

# APPROXIMATING SURFACE MATRIX BAND FOR DENTISTS TO USE FOR PATIENTS

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## Abstract

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### Background

The main objective of this report is to outline the process used to design, manufacture and test a modified dental matrix band that allows the simultaneous filling of an interproximal cavity.

### Methods

Solidwork Simulink testing was performed on the chosen 1008-1010 steel alloy material to ensure parallel mechanical properties with the current standard in dentistry (dead soft stainless steel). Prototype fabrication was outsourced to Sector 67 to ensure dimensional accuracy. Functional testing will be performed on this prototype to qualitatively assess its ability to perform interproximal restorations with the proper tooth contact and contour.

### Results

Solidworks Simulink testing concluded yield strengths were found to be 180.0 MPa and 172.2 MPa for the 1008-1010 steel alloy with maximum displacements at 1.876m. These results closely resemble the mechanical properties of currently used dead soft stainless steel. This suggests the tested alloy either is dead soft or accurately behaves as such. Qualitative testing has not been performed yet, but desirable results would entail an ease of use for the dentist and correct tooth contact and contour post-procedure.

### Clinical Implications

This new design offers dentists an alternative to preparing the matrix band and wedge twice for the separate filling of two adjacent teeth during an interproximal filling. Simultaneous interproximal cavity filling will decrease procedural time while maintaining the appropriate tooth contact. With 175 million

individuals receiving at least one filling every year, this design will assist in helping millions of individuals with untreated cavities.

## Key Words

Dental Matrix Band • Interproximal Cavity • Class II Restoration • Dead Soft Metal

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## Introduction and Background

Matrix bands are a commonly used dental tool which assist dentists by restoring shape and integrity of a decayed tooth. They provide support, shape and contour for replacement filling material while protecting surrounding tissues. During typical filling procedures for cavities on interproximal surfaces, or two adjacent teeth, dentists must fill each tooth separately. This is a tedious procedure as each matrix band must be prepared for each tooth, which includes shaping, placement and securing with dental wedges and rings. These must be done one after the other because two matrix bands cannot fit in the interproximal space as together they are too wide and would create poor tooth contact after the restoration. The designed dental matrix band employs a dual-band system, with a thickness equivalent to current matrix bands throughout, such that the fit is secure and the band molds to the convex contour of each tooth. It also maintains the tensile strength, malleability, and accessibility of current matrix bands, while allowing for adjacent restorations to be done consecutively, without the need for replacement.

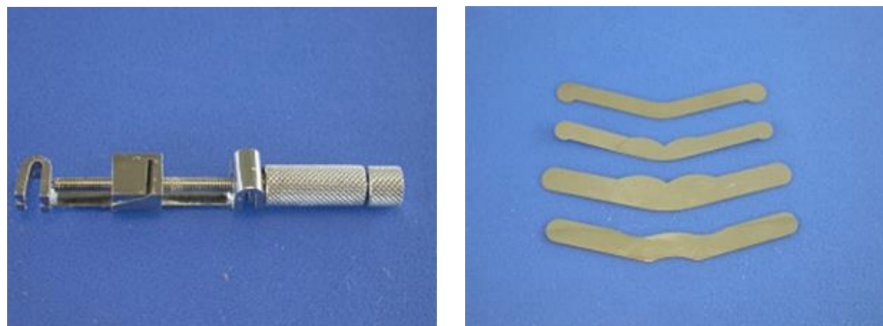
The average American has about three dental fillings, while one in four Americans have eleven or more fillings. Although cavities are one of the most common dental procedures, the CDC still estimates that about one-third of adults have untreated dental caries that require fillings [1]. A new matrix band device could help advance the public dental health industry by helping simplify procedures for practicing dentists, making treatment more efficient, convenient, and less costly.

## Dental Matrix Band Origins and Development

The earliest implementation of matrix bands generally required minor custom fabrication techniques such as soldering, scoring and cutting, or using fusing compounds. However, preformed, adjustable bands became the standard in the last 50 years [2]. Preformed bands reduce the time to placement as structural modifications are not necessary, only forced bending. There are two main types of preformed dental matrix bands, sectional and circumferential [3]. Sectional matrix bands are more suited for proximal cavities and only fit around half of the tooth. They are required to be supported by a ring fit as well as levered by a wedge between two teeth. Circumferential matrix bands are generally used with a Tofflemire™ retainer, seen in Figure 1, and are wrapped around the whole tooth. The Tofflemire is able to tighten the band around the tooth but still requires the use of a wedge for a tight contact, contour, and separation of the teeth. Dental matrix ring clamps are often used as well as dental wedges for the same purposes. Both sectional and circumferential matrix bands are used commonly in practice although 74% of dentists prefer the sectional band method [4].

### The Tofflemire™ Matrix Band

The Tofflemire™ matrix band and retainer is one of the most commonly used systems in dentistry, currently. It is a circumferential design meant to wrap around a single tooth during an interproximal procedure. This system is used in conjunction with dental wedges to create a better fit with the gingival surface and create space in the interproximal area of the teeth. The band is first burnished to create a contour along the bottom edge to fit between the gum line and tooth. Then the band is folded into a teardrop shape, placed into the head of the retainer and clamped into place, ready for tightening around the tooth [5].



**Figure 1:** *Tofflemire™ Matrix Band system. Circumferential matrix band system consisting of the proprietary retainer (left), bands (right), and any dental wedges (not pictured) [2]. Primary 4 matrix band sizes are shown on the right.*

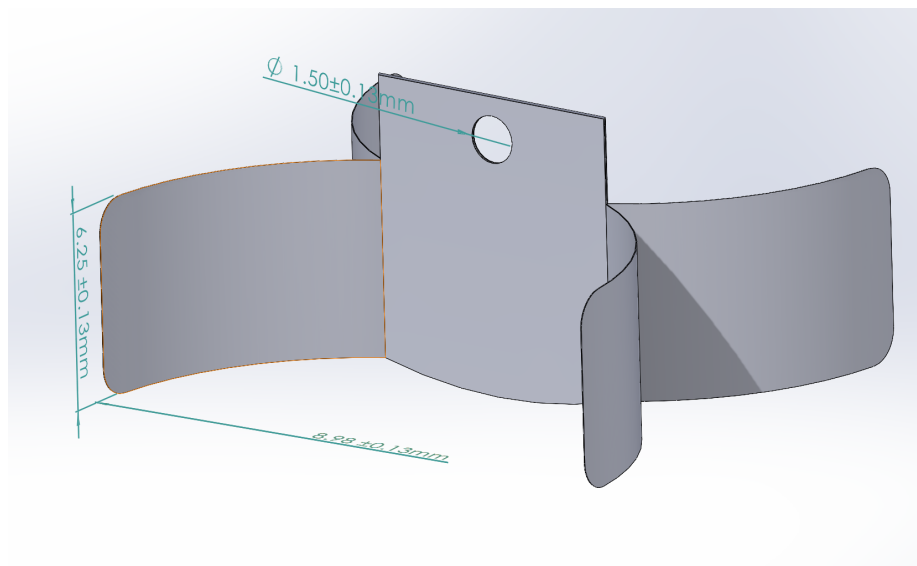
## Relevant Dental Anatomy and Dimensions

The average crown height of maxillary (upper) and mandibular (lower) teeth together is 8.69 mm, with a range of measurements from 7.2 mm to 11.2 mm. The mesiodistal crown width, which measures the diameter of the tooth in the direction from its more anterior adjacent tooth to its more posterior adjacent tooth, averages 8.20 mm, with values ranging from 5.3 mm to 11.4 mm. The faciolingual crown width, which measures the diameter of the tooth in the direction from cheek side to tongue side, averages 8.71 mm, with values ranging from 5.7 mm to 11.5 mm [6]. Based on these values, approximations for tooth perimeter average 33.82 mm, ranging from 22.0 mm to 45.8 mm.

The thickness of dental matrix bands typically ranges from 0.001 to 0.002 inches, or 0.0254 to 0.0508 millimeters [7]. The band width must fall into these precise ranges in order for the device to securely fit between adjacent teeth without exceeding the width of the interproximal space. Correctly placed and effective matrix bands are rigid against the existing tooth structure and maximize matrix-tooth contact, properly contouring to the shape of the tooth [8]. They must restore appropriate contact with the adjacent tooth and be easily removable once the restorative material is set [5].

## Butterfly Prototype

After evaluating multiple initial designs, the final iteration was selected for use in the fabrication of our prototype. The selection process along with the preliminary designs can be found in Appendix B. An image of the final design can be seen below in Figure 2.



**Figure 2: Butterfly Design.** Dimensions of the device include a height of 6.25 mm, a band radius of 8.98 mm, a hole diameter of 1.5 mm, and a material thickness of 0.0254 mm. Key features include rounded edges for safety, a holed tab for placement/removal, and a convex, rounded bottom edge for preventing the escapement of filling material.

## Summary/Conclusion

To create the correct contour, shape and contact while restoring a decayed tooth, dentists most commonly use matrix bands. During a typical interproximal filling procedure, a dentist is unable to place current matrix bands adjacent to one another due the thickness of two bands exceeding that of the proper tooth contact. Thus, the dentist must perform one filling at a time. The Tofflemire™ matrix band is a circumferential matrix band that serves in filling one tooth at a time during an interproximal procedure and is the current gold standard in dentistry. An alternative approach by using a modified dual dental matrix band is discussed in this report. This new design would allow for the simultaneous filing of two adjacent teeth, and with desirable testing results, should prove to provide the correct tooth contour and contact after the procedure is completed.

