Approximating Surface Matrix Band for Dentist to Use for Patients

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Abstract

Dental caries is an infectious, transmissible disease characterized by the breakdown of tooth structure due to bacterial activity. A common infection area is the proximal contact between two posterior teeth, often affecting both teeth. The current treatment is a Class II restoration, which removes decay and restores tooth structure while maintaining proximal contact. Current products used in this procedure include circumferential and sectional matrices; however, when both adjacent teeth are affected, these tools are inefficient as only one matrix can be used at a time, requiring repetition of pre-operative processes. This study aimed to design a device capable of treating two adjacent interproximal cavities in one round of pre-operative steps without compromising the contact area. Out of three preliminary designs, the 316 stainless steel "Hole" design was selected for its efficacy, simpler use and fabrication, and lower cost. MTS tensile, removal force, SolidWorks Finite Element Analysis (FEA), and procedure timing tests were performed to evaluate functionality. Removal forces obtained from testing were applied to the SolidWorks FEA, yielding high stress values indicating the matrix was unable to withstand removal forces, which was further observed during timed trials where a few matrices broke upon removal. Despite this, a 29% reduction in procedure time was observed when using the dual matrix compared to traditional sectional matrices. Future iterations should incorporate surface coatings to reduce the coefficient of friction, a tab with rounded edges to reduce stress concentrations, and a perforation inferior to the hole for easy removal.

Introduction

Dental caries remain one of the most common chronic diseases worldwide and continue to place a significant burden on both patients and providers [1,2]. Interproximal caries, which develop on the contacting surfaces between adjacent posterior teeth, are especially common because these areas are difficult to clean and prone to plaque accumulation [3]. If left untreated, caries can progress to pain, infection, tooth fracture, and eventual tooth loss. As a result, timely and effective restorative treatment is essential for maintaining oral health and preventing more invasive procedures [4].

Class II composite restorations are the standard treatment for interproximal decay in premolars and molars. During this procedure, the decayed tooth structure is removed and replaced with restorative material while recreating the natural contour of the tooth. A critical component of this process is maintaining proper proximal contact between adjacent teeth. Adequate contact prevents food impaction, reduces plaque retention, and helps preserve periodontal health. To achieve this, dentists rely on matrix band systems that temporarily form a wall around the prepared tooth while the restoration material is placed and cured [5].

Currently available matrix systems are highly effective for restoring a single tooth, with sectional matrices commonly preferred for producing stronger contact areas and more anatomical contours than circumferential systems. However, these devices are designed to treat one tooth at a time. When decay is present on two adjacent teeth, the dentist must repeat the restoration process sequentially using two separate matrix setups. This increases procedure time, adds complexity to the workflow, and can create additional inconvenience for both the patient and clinician [6,7].

Given the high prevalence of adjacent interproximal lesions in routine dental practice, there is a clear opportunity to improve procedural efficiency without sacrificing restoration quality. More specifically, demonstrating that decay between adjacent teeth represents a substantial portion of restorative cases encountered by general dentists [8]. Because these lesions frequently occur between neighboring posterior teeth, clinicians often face situations in which two adjacent surfaces require treatment during the same appointment.

The purpose of this project was to develop and evaluate a dual-sided sectional matrix band capable of supporting simultaneous restoration of two adjacent Class II cavities while preserving proper proximal contact. By reducing repeated setup steps and maintaining compatibility with existing clinical techniques, this design aims to streamline restorative treatment and improve the efficiency of everyday dental procedures.

Figure 1: Example of a dental interproximal cavity [9].

Figure 2: Example of a dental interproximal cavity preparation during a filling procedure.

Figure 3: Current market matrix band model: Halo Sectional Matrix Band [10].

Background

Dental caries is a disease mediated by biofilm and diet that results in the net mineral loss of dental hard tissues over time. It remains one of the most prevalent chronic diseases worldwide and affects individuals across all age groups [2,3]. Caries development occurs when acidogenic bacteria within dental plaque metabolize fermentable carbohydrates. These then produce organic acids that lower plaque pH and initiate demineralization of enamel and dentin. Repeated acid exposure without adequate remineralization leads to cavitation and structural breakdown of the tooth [3,11]. Because of its high prevalence and cumulative nature, restorative treatment of carious lesions continues to represent a substantial portion of general dental practice.

A common location for lesion development is the interproximal surface of posterior teeth, which is defined as the contacting surfaces between adjacent premolars and molars. These areas are particularly susceptible to plaque accumulation because they are less accessible to direct visualization and routine mechanical cleaning, allowing biofilm to persist undisturbed for longer periods [3]. Inadequate proximal contact and food impaction can further promote plaque retention, gingival inflammation, and recurrent caries adjacent to existing restorations [5]. When lesions develop on the proximal surfaces of posterior teeth, they are commonly treated as Class II restorations under G.V. Black classification. These restorations require removal of decayed tissue followed by reconstruction of the missing proximal wall and occlusal anatomy using restorative material, most commonly resin composite [12]. Successful Class II restorations depend heavily on reproducing proper proximal contour and contact. Open contacts may allow food packing, gingival irritation, periodontal inflammation, and patient discomfort, whereas excessive contact may hinder floss passage and create occlusal complications. For this reason, matrix systems are routinely used during restorative placement to temporarily replace the missing tooth wall, confine restorative material, and guide formation of natural tooth anatomy [6]. Matrix systems must also be sufficiently thin so that, after removal, the restored tooth maintains a clinically acceptable interproximal relationship [13].

Modern matrix systems for posterior composite restorations generally fall into two categories, those being circumferential matrices and sectional matrices. Circumferential systems wrap around the tooth and are typically secured using a retainer, while sectional systems use a pre-contoured band stabilized by wedges and separation rings. Multiple studies have reported that sectional matrix systems produce tighter and more anatomically accurate proximal contacts than circumferential systems in Class II composite restorations [6,7]. As a result, sectional matrices are commonly regarded as the clinical standard for many posterior composite procedures.

Despite these advances, currently available matrix systems are designed primarily for restoration of a single tooth at a time. When two adjacent teeth present with simultaneous proximal lesions, clinicians commonly perform sequential restorations using two separate matrix placements. This duplicates procedural steps such as placement, wedging, adaptation, removal, and finishing. The repeated setup may increase chair time, reduce workflow efficiency, and contribute to patient fatigue during longer appointments. Although current systems perform well for individual restorations, there remains limited commercially adopted technology specifically intended to restore adjacent Class II lesions simultaneously while preserving proper proximal contact.

