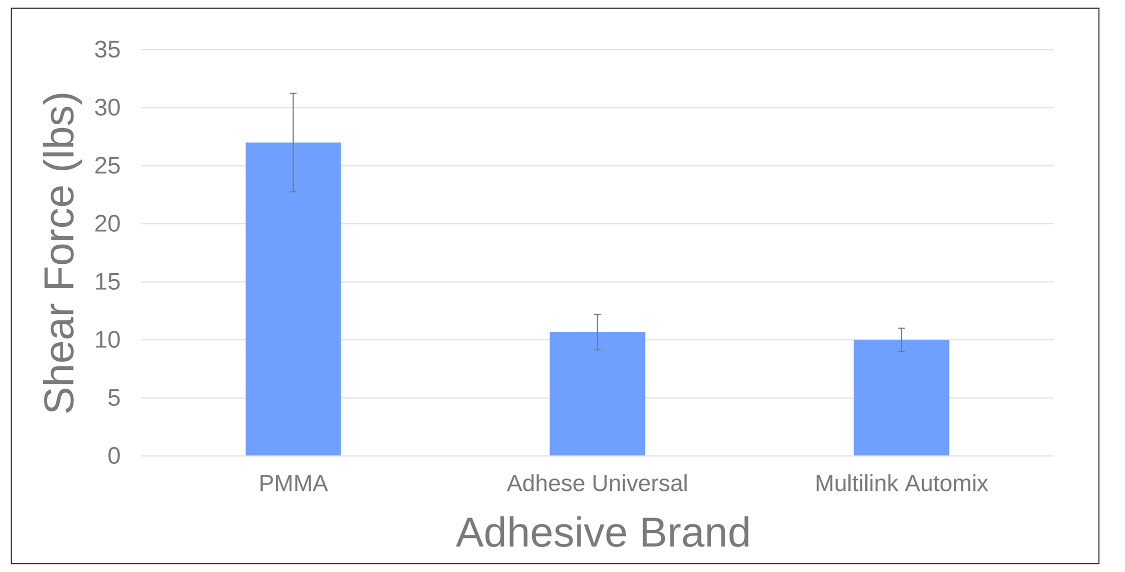
	Immersed in HA			Immersed in water		
	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 1	SAMPLE 2	SAMPLE 3
Weight at 0% moisture	0.078 g	0.1098 g	0.127 g	0.124 g	0.113 g	0.0968 g
Weight at 100% moisture	0.167 g	0.288 g	0.362 g	0.454 g	0.448 g	0.398 g

Table 1: *Masses of pericardium soaked in HA and water*

24 hours after application of Universal Adhesive, the specimens were examined for evidence of attachment. Unfortunately, none of them stuck. It is hypothesized that the liquid has some initial interaction with the adhesive that affects its binding. The tissues were then completely baked in a 80 °C incubator to remove all moisture.

Tests and Results Continued

After completely drying the tissue, adhesion strength was measured and the push-off test was able to be conducted.



Pericardium adhered to PMMA averaged with standing 27 lbs of force while the Adhese Universal and Multilink Automix averaged approximately 10lbs.

Success and Challenges

- PMMA shows the most promise as being the adhesive of choice to incorporate with the fabricated slit condyle
- Have successfully 3D modeled patient specific TMJ
- Challenges:
  1. Determining the strongest area for notch placement using CAD stress analysis
  2. Adequate adhesion force should be close to 40-50 lbs
  3. Determining best design for notches, that act as mechanical endpoints
  4. Calculate any additional forces for the "double attachment technique"
  5. Measure wear and particle formation
  6. Test strength after immersing pericardium in hyaluronic acid for lubricity and nutrition.

Future Directions

Since the TMJ is one of the most complex articulating joints in our body, it would be possible to implement our design into other joints such as the hip or knee. Lubrication of the pericardium, using hyaluronic acid, still needs to be analyzed as well.

Future testing includes using ceramic ingots with the proposed notches and measuring particle formation in the new model, while comparing it to previous designs.

Final testing involves the Proto-tech Oral Wear Simulator, which mimics jaw motion and forces experienced during speech and mastication. This device can simulate wear on the joint over long periods of time in just a few hours.

Acknowledgements

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