## Methods

### Fabrication

The final butterfly prototype was fabricated using a laser cutter and the assistance of Sector 67, a nonprofit company dedicated to educating and training clients on a variety of t. A model of the design was created in Solidworks with the following dimensions: 6.25mm height, 8.98mm length constituting a portion of the circumference of the tooth. A DXF file was exported from solidworks and uploaded to the laser cutter where it was cut out of 1008-1010 shim stock stainless steel with a thickness of 0.001". The final cutout can be seen in the figure 3.



**Figure 3: Butterfly Prototype.** *Dimensions and key features are the same as Figure 2.*

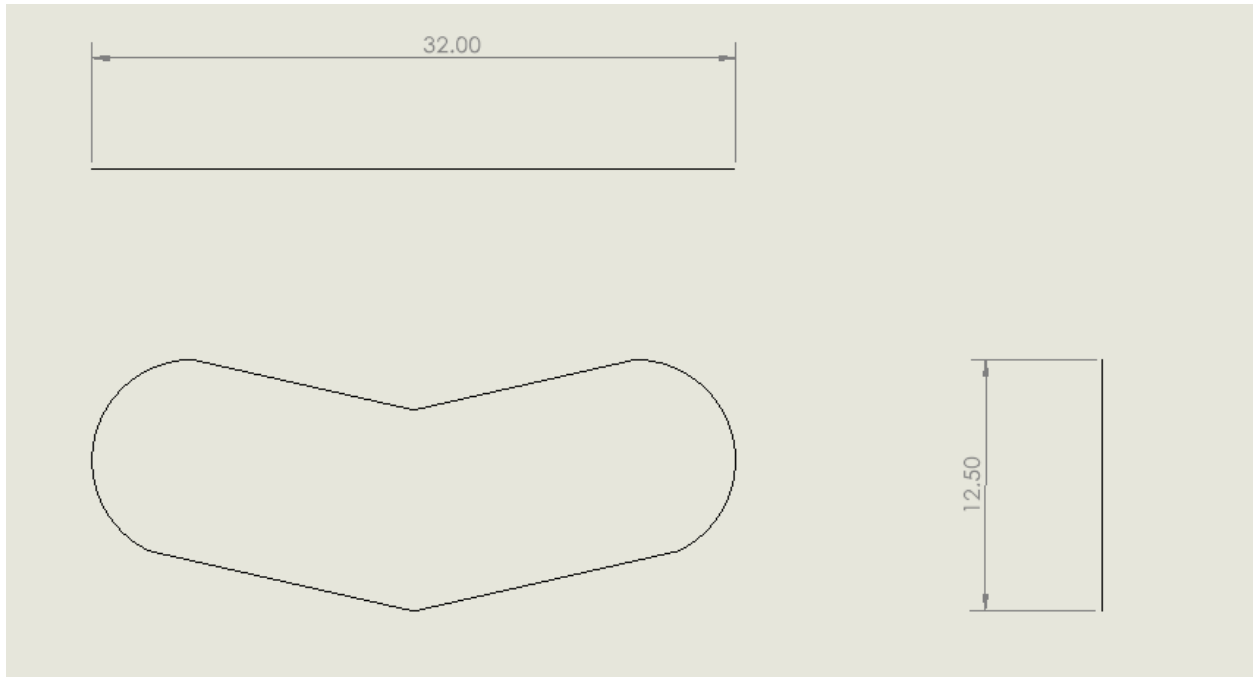
After the fabrication of the prototype by Sector 67, the interproximal space of the matrix band should be sealed together along the top 70% of its contact, leaving sufficient room for wedge placement during the process. The sealing of the interproximal space will ensure the proper tooth contact: the thickness of the two bands on both sides of the dual matrix band put together. Various methods of sealing were considered, and in order to prevent deformation of the material, an epoxy seal should be used. The specific epoxy sealant to be used is the Permatex 84109 PermaPoxy 4 Minute Multi-Metal Epoxy. Successful sealing of the top 70% of the interproximal space should not contribute significant additional thickness to the interproximal space, otherwise, the proper tooth contact would not be maintained.

Additionally, the convexity of the bottom contour of the band is essential in its design to both allow for the proper tooth contour along its entire surface and prevent gingival overhanging. Gingival overhanging is the extension of the restorative material beyond the intended confinement during preparation [9].

## Quantitative - Solidworks Testing

In order to confirm that the 1008-1010 stainless steel alloy would be suitable for use in the prototyping and designing of our product, Solidworks testing was run to analyze the material's mechanical properties. The 1008-1010 alloy must perform similarly to current stainless steel matrix bands on the market by exhibiting dead soft properties. Running Solidworks material testing confirmed that the bands would perform as expected from a higher load than 10kN and that it would resist deformation similar to generic stainless steel.

The test was run on a test model created using the Solidworks 3D modeling software. The modeled band was flat and two wings that jutted slightly upwards to leave a convex point in the middle of the band. The length of the band is 32 cm and the height is 12.5 cm, larger than a normal matrix band but of similar proportion (Figure [4]). Material properties were calculated and applied in the simulation to mimic the 1010 steel alloy used in our prototype as well as a generic stainless steel.



**Figure 4:** *Solidworks 3D modeling software test model. Used in the simulation to mimic the 1008-1010 steel alloy and dead soft stainless steel in testing.*

To perform the testing, first, one of the wings was fixed and on the other wing a 200N force was applied to the flat edge of the band. This was to determine how much force it would be required to bend the wings of the band around a tooth. Next, a 20kN load was applied to the edge of the band and pulled it parallel to the fixed edge of the simulation. The force required to see significant changes is much higher, similar to how it's hard to pull a sheet of paper in half. The maximum displacement, yield strength, and von mises stress distributions were measured in both scenarios to determine how strong the bands were for the specific material.

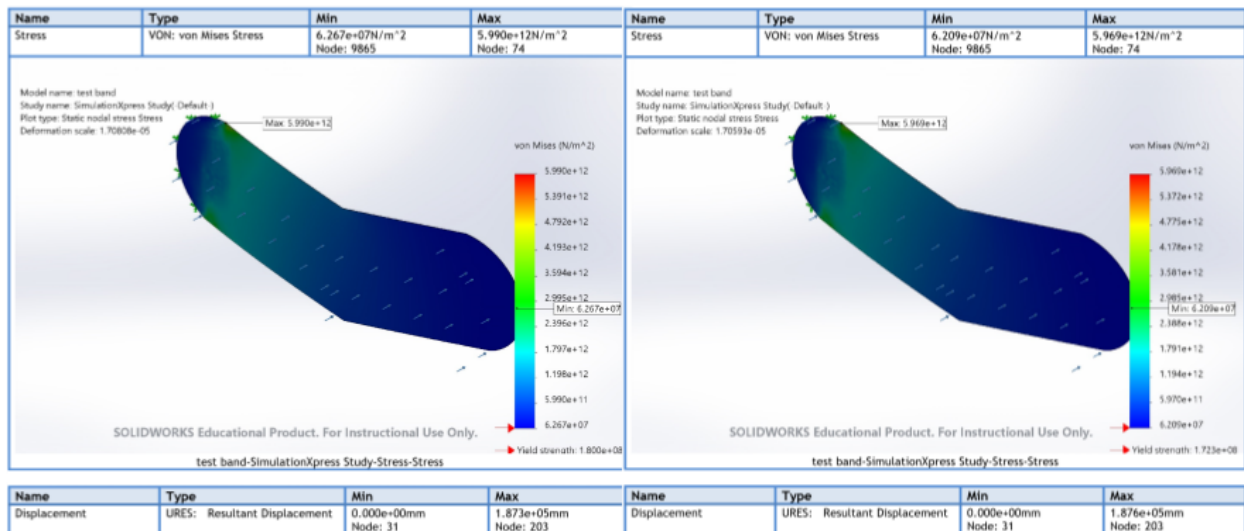
## Qualitative - Dentist Evaluation

The ultimate goal of this redesign is to make the filling of interproximal cavities more efficient and convenient, without sacrificing the quality of the restoration. To evaluate these qualities, a functionality evaluation was created for Dr. Donald Tipple of Nakoma Dental, comparing multiple aspects of both the Butterfly prototype and the existing Tofflemire™ system. This evaluation asks Dr. Tipple to grade each method on the following criteria: how easy the device is to use, the quality of the restoration contour, protective coverage, restoration contact, procedure efficiency, and compatibility with existing tools and procedures. Each grade is on a scale, 1 to 5, with 1 being unsatisfactory and 5 being excellent. The dentist performs the standard filling procedure for an interproximal cavity for both matrix bands, both using a dental wedge, dental ring clamp, and adult human mouth model. For the Butterfly design, the placement will

only occur once while the Tofflemire™ system will need to be placed once and replaced for the second filling. The evaluation form can be found in Appendix F.