The project addresses this unmet need through the development of a dual-sided sectional matrix band intended to allow simultaneous restoration of two adjacent posterior proximal lesions. By maintaining compatibility with existing restorative techniques while reducing redundant procedural steps, the proposed device aims to improve clinical efficiency without compromising restoration quality or patient safety.

Figure 4: Dental circumferential matrix system [14].

Figure 5: Dental sectional matrix system [15].

Materials and Methods

Preparation of Mechanical Testing Samples

Preliminary testing was conducted on various stainless steel to match stiffness characteristics of existing sectional matrices. Samples tested were 301 and 302/304 stainless steel from Trinity Brand Industries [16,17]. The 301 stainless steel was rated with a half-hardness heat treatment and had dimensions of 8”x12” (203 mm by 305 mm; width by length) with a thickness of 0.002” (0.0508 mm). The 302/304 stainless steel was rated with a full-hardness heat treatment and had dimensions of 6”x12” (152 mm by 305 mm; width by length) with a thickness of 0.002” (0.0508 mm). Testing coupons were cut from stock using scissors and a dremel. Coupons were cut with a testing length of 50 mm and a width of 2 mm to maximize data collected on a limited load cell capacity (Figure 6).

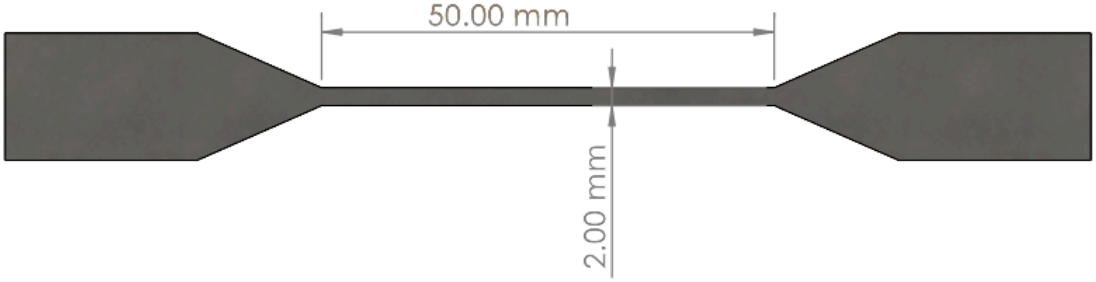

Figure 6: SolidWorks model of testing coupons.

Preparation of Initial Matrices

Initially, 316 stainless steel was purchased from Maudlin Products with 203.2 x 304.8 mm (8”x12”) length and width, 0.0254 mm (0.001”) thickness, and full annealing [18]. Waterjet cutting was initially attempted to cut prototypes from 316 stainless steel using a Protomax waterjet. Prototyping failed because of the thinness and compliance of the stock, which resulted in samples being either completely lost or left with significant edge deformations and tears. After initial efforts failed, prototypes were fabricated out of 301 and 302/304 stainless steel because its increased stiffness allowed for higher resolution with manual fabrication. Templates of the flat two-sided surface matrix were cut on a Universal Laser Systems model ILS9.150-D-150 laser cutter out of 6.35 mm(¼ in) HDF. The metal stock was clamped between two templates and cut to size using scissors and a dremel (Figure 7). The dimensions of the flats cut are shown in Figure 8 and the initial prototype is shown in Figure 9. The matrix includes a hole in one side located at a point which matches the natural interproximal contact between teeth. The hole allows for the matrix to have a single matrix thickness at the location of the proximal contact, allowing for the interproximal contact point to be tighter.

Figure 7: Setup for initial fabrication.

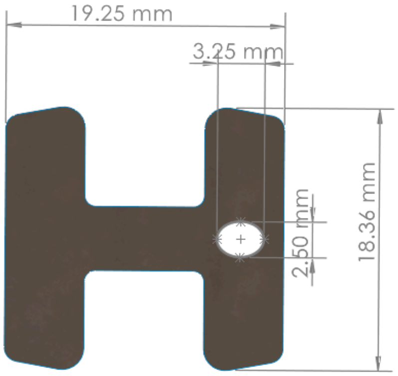

Figure 8: SolidWorks model of flat.

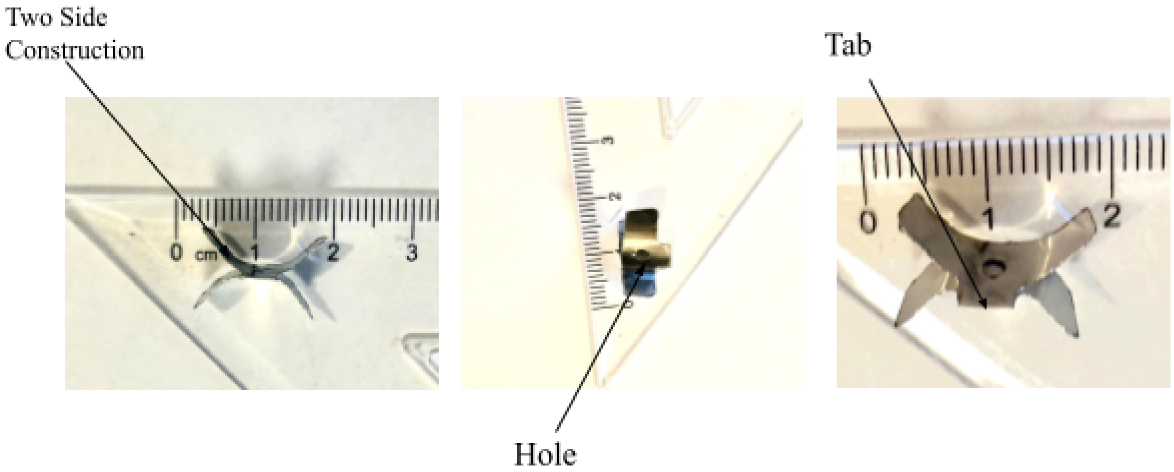

Figure 9: Initial prototype.

Preparation of Final Matrices

Final matrices were fabricated from 316 stainless steel using scissors to cut the shape and a dremel to cut the hole. In contrast to the first attempt, templates were 3D-printed and the outline was traced onto the stainless steel stock (Figure 10). The trace was cut out using scissors, then placed in a second template to cut the hole. The stock was clamped between the templates using vice grips. The final dimensions of the flats are shown in Figure 11. The flats were shaped using the form shown in Figure 12, and the final part is shown in Figure 13.