## Results and Discussion

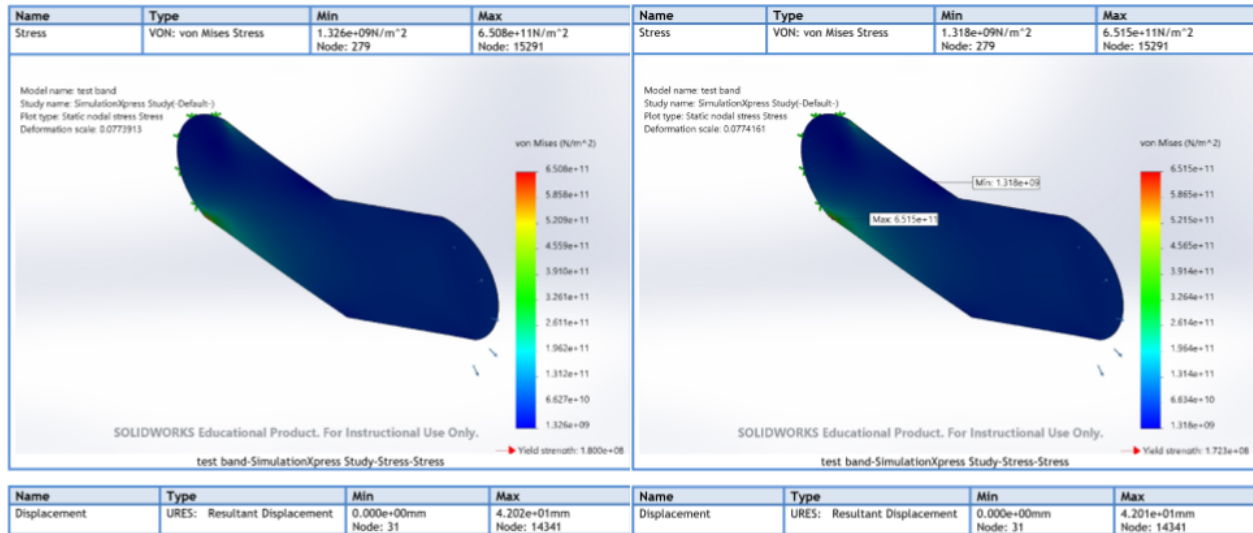
The results of the Solidworks Simulink testing suggested that the 1010 steel alloy that was tested is very similar to the dead soft generic stainless steel it was compared to. In the 200N load test, yield strengths were 180.0 MPa and 172.2 MPa for the 1008-1010 and stainless steel bands respectively and the maximum displacements were 18.76 mm for the 1008-1010 alloy band and 18,73 mm for the stainless steel band. The Von Mises stresses matched up very similarly (5969 GPa and 5990 GPa for the stainless steel and 1008-1010 alloy). The band would most likely fail from a lateral force near the bending point of the band as seen from Von Mises stress distribution (Figure[5]).



**Figure 5:** Solidworks 3D modeling software test model. 200N Test to determine the von mises distribution of forces to find the failure point

For the tensile load test using 20kN, the displacements were within .001 mm with the 1008-1010 alloy at 4.202 mm and the stainless steel at 4.201 mm. The Von Mises max stresses for the 1008-1010 alloy recorded a maximum Von Mises stress of 650.8 GPa and the stainless steel recorded a Von Mises max stress of 651.5 GPa. The distribution of the von mises stresses would suggest that the band would most likely yield around the side of the band near the edge closer to the fixation (Figure [6]).





**Figure 6:** Solidworks 3D modeling software test model. 20kN Test to determine the von mises distribution of forces to find the failure point

The results of the Simulink testing suggests that the 1010 steel alloy exhibits mechanical properties of dead soft metal and would be comparable to the stainless steel used on market available matrix bands. The values for yield strength and average displacement were within 5% of each other, implying the difference between the two kinds was insignificant.

In the future, our team plans to perform qualitative testing on our design to confirm that the design will work as intended. This testing will be performed by a client funding this project who is a practicing dentist and involve him rating aspects of the model relating to the ease of use. Getting a professional's opinion in the industry would give us insight into whether the design would be desired to use.

## Conclusions

The viability of the proposed matrix band is dependent on its performance in functionality testing since mechanical testing has yielded successful results. Upon retrieval and qualitative assessment of the prototype, the team will determine whether its effectiveness matches that of the existing Tofflemire Matrix Band while minimizing procedure time. Specifically, the prototype should display ease of use, while yielding the proper tooth contact and contour post-procedure.

# References

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# Appendix

## A. Product Design Specifications

### Function

Matrix bands are a commonly used dental tool which assist dentists by creating an outside contour of a decayed tooth. This contour maintains the tooth's structure and shape during restorative procedures, such as cavity fillings. During typical filling procedures for cavities on interproximal surfaces, dentists must fill each tooth separately. This tedious procedure is due to matrix bands not fitting adjacent to one another in the interproximal space, as the thickness of two bands exceeds the tooth contact diameter between the teeth. The resulting process of placing matrix bands for both teeth is cumbersome and time inefficient. A new dental matrix band design is desired to alleviate the need to repeatedly place bands. The device should employ a dual-band system with a thickness less than or equivalent to current matrix bands, 0.05 mm, throughout such that the fit is secure and the band molds to the appropriate convex/concave contour of each tooth. The finalized product should also maintain the tensile strength, about 400 MPa, malleability, and space efficiency of current matrix bands. The material used to fabricate the matrix band must not cause any irritation, must be biocompatible, and must be non-reactive to filling materials.

### Client Requirements

1. The matrix band should be sectional, or non-circumferential, so that only the approximating surfaces of the teeth being filled are in contact with it.
2. Nickel and other irritating materials must not be used to make the matrix band.
3. The material used to fabricate the matrix band should not interact with or adhere to materials used in filling cavities and must be biocompatible.
4. The device must either be single-use or sterilizable if used more than once.
5. The matrix band should include a small hole for floss to fit through so that dentists may easily retrieve the piece if it falls into a patient's mouth.
6. The inferior edge, or the gum edge, of the matrix band should be made slightly convex to encapsulate the entire cavity being filled and to help with orientation of the device.

### Design Requirements

#### 1. Physical and Operational Characteristics

##### a. Performance Requirements:

- i. The matrix band should be able to maintain its structure and function from the time it is placed in the mouth until the filling procedure is over, up to 1 hour [1].

1. The device will most likely be single-use, but if sterilizable, it should be capable of performing up to 50 procedures.
- ii. The device should maintain similar mechanical characteristics of existing matrix bands, withstanding loads placed on it during filling.
  1. It should still be malleable and able to shape around any tooth.
- iii. The device should incorporate wedges or another component that effectively separates the approximating teeth being filled.

*b. Safety:*

- i. The material used to fabricate the matrix band should not cause any irritation to patients (i.e. Nickel) and must be biocompatible.
- ii. The device must come with a safety label to inform users how to properly handle it to ensure safety.
  1. It must also come with a safety warning that encourages users to dispose of the device if sterile packaging is tampered or the device is broken.

*c. Accuracy and Reliability:*

- i. The device thickness should be accurate to a hundredth of a millimeter during manufacture to ensure it remains below 0.05mm, an acceptable interproximal space [2].
- ii. The matrix must maintain this thickness and its conformation to the tooth such that there are no abnormalities when the filling is packed and solidified.

*d. Life in Service:*

- i. The device must maintain the target properties for the duration of the procedure in which it is used. For a cavity filling, this is generally within an hour [1]. Currently, most matrix bands are single-use to ensure sterile conditions.

*e. Shelf Life:*

- i. Most current matrix bands are made of stainless steel or natural plastics which have an indefinite shelf life for practical purposes. Our device should match this shelf life while kept in the proper packaging.
- ii. This device should be kept at or near room temperature.

*f. Operating Environment:*

- i. The human mouth is a variable environment with both physical, chemical and biological factors to consider.

1. This device must maintain its integrity when forced in between teeth which have a Mohs hardness rating of 5 [3]. It must also be blunt enough to prevent injury of the, potentially compromised, tooth and surrounding gums. Operating temperature ranges from room temperature ( $\sim 20^{\circ}\text{C}$ ) to body temperature ( $\sim 37^{\circ}\text{C}$ ).
2. The mouth has a pH with a range of 6.2-7.6. There are also a variety of enzymes in the saliva that the device must withstand [4].
3. The device must be non-toxic to the cells of the body as well as essential bacteria of the mouth and free of common allergens like nickel.

*g. Ergonomics:*

- i. The new device should be easier and much less time consuming to install, adjust, and use than existing products on the market, like the sectional and circumferential matrix bands.

*h. Size:*

- i. The device should be adjustable and/or scalable to accommodate all sizes of teeth. The dimensions of human teeth can vary greatly with type of tooth, sex, age, race, and many other factors. On average, maxillary teeth have a crown height of 8.77 mm, ranging from 7.2 mm to 11.2 mm, and mandibular teeth have a crown height of 8.62 mm, ranging from 7.5 mm to 11.0 mm [5].
- ii. The perimeter of teeth can be approximated by treating teeth as rectangles and using average mesiodistal and faciolingual measurements. This approximation would result in an average tooth perimeter of 33.82 mm, with a range of 22 mm to 45.8 mm [5].
- iii. Current matrix bands commonly come in three different thicknesses: 0.001 gauge (0.0254 mm), 0.0015 gauge (0.0381 mm), and 0.002 gauge (0.0508 mm) [6]. The device should have a similar or smaller thickness than current matrix bands.

*i. Weight:*

- i. Current matrix bands are made of stainless steel. Using the gauge size (0.0015), approximate tooth size (height = 8.695 mm, perimeter = 33.83 mm), and the density of stainless steel ( $7.99 \text{ g/cm}^3$ ) we can calculate the weight of one matrix band [7]. This comes out to a weight of 0.0895 grams. The device should weigh similar to current matrix bands.

*j. Materials:*

- i. The matrix band is expected to be made out of a dead soft metal, meaning it is rigid in its resting state while still being malleable [8]. This would include materials such as stainless steel and aluminum. The material must also be non-toxic to humans to prevent harm to a patient. The material also must not react with both silver fillings and white fillings.
- ii. If possible, the material should be able to be sanitized. This would allow for a more sustainable product that is also more cost effective.
- iii. The wedge is traditionally made out of wood. For the purposes of this project, the wedge will likely be made of some sort of plastic due to the ease of fabrication.

*k. Aesthetics, Appearance, and Finish:*

- i. The band and the wedge should not be colored the same as a tooth to avoid confusion while operating. The aesthetics were not a priority with the client and depend more on functionality.

## **2. Production Characteristics**

*a. Quantity:*

- i. The product is expected to be non-reusable. That means if it is made market available, the product would need to be mass produced to meet the demand of dentists for every adjacent tooth filling procedure. If the final design were able to be sterilized, then the demand for the product would go down to one per dentist. For the purposes of the product, there will likely be a couple models produced.

*b. Target Product Cost:*

- i. The goal when planning out the designs is to keep the products as cost effective as possible without sacrificing quality. Current matrix bands go for about 50 cents to a dollar [9]. Given the possible complexity of our design, it might be more expensive to fabricate but keeping the price under \$3-5 should be prioritized.
- ii. The budget for the project is expected to be around \$200-300 given the testing needed to be done.

## **3. Miscellaneous**

*a. Standards and Specifications:*

- i. FDA approval is necessary for medical devices. Current matrix bands are Class 1 devices as specified in the Codes of Regulations Title 21, Chapter 1, Subchapter H, Part 872 Subpart E. They are identified as low risk devices that present minimal potential for harm. If the new design utilizes

the same materials used before 1976 , it would be exempt from premarket notification procedures specified in Subpart E [10]. Otherwise, a premarket notification submission would need to be completed to the Food and Drug Administration at least 90 days prior to the proposed introduction of the product [10]. An Investigational Device Exemption (IDE) would need to be obtained to pursue clinical studies with the device to collect data on safety and effectiveness in support of the Premarket Approval (PMA) application or Premarket Notification 510(k) submission. These studies must be approved by the Institutional Review Board (IRB) before the studies begin [11].

*b. Customer:*

- i. This design should mainly appeal to dentists. Thus, the design needs to be optimized to fit the user's comfort and ease of use while decreasing procedural time. Dental suppliers would also be target customers, so the design must outcompete others on the market. The client specifications should be closely followed, as the client has the perspective of a dentist and, thus, potential customer.

*c. Patient Related Concerns:*

- i. The device will be in direct contact with the patient's oral cavity, so the materials must be non-toxic and non-allergenic. Common metal allergies include: nickel, cobalt, copper and chromium [12]. This design should also be one-time use, similar to the current matrix band used. Thus, sterilization would not be a concern. Ideally, the device would not add any additional discomfort during the filling process.

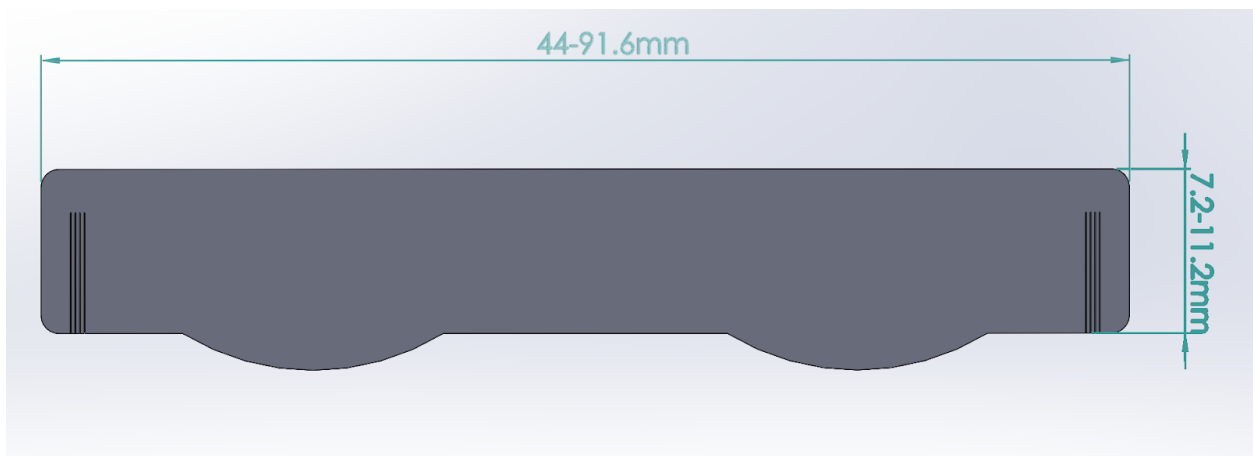
*d. Competition:*

- i. There are numerous devices and techniques that can be considered competing designs, however, those that relate most to this project are sectional matrix systems. The Triodent V3 Ring used alongside the Triodent Wave-Wedge are advertised as a sectional matrix system that allows for superior functionality compared to the circumferential band (tofflemire) [13][14][15]. If this Triodent ring is used to separate adjacent teeth with the placement of two matrix bands, the contact between the teeth would not offer optimal contact leading to a larger gap than desired.

## B. Preliminary Designs

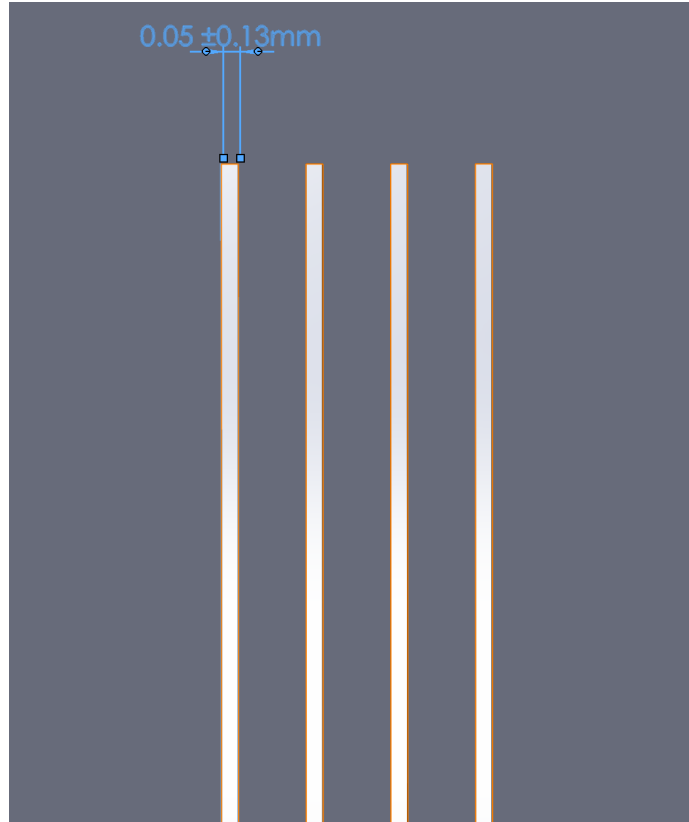
### Design 1 - Handcuff Design

The Handcuff Design is a modification of a circumferential matrix band so that it can be used to surround two adjacent teeth. The design consists of a single band of fairly thin width, 0.0254 mm, with slot fittings on either end that are slightly wider, as seen in Figures 1 and 2. The idea is that the band would wrap around the two targeted teeth laterally (cheek side) and come together medially (tongue side) in the interproximal space, visually shown in Figure 3. The band should be thin enough to fit through this space, but if the teeth are too close together for the band to fit, the dentist can use a ring to create a temporary gap in the teeth. However, to save time, the thickness of the device could be changed to better fit a majority of interproximal spaces. Once the band is in place, each end of the band is pulled tight. One pair of the slot fittings (one from each side of the band) would then slide over the middle of the band, completing the loops around the teeth and locking the band securely in place. To account for multiple different tooth sizes, different length bands could be produced with just a few slots at a specified distance from the end, or one larger size band could be produced with a large number of slots across the majority of the band. The band would need to be made of a dead soft metal in order to ensure its form-fitting properties. The band would also likely be one time use before needing to dispose of it. The band would have to be used in tandem with a wedge in order to provide more support in driving matrix bands against the wall of the tooth. Fabrication of the device could be carried out relatively easily by using a laser cutter on a very thin sheet of dead soft metal. A few major drawbacks to this device is that it may run into some issues when trying to create a very tight fit around the teeth and sliding the tiny slots around the thin matrix band may turn out to be very time consuming.

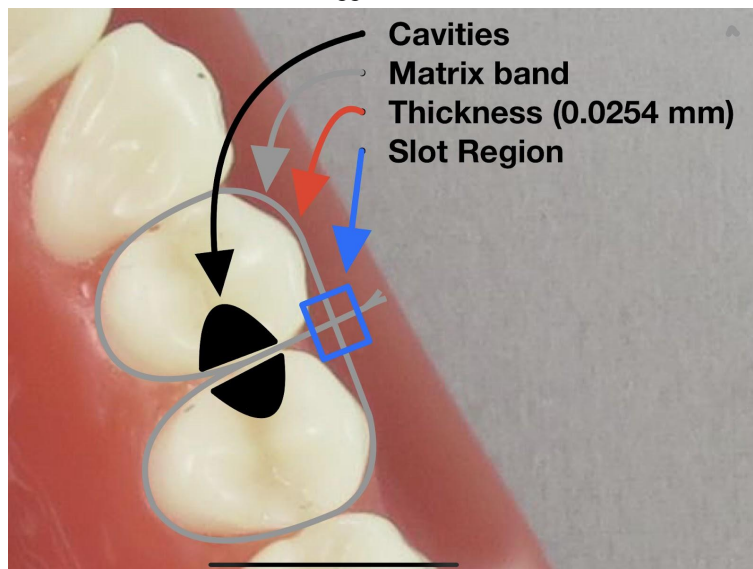


**Figure 1: Handcuff Design Side View.** Slot fittings are gaps in the matrix band used to secure the device during installation. The fins (rounded protrusions along the bottom edge) are used to help keep the device in place and prevent cavity material from seeping into the gums. The height of the fins is variable depending on the procedure and patient.