Figure 10: Template used for scribing pattern.

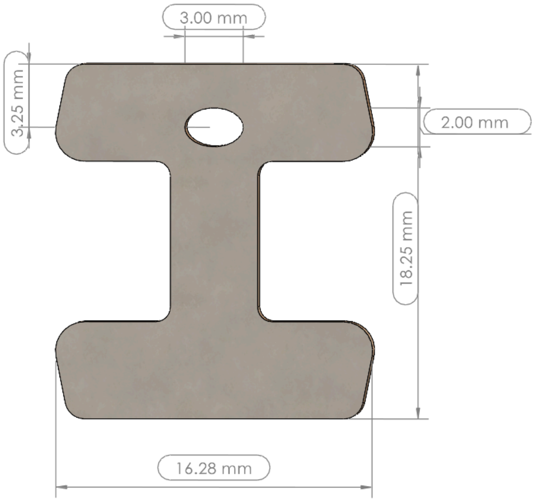

Figure 11: Flat dimensions.

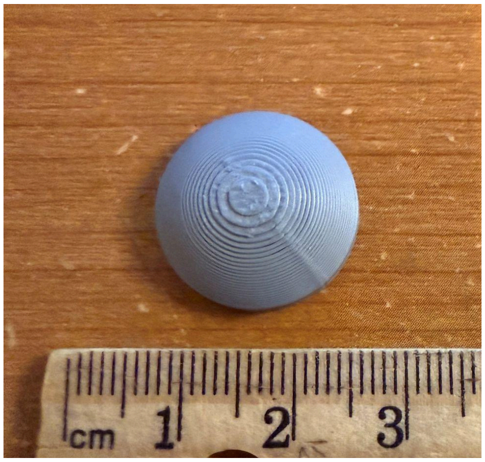

Figure 12: Mold used to form matrices.

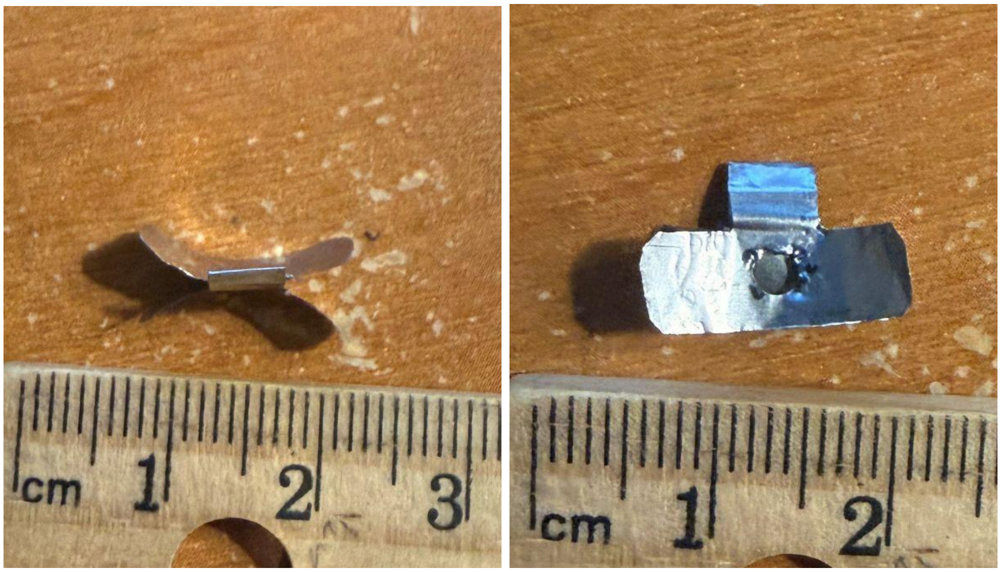

Figure 13: Final Prototype.

Elastic Modulus

The mechanical properties of the purchased materials were compared to the materials of existing matrices by placing testing coupons of the purchased materials into the MTS Criterion-Model C43 machine. Tension tests were performed on three groups of three samples: 304 full hardness 0.002" (0.0508 mm) stainless steel shim stock, 301 ½ hardness 0.002" (0.0508 mm) stainless steel shim stock, and existing matrix material. Tests were run at an extension rate of 0.1 mm/s until force extension curves became non-linear. Then, the elastic moduli of the materials were obtained from the initial linear slope of the resulting stress-strain curve.

Filling time

In order to determine the time it takes to do a filling between the different matrices, Class II restorations were performed by a dentist experienced in the procedure. Currently available (control) sectional matrices were tested on an artificial dentoform mouth model. Two cavities were drilled out in two adjacent molars and the filling procedure was simulated. For control matrices, one cavity was filled at a time following a series of pre-operative steps for each tooth and one matrix was used. This process was repeated one more time for the second tooth. A time study was run with times for all major steps being recorded. The Class II restorations were then done using the proposed matrix design on the same model via a parallel procedure. One matrix was placed between the two drilled teeth and each step was completed on both teeth before moving onto the next step. All filling materials and restoration steps that were standardly used in the procedure were used for testing, except for etching, which was skipped because the model lacked dentin (Appendix B). Overall procedure time and individual task times were recorded. A Student's t-test with independent samples was run on the overall times to determine significant difference between the proposed and current designs.

Removal Force

The force to remove the matrix post-filling was found using a standard digital force gauge. A hemostat was used to grab the matrix and the hook of the force gauge was attached to the hemostat loop. The maximum force reading was recorded. One control matrix and one designed matrix were tested.

Finite Element Analysis

Finite element analysis was performed using SolidWorks static simulation on the model shown in Figure 10. Local interactions were defined between the two mirrored bodies. Bonded interactions between the edges of the top of both tabs and the faces of the tabs was created to simulate real-world construction. A contact interaction was created between the two main faces of the matrix. Fixed geometry was applied to the faces and load was applied to the tab. Due to the lack of literature values for the force produced upon matrix removal, the applied load was set to equal the maximum force reading from the removal force testing. The part material was defined as 316 annealed stainless steel bar from SolidWorks' material database. Finally, failure and weak points were identified and the maximum stress experienced during removal was determined.

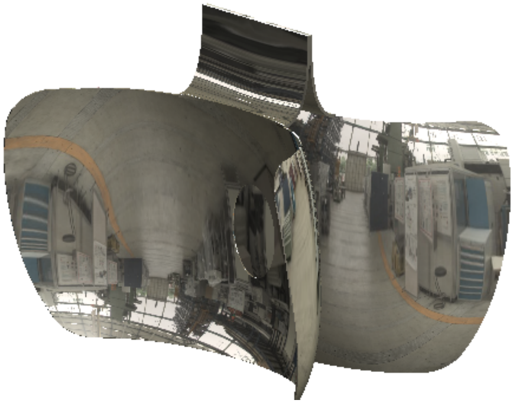

Figure 14: SolidWorks model used in the FEA analysis.

Results

Mechanical Testing

For the tensile strength testing of the final material, stress-strain curves were generated from each run and an equation from the linear region was used to determine the different material properties of the samples, namely the modulus of elasticity. Figure 11 depicts the stress-strain curve for the 304 full-hard sample with the median modulus of elasticity of the three samples; this sample had a modulus of elasticity of $5.486*10^4$ MPa. Additionally, the linear region lasted from a strain of about 0.002 mm/mm to 0.006 mm/mm before the beginning of the plastic deformation region. The average modulus of elasticity for the three 304 full-hard samples was $5.31*10^4$ MPa. Figure 12 represents the stress-strain curve for the 301 half-hard sample with the median modulus of elasticity of the three samples. This sample had a modulus of elasticity of $5.53*10^4$ MPa. Additionally, the linear region lasted from a strain of about 0.002 mm/mm to a strain of about 0.055 mm/mm before the plastic region began. The average modulus of elasticity for the three 301 half-hard samples was $5.504*10^4$ MPa. Overall, this graph is similar to that of the 304 full-hard sample, with a modulus of elasticity that is within the standard error range of the 304 full-hard elastic modulus. Figure 13 is the stress-strain curve for the dental matrix control sample with the median modulus of elasticity of the three samples. This sample had a modulus of elasticity of $1.148*10^4$ MPa. The linear region lasted from a strain of about 0.005 mm/mm to a strain of about 0.01 mm/mm. The average modulus of elasticity for the three control dental matrix samples was equal to $1.477*10^4$ MPa. In the control samples, the toe region of the stress-strain curve is substantially larger than that of the proposed samples, suggesting that, in comparison to the larger testing strips used in 304 full-hard and 301 half-half testing, the sample was not as secure within the MTS machine grips. The average modulus of elasticity for each sample type is shown in Table 1.

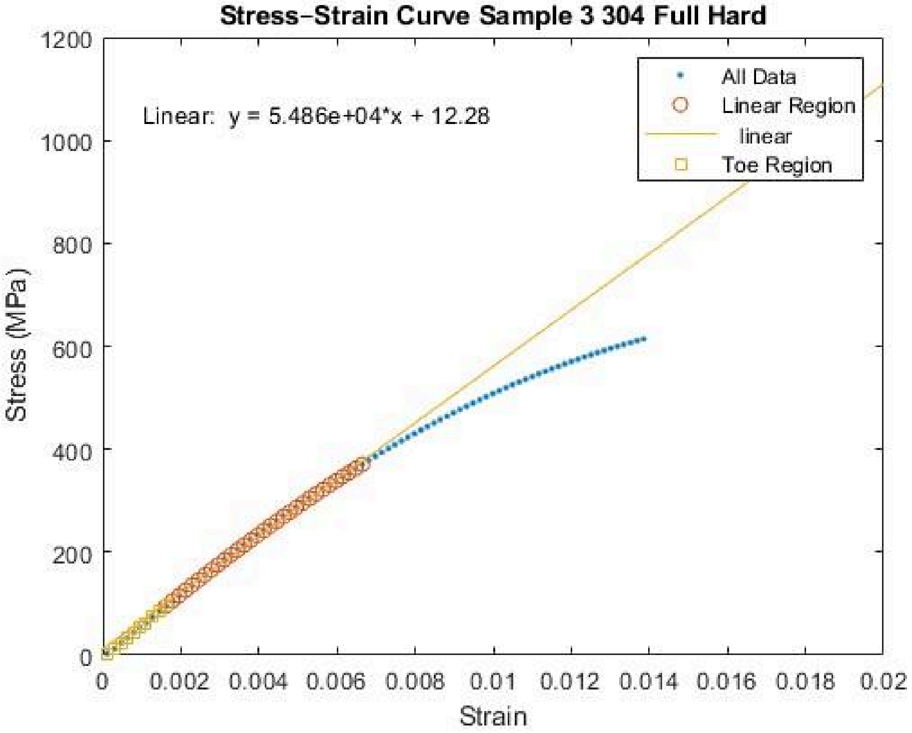

Figure 15: Stress-strain curve for 304 full-hard median modulus of elasticity sample.

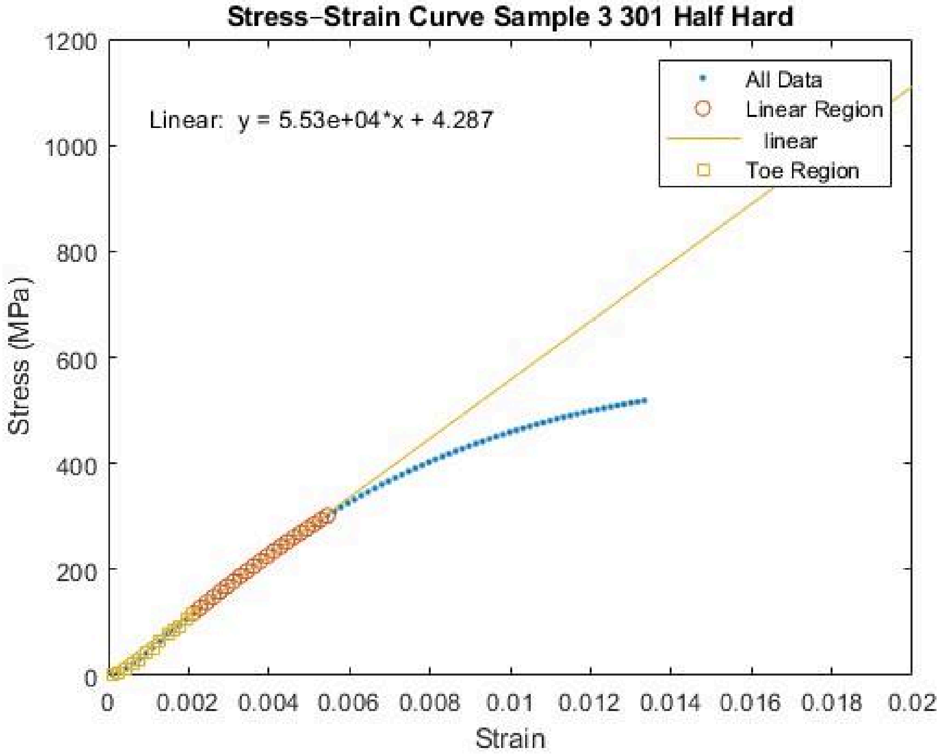

Figure 16: Stress-strain curve for 301 half-hard median modulus of elasticity sample.