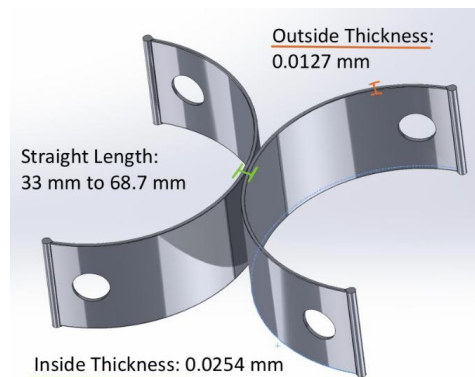
**Figure 2: Handcuff Design Securing Mechanism.** Close-up of the slot fittings used to secure the handcuff design once it is wrapped around the teeth.



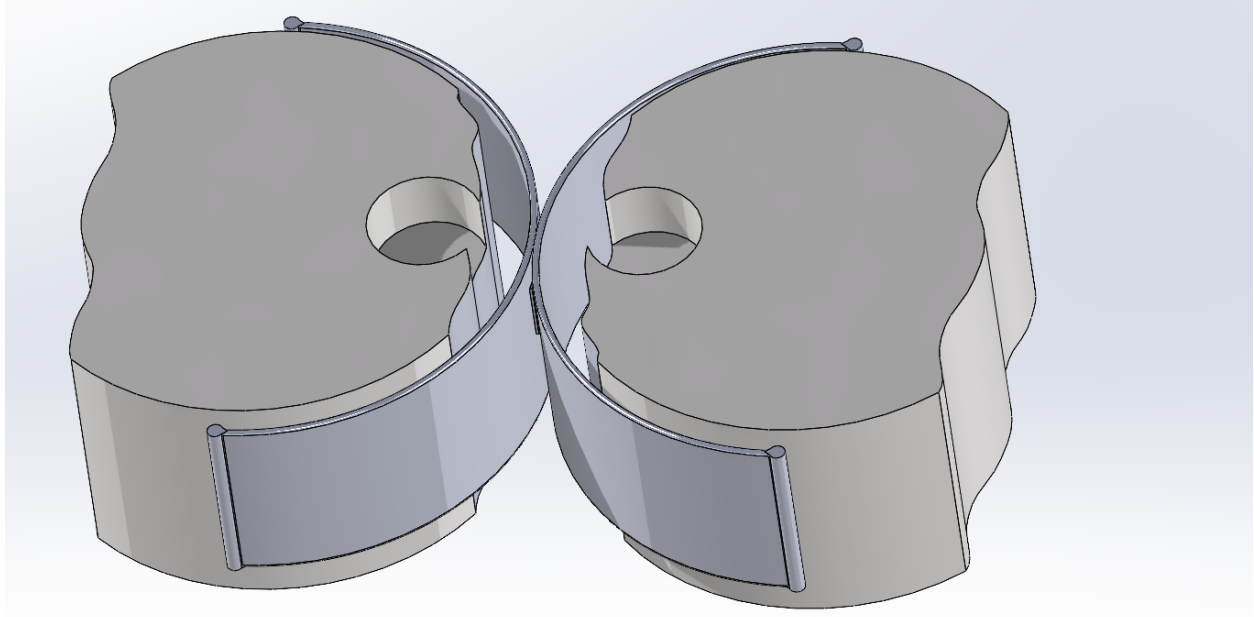
**Figure 3: Handcuff Design Top View.** The handcuff band is wrapped around two teeth with an interproximal cavity. The band is held in place by placing the center of the band through any of the slots located in the region with the blue box.

## Design 2 - Butterfly Design

The Butterfly Design is a single matrix band that can be thought of as two sectional matrix bands conjoined where tooth contact will occur. The curvature of each side of the band would allow this design to wrap around each tooth. The center of the butterfly band would have a thickness of 0.0254 mm to ensure a fit between the teeth. To ensure the center thickness, each half of the butterfly band would have a thickness of 0.0127 mm, shown in Figure 4. As in the Handcuff Design, this device would also be fabricated from a dead soft metal. Installation of this device should be much faster and easier than installation of the Handcuff Design, as this design would only require the dentist to separate the teeth if needed and then the band could be slid into place, Figure 5. Once the device is installed between the target teeth, two wedges must be placed between the gums and the band to help secure it in place. This device may also need to be used in combination with two rings, to secure the edges of the matrix band to the teeth and ensure proper contact to prevent any cavity filling material from seeping out of the device and into the gums of the patient. These rings can be quite large and may end up inhibiting the cavity filling process.



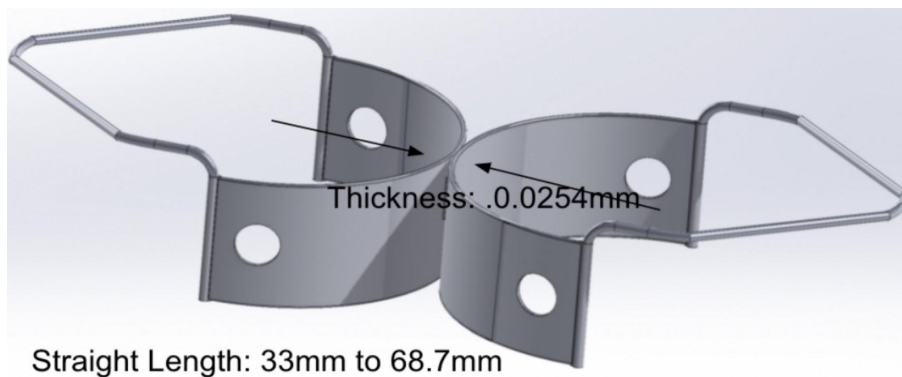
**Figure 4: Butterfly Design Solidworks 3D Model.** This design consists of two sectional matrix bands conjoined together in the middle to produce a band that slightly resembles a butterfly. Holes in the band will help to aid the removal of the device.



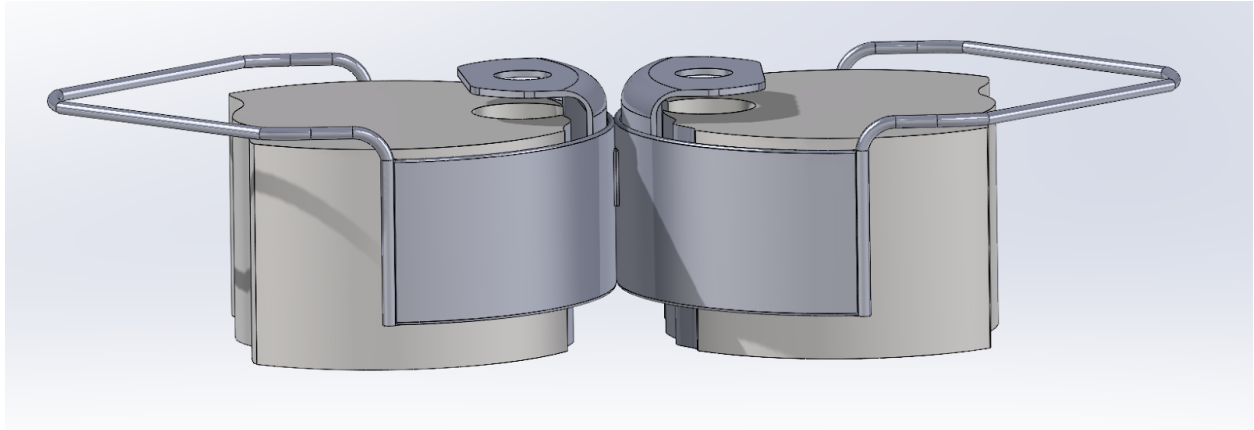
**Figure 5: Butterfly Design installed.** This CAD image shows how the butterfly band (silver) would sit between two teeth infected with a cavity (gray/tan).

### Design 3 - Butterfly + U Pinchers Design

The Butterfly + U Pinchers Design is similar to the Butterfly Design in its shape, size, and thickness but has incorporated a spring clamp and U Pinchers to fix some flaws of the design, as shown in Figures 6 and 7. The U Pinchers serve a main purpose of creating an inward force that pulls the matrix bands close to the teeth to maximize surface contact. In addition, they could also be used as something to hold onto while the dentist is placing the matrix bands in the patient's mouth. The design also incorporates an innovative spring clamp to hold the matrix bands in place and widen the gap between the targeted teeth during a filling. Like the other two designs, this design would be created out of a dead soft metal, would most likely be single use, and would have a center thickness of 0.0254 mm. All dimensions of the butterfly band in this design would be the same as in the Butterfly Design. With the inclusion of all of these components, the device will be the most expensive and hardest fabricate.



**Figure 6: Butterfly + U Pinchers Design Solidworks 3D Model.** Similar to the butterfly design, the device consists of two sectional matrix bands with the addition of U Pinchers. Holes added to aid in the removal of the device. Not shown in figure: spring clamp.