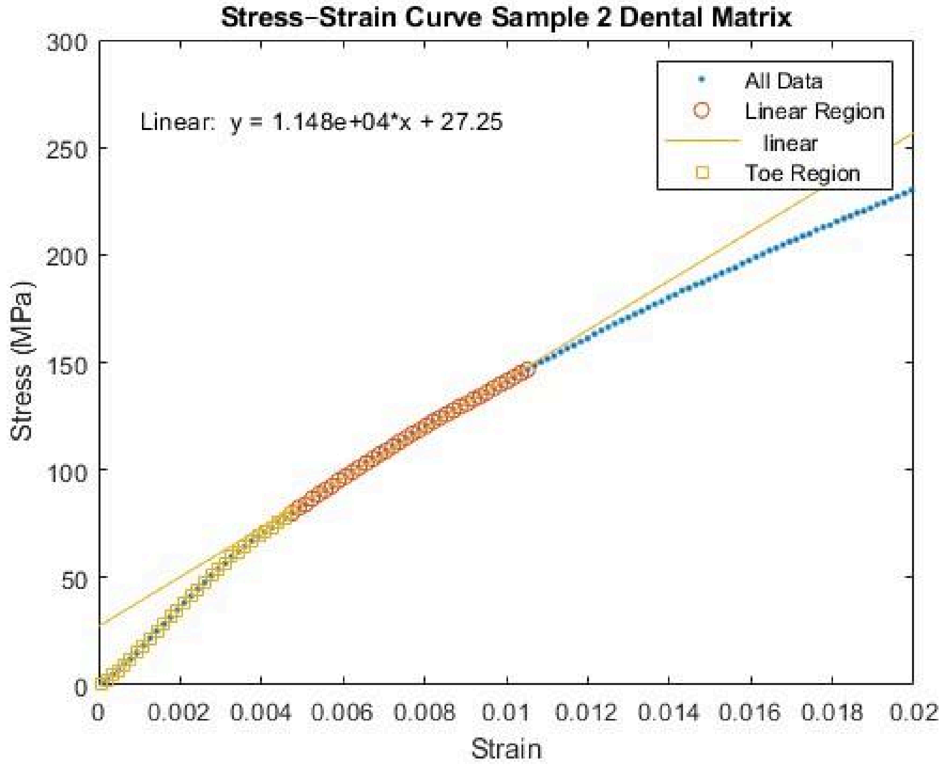

Figure 17: Stress-strain curve for dental matrix control median modulus of elasticity sample.

Table 1: Average modulus of elasticity based on material.

Material	Average Modulus of Elasticity (MPA)
304 Full Hard Stainless Steel	$5.313*10^4$
301 Half Hard Stainless Steel	$5.504*10^4$
Dental Matrix Control	$1.477*10^4$

Based on the final results shown in Table 1 and the stress strain curves shown in Figures 11, 12, and 13, the material properties of 304 full-hard and 301 half-hard are similar. Additionally, the control dental matrix material is not as stiff as the other materials, as shown by its lower modulus of elasticity. It is important to note that the control dental matrix band samples had smaller dimensions, and therefore, were more difficult to secure and align within the MTS machine in a way that applies force at a uniform rate and magnitude across the entire cross-sectional area. An uneven loading rate could result in one side of the cross-section being loaded more than the other, possibly resulting in altered material property results.

Filling Time

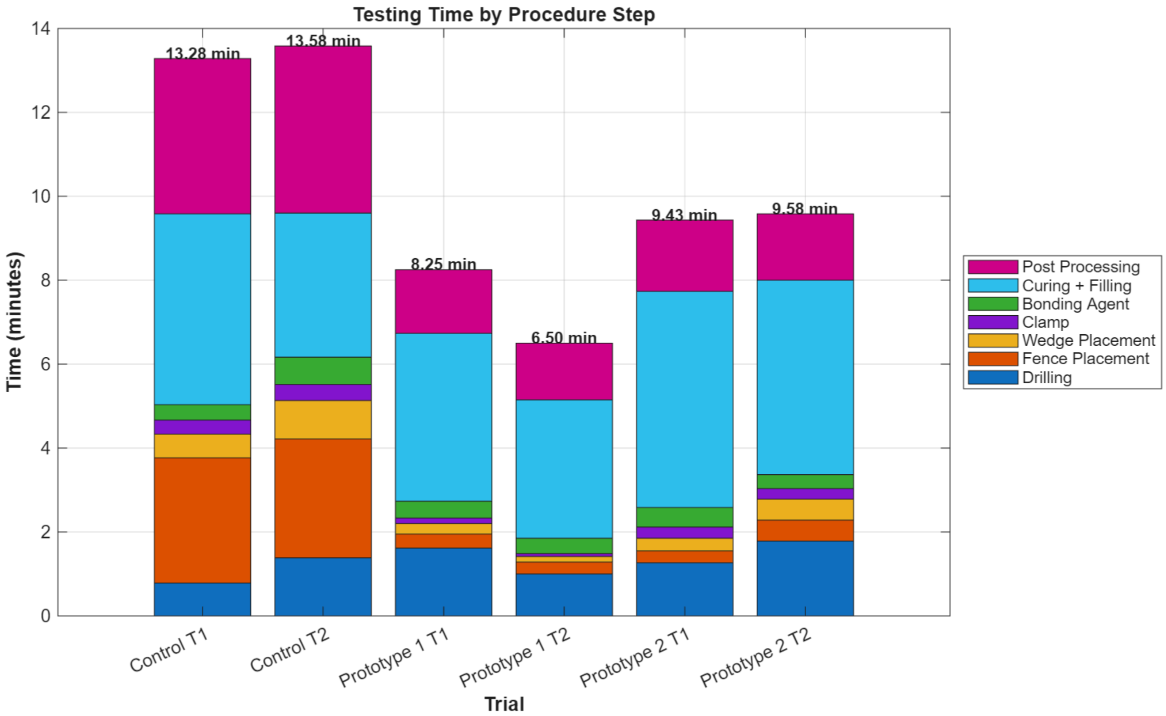

Figure 18: Bar graphs comparing the multiple components of the Class II filling restoration between matrix models.

The results of the clinical testing with the assistance of a professional dentist show that both prototype versions of the proposed design decrease the time it takes to fill a model cavity compared to the control group (sectional matrices). An independent sample t-test, using a significance level of $\alpha = 0.05$, revealed that the total procedure time using the prototype was significantly lower ($p = .00091 < \alpha$) than the control. It should be noted that while testing the first prototype, the dentist gave feedback on flaws with the design that, in his opinion, interfered with the efficacy of the device as a whole and would potentially decrease the usability of the device in-field. The main issue that the dentist pointed out was the placement of the hole in the matrix was lower than that found in naturally contacting teeth. When testing Prototype 2, the dentist expressed less concerns about the dimensions of the matrix, but ran into issues removing the matrix due to both mechanical and material bonds between the composite resin filling material and the matrix itself. Upon attempted removal of the matrix, the prototype experienced tearing in high stress concentration areas, requiring the dentist to tediously pull out the remnants of the steel.

Finite Element Analysis

The force removal testing of the traditional matrix yielded a load of 1 kg. On the other hand, removal of the dual matrix failed and provided no usable data. An FEA was conducted using the obtained load from the removal of the traditional matrix and the SolidWorks model shown in Figure 15. The results of the Von Mises stress output under tension is shown in Figure 19, indicating that the maximum force applied to the matrix is significantly greater than the yield strength of the 316 stainless steel. The Von Mises safety factor was found to be equal to 0.060. The results of the FEA of deflection under tension, shown in Figure 20, indicate that the largest area of deflection is in the middle of the tab. The largest deflection that the tab encounters is 0.50 mm.

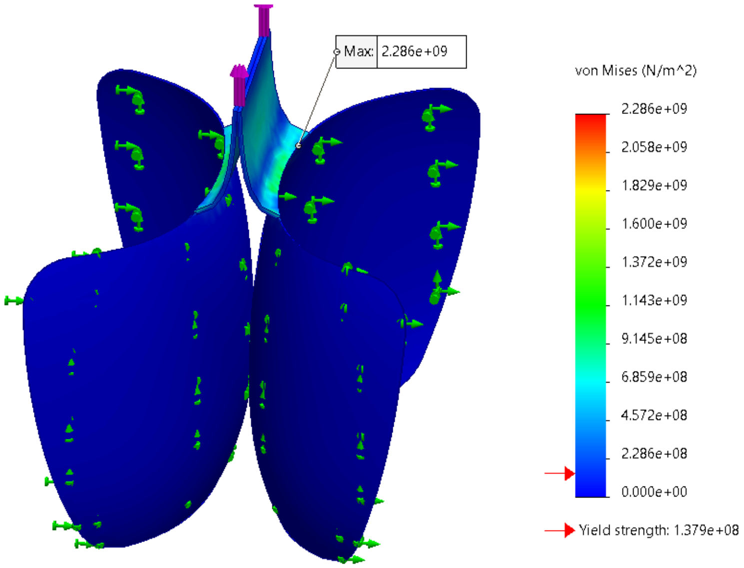

Figure 19: FEA of Von Mises stress output under tension.

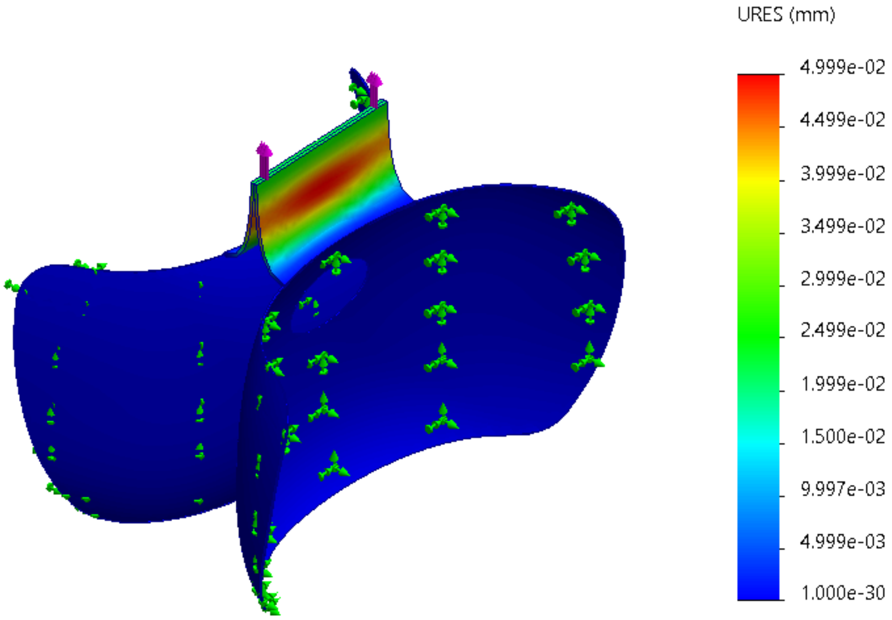

Figure 20: FEA of deflection under tension.

Discussion

The original material testing in the Fall of 2025 found the Young's Modulus of the 301 and 302/304 stainless steel to be significantly different than that of the currently used dental matrix. However, the FEA analysis yielded a safety factor of 6.19 (based on ultimate strength), indicating that the design will not fail in tension when 304 stainless steel is used with the given dimensions and geometry. On the contrary, when using 316 stainless steel and the force obtained via strain gauge for the FEA analysis, dividing the yield strength of the material by its maximum Von Mises stress yielded a safety factor of approximately 0.060. Because the safety factor value is less than 1, this suggests that the matrix will experience yielding failure under the applied tensile load, given the dimensions and geometry of the design. One method of increasing the safety factor in future iterations would be to use a material with a higher yield strength. However, a stiffer material could be more damaging to the surrounding gingival tissue of the patient, which should be taken into account as well. Additionally, stiffer materials are less malleable, which could lead to insufficient conformation of the matrix to the natural shape of the tooth. Insufficient malleability may reduce the quality of the filling (i.e., lead to overhangs) and require additional burnishing of the tooth by the dentist, which would increase the effort and the time required for the procedure [7]. This was addressed by switching to 316 stainless steel stock, which is a less stiff alternative to the prior two options while having similar corrosion resistance and biocompatibility. Further testing could be used to confirm the mechanical properties of the 316 stock purchased from McMaster Carr in comparison to multiple other traditional matrix samples.