**Figure 7: Butterfly + U Pinchers Design installed.** This CAD image shows how the butterfly band (silver) will sit between the teeth (gray/tan). U pinchers (silver) will produce an inward force on the butterfly band to help the band sit flush against the teeth. Not shown in figure: spring clamp

## C. Design Matrix and Evaluation

The designs from the previous section were evaluated based on weighted criteria. These criteria and the evaluations can be seen below in Table 1.

### Design Matrix

*Table 1: Preliminary Design Matrix*

Dental Matrix Band Design Matrix						
Design Criteria (Weight)	Design 1 (Handcuff)		Design 2 (Butterfly)		Design 3 (Butterfly + U pinchers)	
						
Functionality (30)*	3/5	18	2/5	12	5/5	30
Ease of Use (20)	2/5	8	4/5	16	4/5	16
Fabrication (15)	4/5	12	3/5	9	3/5	9
Ease of Sterilization (15)	3/5	9	3/5	9	3/5	9
Safety (10)	4/5	8	5/5	10	5/5	10
Cost (10)	4/5	8	3/5	6	2/5	4
Total (100)	63		62		78	

\*\*The six design criteria on the far-most left column were evaluated for each preliminary design. The designs were given a number score out of 5 for each category and ratings were totalled to determine which design was best (described under justification of criteria section below). Shaded sections indicate the highest ranking design for each criteria. The lighter shading indicates ties between designs.

\*The functionality criteria was based on the design's ability to allow the dentist to complete the procedure with both quality and time efficiency.

### Justification of Criteria

**Functionality:** The functionality criteria was based on the design's ability to allow the dentist to complete the procedure with both quality and time efficiency. The Butterfly Design received the lowest score in this category (2/5) due to its lack of adjustability and tightness. The band needs to securely fit around the tooth in order for a quality tooth contact, however, with the Butterfly Design, some variation in tooth sizes amongst different patients would result in different results. For example, the greater thickness in the middle of the band may need to be longer for some patients than others. The Butterfly + U Pinchers Design received the highest score in this category (5/5). This design has pinchers which maintain a close fit between the teeth and matrix across the entire section. This inward force allows the design to be used across varying shapes and sizes of teeth. The spring clamp also improves the design by widening the gap between the teeth if needed. The Handcuff Design received a score of 3/5 because it may have factors that contribute to increased procedural time. It is a circumferential design, rather than a sectional one, that

would require steady placement of the band in its slot fillings. This may be both a frustrating and time consuming task.

*Ease of Use:* This design criteria outlined how easy the dental matrix band design would be for dentists to place in between teeth and remove from the mouth. It also took into consideration any view obstruction the dentist would encounter from the shape of the design. The Handcuff Design scored the lowest (2/5) in this area due to it requiring a tedious placement procedure and therefore tedious removal. Both the Butterfly and Butterfly + U Pinchers designs tied for the higher scores of (4/5). Neither design received a perfect rating due to the Butterfly Design's slightly more time consuming placement and the Butterfly + U Pinchers Design's possible view obstruction.

*Fabrication:* This criteria was graded on how easily the design could be fabricated based on the intricacy of parts as well as characteristics and availability of materials. While it is important to ensure that the design is viable to actually manufacture, and do so on a scale that would allow for the device to be single-use, the function does not require intricacy and there is significant literature available on viable materials. Therefore, this section was given a relatively low weight of 15/100. The Handcuff Design scored the highest on this criteria (4/5) as it only requires simple modifications to the matrix bands currently used, and the same, single material. Both the Butterfly and Butterfly + U Pinchers designs scored lower at (3/5) because of the thin, split, and curved metal structures that must be custom manufactured and accurate on a very small scale.

*Ease of Sterilization:* All of the designs have the same score for sterilization. This is due to the fact that all are made from the same material and all would react the same to sterilization processes. While all designs are meant to be one time use, they could be sterilized based on the material used and durability of the material.

*Safety:* Each design ranked very similarly in safety as all designs have little chance of harming the patient during a filling procedure. Also any materials that could be toxic to a patient could be subbed out easily in all designs. However, the handcuff design ranked slightly worse in safety due to a higher chance of the band slipping off or coming undone.

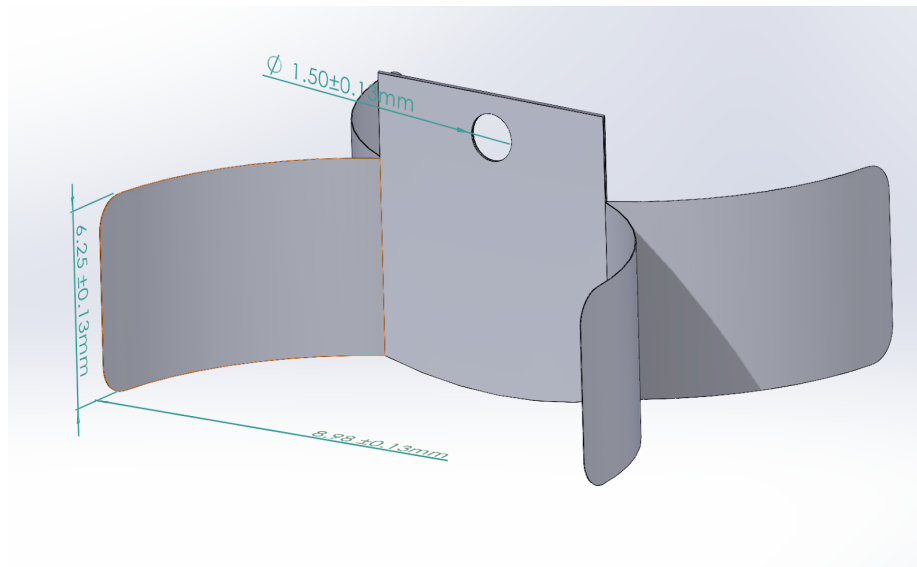
*Cost:* The cost criteria was scored based on type, and amount of material required, and associated fabrication costs. This section was given a weight of 10/100 as there likely won't be much variability and early cost estimates are not a primary concern. The Handcuff Design ranked highest in this section (4/5) as it is a modification of the most common current matrix bands which are inexpensive. The Butterfly Design was given a 3/5 as the fabrication process is more involved. The Butterfly + U Pinchers Design was given a 2/5 as both the fabrication process is more difficult and more material is required.

## Proposed Final Design

The team weighted and scored each criteria of the design matrix while taking the client's preference for sectional matrix bands over circumferential matrix bands into consideration. This determined the highest scoring design idea to be the Butterfly + U Pinchers Design. The design will be harder to fabricate and will cost more in terms of materials and fabrication, but the team believes that these hurdles will be worth the final result.

## D. Design Iterations and Modifications

After concluding that the proposed final design, the Butterfly + U Pinchers Design, would require a tedious and difficult fabrication, the team decided to move forward in a different direction. The Butterfly Design was reconsidered, and adjustments were made to the design so that it better satisfied the client's needs and the specified design criteria. The updated Butterfly Design, as seen in Figure 8, can be made from a single sheet of material, decidedly the 1008-1010 stainless steel, to make the fabrication process more feasible for the team and for possible mass production. The design has a band thickness throughout of 0.0254 mm, except at the center portion where the thickness is twice that, 0.0508 mm, due to folding of the steel sheet. Its height is 6.25 mm, consistent with the height of the circumferential matrix bands given to the team by the client. The updated design incorporates rounded edges for safety in the patient's mouth, a holed tab to aid in placement and removal of the device, and a convex bottom edge to prevent filling material from entering the gingiva during a procedure. Due to the folded nature of the design, there is space between each band to allow the use of a wedge during a procedure as well.



**Figure 8: Updated Butterfly Design.** Dimensions of the device include a height of 6.25 mm, a band radius of 8.98 mm, a hole diameter of 1.5 mm, and a material thickness of 0.0254 mm. Key features include rounded edges for safety, a holed tab for placement/removal, and a convex, rounded bottom edge for preventing the escapement of filling material.

## E. Final Design

### Materials

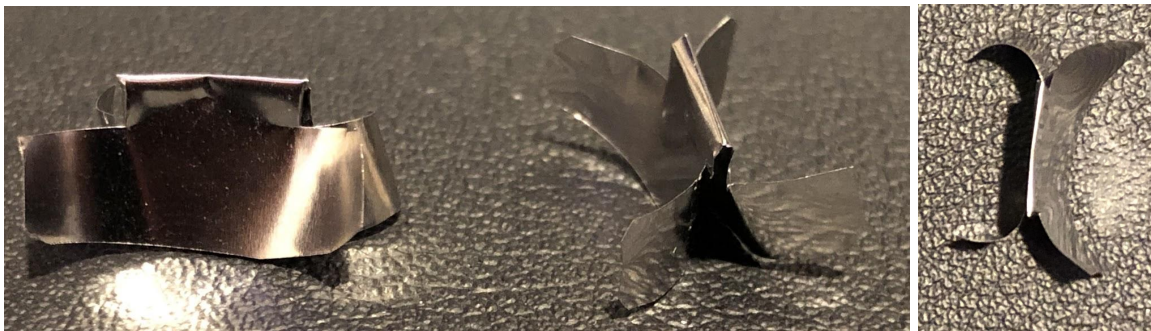
The current industry standard for matrix bands is a dead-soft steel primarily due to its mechanical properties and non-toxicity [16]. “Dead-soft” steel refers to a lower carbon and manganese content at less than 0.1% and 0.2-0.5%, respectively [17]. Additionally, it is processed by heating to a critical temperature and cooled more slowly, creating larger grains, making the material less hard, but more ductile. The tensile yield strength is 260-340 MPa, which must be relatively high to withstand tightening

around the tooth [17]. The Rockwell B hardness is about 55, which is important for preventing deformations from forming when pressed up against the teeth but is limited due to the method of processing which allows for a lower elastic modulus. The elastic modulus is 200-215 GPa, sufficient for both allowing the thin material to bend around the tooth while maintaining tight contact with the tooth even when withstanding high outward stresses from packing the filling material [18].

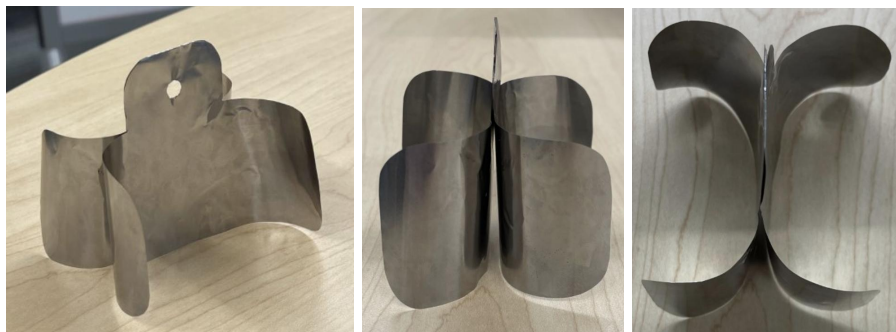
In the past, materials such as copper, silver and titanium have been used to fabricate matrix bands but the mechanical characteristics, biocompatibility, and cost of dead-soft steel eliminated them from our considerations [16]. The team decided upon using a shim stock roll of 1008-1010 Grade Stainless Steel, steel containing 0.08 to 0.1% carbon by weight, for fabrication of the matrix band device [19]. The material has a thickness of 0.0254 mm, consistent with the thickness of current matrix bands [20]. The finalized expense table including this steel product as well as the dental tooth model used in brainstorming can be found in *Appendix H - Expense Table*.

## Final Prototype

An initial prototype was fabricated out of the 2540 mm long by 152.4 mm wide by 0.0254 mm thick shim stock made from 1008-1010 Grade Stainless Steel. This naming convention means that the stainless steel used in the prototype contained 0.08 to 0.1% carbon by weight [20]. As mentioned above, two prototypes were fabricated by hand. The scaled prototype can be seen in Figure 9. An enlarged, unscaled prototype was fabricated to include the key features that the small scale could not incorporate. The larger prototype can be seen in Figure 10.



**Figure 9a and 9b: Scaled Prototype.** From left to right a view of the front, side, and top are shown. Take note of the pointed corners and lack of a hole on the top tab.



**Figure 10a, 10b, and 10c: Enlarged Prototype.** From left to right a view of the front, side, and top are shown. Take note of the curved corners and included hole on the top tab.



After proving the feasibility of the design, the team reached out to a non-profit collaborative workspace in Madison, Sector67. With their help and the use of their laser cutter a higher fidelity prototype was created, Figure 11. The laser cutter managed to cut a prototype to the proper scale and left no sharp corners or edges. Heat lines can be seen on the device, however the final design will not have these lines as it will more than likely be manufactured using a punch instead of a laser. Different iterations of the device will be created by varying dimensions of the device like height, circumference length, depth of convex bottom edge, and top slab size. These different iterations will be evaluated by Dr. Donald Tipple using the testing protocol found in *Appendix G - Qualitative Testing Protocol*.



**Figure 11: Laser Cut Prototype.** High fidelity model produced by a laser cutter. Take note of the convex, rounded bottom edge, smooth corners, and smooth edges.

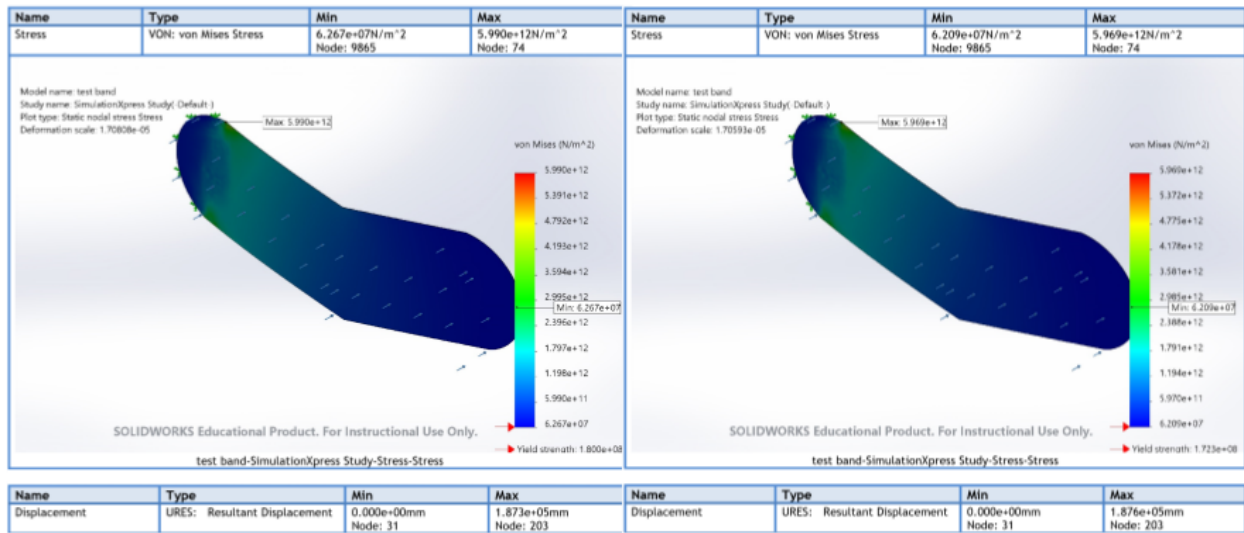
## F. SolidWorks Material Testing Protocol

### Testing

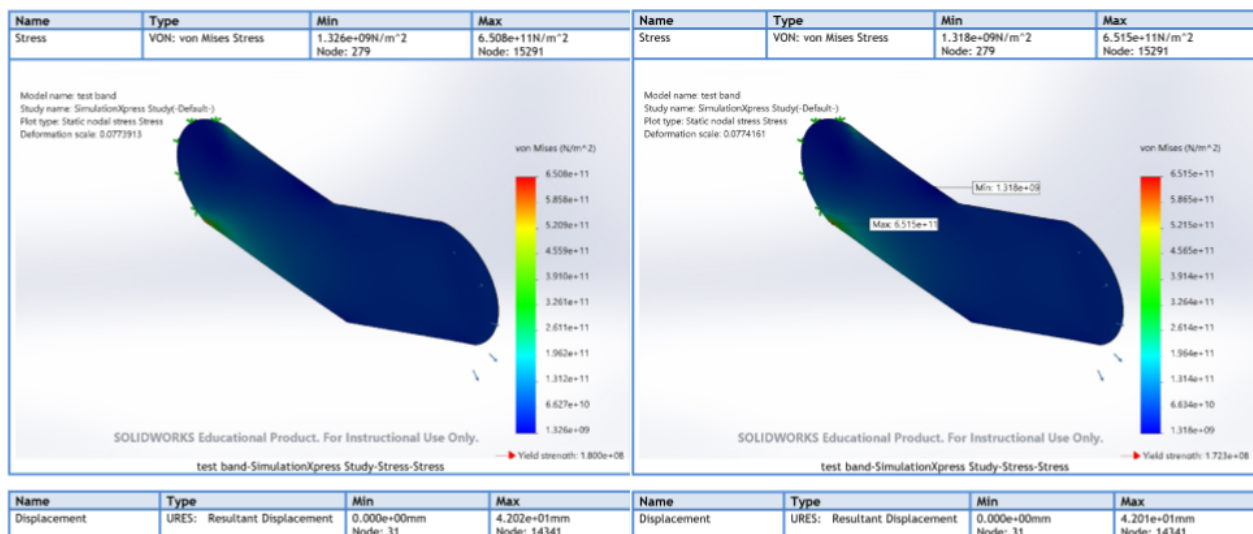
The purpose of the testing was to determine if the mechanical properties of 1008-1010 steel alloy had more favorable characteristics than the material that matrix bands are usually made out of, dead soft stainless steel. In the first test, a Solidworks Simulink simulation was run on a test matrix band while one of the lateral ends of the band was fixated. Loads were then applied normal to the band and laterally to the band as separate tests, in order to get resultant stress and strain calculations for multiple directions of force. In the normal test, a 200 N load was applied as the force required to move the band wouldn't need to be super high. Conversely, the load applied laterally was 20 kN as the force required to pull the band apart is much higher than the force required to bend the band. Lastly, each test was run twice to account for the two different materials being compared, totalling in four tests. The output of the simulation provides the Von Mises stress distribution which highlights where the highest stresses are seen on the band via a color gradient key. The simulation also provides the maximum displacement as well as the tensile yield strength and ultimate stress. An example of this output can be found in the *SolidWorks Simulink Simulation Output (Normal Force/1008-1010)* section of *Appendix F - SolidWorks Material Testing Protocol*

## Results

The Solidworks Simulink testing suggested that the 1008-1010 steel alloy is very similar to the dead soft stainless steel it was compared to. In all of the tests, the yield strengths were 180.0 MPa and 172.2 MPa for the 1008-1010 and stainless steel bands respectively, showing little disparity between the materials. The maximum displacements were also nearly identical at 1.876 m for the 1008-1010 alloy band and 1.873 m for the stainless steel band. The Von Mises stresses matched up very similarly (5969 GPa and 5990 GPa for the stainless steel and 1008-1010 alloy), and the observed forces were distributed very similarly, as outlined in Figure 12. For the tensile load test, the displacements were within .001 mm with the 1008-1010 alloy at 4.202 mm and the stainless steel at 4.201 mm. Likewise, the Von Mises max stresses were also similar for the tensile stress test. The 1008-1010 alloy recorded a maximum Von Mises stress of 650.8 GPa and the stainless steel recorded a Von Mises max stress of 651.5 GPa, as outlined in Figure 13.