Preliminary FEA testing was conducted for the deflection of the device under compression, implementing the same material properties and load magnitudes as the Von Mises analysis (Figure 15). The simulation showed that the greatest deflection was equal to 7.87*10-2 mm, occurring at the outer corners of the device (Figure 16). Since these areas will be secured with a ring clamp regardless, the deformations in these areas do not have an impact on the functionality of the device. This result indicates that the removal of the matrix poses a higher risk of matrix failure than insertion.

Using the updated 316 stock prototypes, time trials were performed by Dr. Donald Tipple. The trials revealed a significant difference in procedure times between the prototypes and the control traditional matrix, with a p-value of 0.00091 well under the standard significance threshold of 0.05. Prototype 2 reduces total procedure time by an average of 3.9 minutes (29%) compared to the control. A majority of this time loss can be attributed to reductions in wedge placement and post-processing steps. This indicates that the design worked as intended, saving time by consolidating two placement and processing steps into one. As mentioned in the results section, this testing also brought to light a major issue with the design: it was difficult to remove from the dental model. This problem could be exacerbated by the higher rigidity of the dental model's gums compared to a real mouth. Natural teeth are able to shift slightly within the gums which allows for a wedge to be used to increase the interproximal gap and aid in the dental procedure. The ability of teeth to shift would also make removing a matrix from actual teeth easier than from a dentoform model. The extent of this issue should therefore be tested on a more anatomically correct model to understand if the increased difficulty of removal is still an issue or if it only presents itself in non-anatomical conditions.

Notable limitations of the time trial study include a small sample size, the testing being conducted by one dentist, and the previously noted use of a dental model over a real patient. With only two trials per prototype, the risk of outliers is elevated, potentially skewing the data away from a true population mean. This was a necessary limitation to the study due to the significant time per trial required from Dr. Tipple, who performed the trials outside of business hours. Dr. Tipple, as the client, was the most convenient dentist to run these time trials. However, this also makes the time recorded representative of only Dr. Tipple's technique. Without having more dentists perform trials with both matrices, it cannot be fully confirmed how much of the difference perceived is attributable only to Dr. Tipple rather than to the general population of dentists. Finally, the dental model lacks the anatomical challenges of a live patient, such as restricted access and tissue compliance. The dental model is easily accessible from all angles, which is not true for teeth inside a patient's mouth. Additionally, the model is stiffer and less compliant than a real mouth. This provides different mechanical forces on the used instruments and matrices, making the conditions less clinically relevant. Due to necessary ethical constraints, the device can not be tested on an actual patient or a cost prohibitive animal model. In the future, a dental model with more accurate tooth mechanics could be used to minimize this fault.

Conclusion

This project aimed to design a dental matrix band capable of allowing dentists to restore two adjacent interproximal cavities simultaneously while maintaining appropriate proximal contact and procedural efficiency. Three preliminary concepts were evaluated, and the “Hole” design was selected based on its projected efficacy, ease of use, fabrication feasibility, and cost. Initial fabrication and modeling indicate that the design is mechanically viable and capable of fitting within typical dimensional constraints of current matrix systems. However, the waterjet fabrication method proved unreliable and resulted in a worse surface and edge finish. Laser metal cutting was also explored, but thermal warping resulted in similar inconsistencies. Manual fabrication proved to be the most reliable method despite its higher time spent per unit.

The validation confirms that the final design works for interproximal fillings and significantly reduces procedure times over traditional dental matrices. Further improvements could be made through the use of more representative dental models for testing, a larger sample size of fillings to compare, and input from a wider population of dentists. On the manufacturing side, metal stamping would be the next idea to pursue to reduce the warping of edges. Laser metal cutting remains promising, but fixing the technical problems would require a large time investment and potentially different equipment or materials. Nonstick coatings, as some market matrices use, could prove to be another avenue for improving the performance of the matrix by reducing the coefficient of friction of the material. Finally, changing the shape of the tabs from sharp corners to rounded edges could reduce stress concentrations during removal and potentially prevent breakage. Overall, the current matrix design addresses the problem of interproximal cavity procedures by reducing the procedure time. Future work would involve more realistic testing, using larger sample sizes during testing, cheaper and more reliable manufacturing, and further additions to the device to improve filling quality and ease of use.

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Appendix

Appendix A

Approximating Surface Matrix Band for Dentist to Use for Patients

Product Design Specifications | September 18th, 2025
BME 400 Lab 305

Client: Dr. Donald Tipple

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Function:

Surface matrix bands are devices used by dentists to separate adjacent teeth during restorations of interproximal cavities (cavities found in-between two teeth). The matrix band serves to support the restoration material, to provide shape and contour to the tooth being restored, and to protect the adjacent tooth. Ideally, the width of the space between the two adjacent teeth is just large enough to fit one matrix band in order to ensure close proximal contact area, which prevents food impaction and decay. In the case of two cavities on two adjacent teeth, this process is tedious, as the dentist must complete the process from start to finish for each adjacent tooth individually. The goal of this project is to create a dental matrix band that effectively separates adjacent teeth for more efficient tooth restoration procedures on interproximal cavities by making it possible to complete two adjacent restorations simultaneously.

Client requirements

1. The new design of the surface matrix band should not be thicker than existing matrix bands on the market.
2. The new device should make it possible to perform two Class 2 restorations simultaneously instead of sequentially.
3. The device should come into contact with both surfaces of the two adjacent teeth.
4. The device should avoid harming the gums in-between the two affected teeth.