**Figure 12a, 12b: Solidworks Simulink stress simulations with load applied normal to the band. Output yields the distribution of Von Mises stresses. 1008-1010 alloy on the left and dead soft stainless steel on the right.**




**Figure 13a, 13b: Solidworks Simulink stress simulations with load applied laterally to the band.** Output yields the distribution of Von Mises stresses. 1008-1010 alloy on the left and dead soft stainless steel on the right.

## Discussion

The results of the Solidworks Simulink testing does not show any major mechanical differences between the bands made with the 1008-1010 steel alloy and the bands made with stainless steel, suggesting that the 1008 alloy either is dead soft, or can mimic dead soft metal. More Solidworks Simulink testing could be done by applying loading in different directions and fixing the model in varying locations. However, it was hypothesized that the materials would behave similarly under these conditions as both are dead soft steels that are malleable, yet tough. Therefore it would likely be unhelpful to continue testing as the odds that the materials would display very similar properties once again would be very high. This set of testing suggests that the 1008 steel alloy would be a good substitute for dead soft stainless steel in the final design as the materials behave extremely similarly.

## SolidWorks Simulink Simulation Output (Normal Force/1008-1010)



**Description**  
No Data

**Simulation of test band**


Date: Tuesday, December 7, 2021  
 Designer: Solidworks  
 Study name: SimulationXpress.Study  
 Analysis type: Static

**Table of Contents**

- Description..... 1
- Assumptions ..... 2
- Model Information ..... 3
- Material Properties ..... 4
- Loads and Fixtures..... 4
- Mesh information ..... 5
- Study Results ..... 7
- Conclusion ..... 10


**Assumptions**

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Analyzed with SOLIDWORKS Simulation

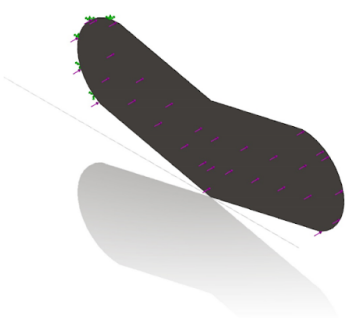
Simulation of test band 1



Analyzed with SOLIDWORKS Simulation

Simulation of test band 2


### Model Information



Model name: test band  
Current Configuration: Default


Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1	Solid Body	Mass: 5.96039e-05 kg Volume: 7.57356e-09 m <sup>3</sup> Density: 7,870 kg/m <sup>3</sup> Weight: 0.000584118 N	C:\Users\mafa1\OneDrive\Documents\College\Senior\BME400\test band.SLDPRT Dec 6 22:22:10 2021

### Material Properties

Model Reference	Properties	Components
	Name: AISI 1010 Steel, hot rolled bar Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 1.8e+08 N/m <sup>2</sup> Tensile strength: 3.25e+08 N/m <sup>2</sup>	SolidBody.1 (Boss-Extrude1) (test band)

### Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-3		Entities: 1 face(s) Type: Fixed Geometry

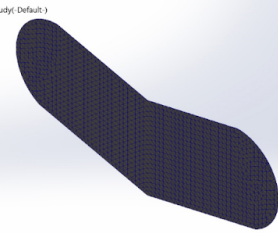
Load name	Load Image	Load Details
Force-3		Entities: 1 face(s) Type: Apply normal force Value: 200 N

### Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points for High quality mesh	16 Points
Element Size	0.489198 mm
Tolerance	0.0244599 mm
Mesh Quality	High

### Mesh Information - Details

Total Nodes	15445
Total Elements	7488
Maximum Aspect Ratio	52.594
% of elements with Aspect Ratio < 3	0
Percentage of elements with Aspect Ratio > 10	100
Percentage of distorted elements	0
Time to complete mesh(hh:mm:ss):	00:00:02
Computer name:	

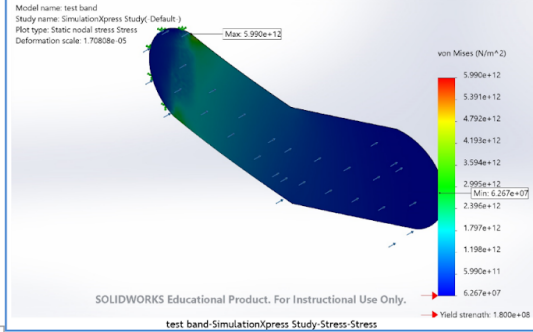


Model name: test band  
Study name: SimulationXpress Study1 (Default)  
Mesh type: Solid Mesh

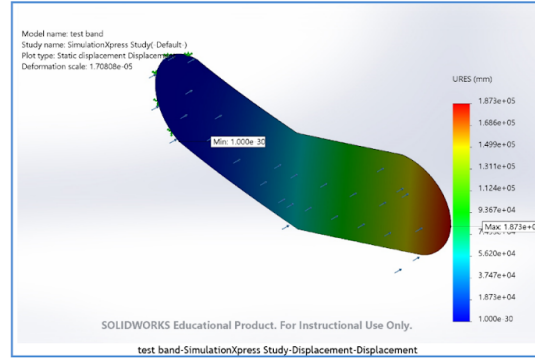
SOLIDWORKS Educational Product. For Instructional Use Only.

### Study Results

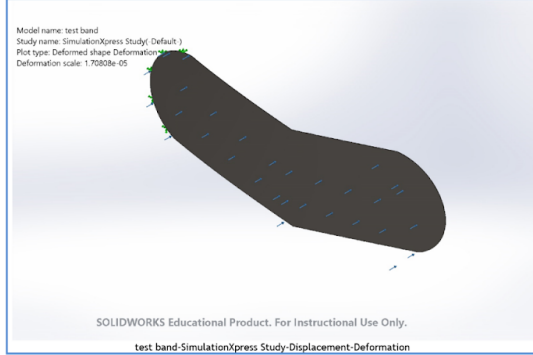
Name	Type	Min	Max
Stress	VON: von Mises Stress	6.267e+07N/m <sup>2</sup> Node: 9865	5.990e+12N/m <sup>2</sup> Node: 74



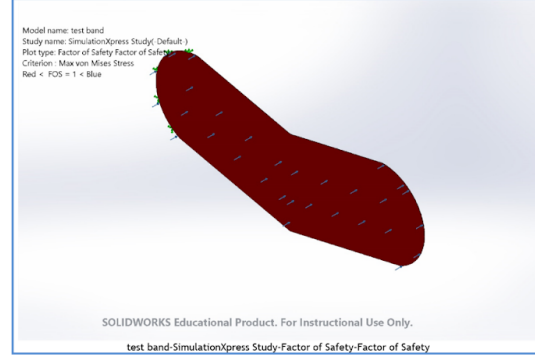
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0.000e+00mm Node: 31	1.873e+05mm Node: 203



Name	Type
Deformation	Deformed shape



Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	3.005e-05 Node: 74	2.872e+00 Node: 9865



### Conclusion

## G. Qualitative Testing Protocol

### **Materials:**

- Different Sized Butterfly Matrix Bands (V1-V6 for each different version)
- Universal Tofflemire Matrix Band (0.002") (UTMB)
- Tofflemire Retainer
- 2 Dental Wedges
- 1 Dental Ring Clamp
- Adult Tooth Model

### **Procedure:**

1. Rate each of the different design iterations and the Universal Tofflemire Matrix Band on a scale from 1-5 for each of the different evaluation criteria. Add up the total scores for each of the different devices and compare their scores. The device with the highest score will be chosen as our final design.

Evaluation Criteria	V1	V2	V3	V4	V5	V6	UTMB	Comments
Ease of Use								
Tooth Contour								
Protective Coverage								
Restoration Contact								
Efficiency								
Compatibility with existing tools & Procedures								
Total Score (out of 30)								

## H. Expense Table

Item	Supplier / Brand	UPC / Item Number	Link	Quantity	Date	Price
Dental	Amazon /	UPC:	<a href="https://ww">https://ww</a>	1	10/20/21	\$28.42

Implant Teeth Model Study Teach Standard Model with Removable Teeth	Smile1000	601263927587	w.amazon.com/dp/B071JVJ1LG/ref=cm_sw_r_sms_api_glt_fabc_BZN7G1DC333NTE4CCJVE			
Steel Shim Stock Roll, 1008-1010 Grade, 0.001 in Thickness, +/-0.0001 in Thickness Tolerance	Grainger	Item Number: 3L432	https://www.grainger.com/product/PRECISION-BRAND-Steel-Shim-Stock-Roll-3L432?opr=PDPRRDSP&analytics=d_srrItems_5EY10	1	11/21/21	\$35.96
Permatex 84109 PermaPoxy 4 Minute Multi-Metal Epoxy, 0.84 oz	Amazon	UPC: 8622684109	https://www.amazon.com/dp/B000ALDXV2/ref=cm_sw_r_sms_api_glt_i_GVTR56HW6JCMF75DXPMF?_encoding=UTF8&psc=1	1	2/24/2022	\$8.11
					Total	\$72.49

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