Design requirements

1. **Physical and Operational Characteristics**
    a. **Performance requirements:**

    Surface matrices are used in dental restoration to recreate the natural tooth shape and protect the surrounding tissue. This product must fulfill all the existing requirements of surface matrices in addition to creating a more efficient reconstruction procedure. Surface matrix systems are most commonly used for treatment of smooth surface class II posterior caries [1]. Because proximal contact must be maintained in the restoration, the surface matrix must be very thin. Common surface matrix thicknesses in industry range from 0.038 mm to 0.05 mm [2]. If the matrix band's thickness is too great the interproximal contact between teeth will be lost post procedure causing food packing, which can lead to gingivitis and periodontitis, and loss of arch stability. A large part of maintaining this critical proximal contact is reconstructing the natural shape of the tooth. To ensure this dentists often use wedges and tension rings to help form the matrix to the tooth. To allow full functionality and easier adoption by dentists, this product must be compatible with these existing products. To help match the shape of the biting surface of the tooth, surface matrices have an occlusal curve which allows for better reconstruction. Additionally, sectional matrices often have a curve or extended section that sets into the sulcus between the tooth and gum. This protects the gums and allows for better filling. The product should include these features to be an effective solution. The surface matrix must be malleable enough to easily wrap around the tooth. Most current matrices are near dead soft meaning they are nearly fully annealed, however, over annealing and creating a grain structure too large can cause the matrix to be too ductile and crimp upon insertion into the interproximal space or during wedge insertion. Therefore, the mechanical properties of the matrix must balance ductility, malleability, and durability. This balance must be determined through testing to find a correctly annealed alloy. Surface matrices are usually considered single use products so repeated loading is not a major concern. This is because the matrix is often warped as it is conformed to the patient's tooth and would compromise future filling success. Filling overhangs are another point of concern for dentists. To address this problem, the product must be malleable enough to properly conform to the tooth and work seamlessly with tension rings and wedges. The material, again, must be properly annealed, near dead soft but not too soft, to achieve this task. Some sectional matrix systems have a tab or extended piece at the top of the tool for easier handling. This is not a required feature, but easy handling for dentists in a constrained environment must be considered in design.

b. **Safety:**

The device should avoid any materials that patients are commonly sensitive to, for example, nickel. Additionally, the final product should have rounded, not sharp, edges to minimize irritation and damage to the patient's gums. If sold, the product must be within sterilized packaging with warnings to discourage tampering.

c. **Accuracy and Reliability:**

Accuracy is an important consideration for dental matrices because they must be able to form to the tooth, interact with other components, and maintain the interproximal gap between teeth. The accuracy of thickness, the most important dimension for matrix systems, will depend on the supplier because post processing of metal alloys can be expensive and challenging, so modifying the thickness of the material after purchasing will be difficult. McMaster-Carr sets their thickness tolerance for 0.0508 mm thick (0.002") austenitic grade stainless steel at ±0.00508 mm, which is a reasonable standard for the thickness of the product [2]. The height of sectional matrices vary depending on tooth type from 3.5 mm to 7.5 mm. This variety in size gives more leniency in tolerance, especially because the height dimension of the matrix has fewer interactions with other components. Additionally, with the variety of tooth sizes from both genetic and gender differences, height dimensions are not as critical as the thickness. Because the variance in length from the occlusal surface to the gingival surface has variance from patient to patient a larger tolerance of ±0.2 mm is permissible. This should be achievable for larger scale stamping or laser cutting procedures while not compromising the effectiveness of the product [3]. Dimensions like length of the band are also not as critical as the thickness of the band because of the variation between teeth and patients. However, because the width of the matrix has interactions with other components like tension rings and must be able to accommodate a variety of filling sizes its accuracy is still important. Considering this the tolerance should be kept to ±0.1 mm. In terms of GD&T specifications that must be considered are symmetry, surface profile, and line profile when the product is in its final configuration before use and surface roughness before product is formed to its final shape. Symmetry is important because of its interaction with other components like the tension ring as well as forming to the tooth and recreating a natural looking filling. Surface and line profile tolerances are important for the curvature of the matrix and recreating the natural form of the tooth. Surface roughness should be measured before the matrix is curved to ensure that the product is smooth and will not create any defects in the filling or adhere to the filling. These tolerances are harder to measure and specify, additionally, line and surface profile tolerances may not be as critical because the dentist can use rings and wedges to modify the shape of the matrix to match the tooth. Specifying these dimensions is difficult and outside of the scope of this project, however, they should not be entirely neglected and should be kept in consideration during design and manufacturing. Repeatability will vary depending on the manufacturing process. The most likely processes will be metal stamping, laser cutting, or water jet cutting. Each of these should be able to produce parts with high fidelity. During initial prototyping, a standard of 9/10 units should be within specification. If the product scales 1/100,000 should be defective.

d. **Life in Service:**

The device is designed to be single-use. It must maintain its structure for the duration of the procedure and be able to withstand removal from the patient in one piece.

e. **Shelf Life:**

The product should be kept in a dry and sterile environment. The humidity of the storage area should be low to prevent corrosion of the metal. It should be away from potential contaminants and oxidizing agents that could potentially damage the mechanical integrity of the matrix or mar the finish of the unit. If more than one size is produced this should be clearly organized and distinguished to avoid confusion. The product should be kept near room temperature to avoid compromising material properties and shape of the product. The matrix should be stored with care to avoid bending and deforming the preformed shape.

f. **Operating Environmen**t:

The product will be used within the human mouth, which will expose the device to multiple physical, chemical, and biological factors.

I. The human mouth exposes the device to high levels of moisture. While stimulated, like during a dental procedure, the human mouth can produce 4-5mL/min of saliva [4]. This can cause corrosion or rusting in certain untreated metals. Another factor that increases the risk of corrosion is the slight acidity of saliva with a pH of 6.7 [5]. Though slight, this decreased pH can cause increased corrosion in metals like steel.

II. Heat is another important factor when operating within the mouth. The standard temperature of the mouth is 37℃ (98.6℉); the device must be able to maintain its mechanical properties within a range of 20℃ (room temperature) to 37℃ at a minimum to reach design requirements.

III. The device must be able to withstand being pushed between teeth while not damaging them. The enamel of the tooth has a Vickers hardness of 274.8 [6]. Any material under consideration must have a hardness score below that to minimize damage.

g. **Ergonomics:**

The device must be at least as easy to install and use as current solutions, such as sectional and circumferential matrix bands. The device must also be faster to use than the two prior solutions it aims to replace. After use, the device must come out of the teeth easily and without excessive damage to the patient's gums.

h. **Size:**

As specified by the client, the thickness of the improved dual sectional matrix design should be the same as that of sectional matrices currently on the market. This is to ensure that there is sufficient proximal contact between the two restored teeth to prevent food impaction and further decay [7]. The typical thickness of sectional matrix bands currently on the market is 0.0381 mm, and in previous semesters, a thickness of 0.0254 - 0.0508 mm was used for the matrix band design [8]. Typically, current sectional matrices on the market have lengths between 12.57 - 14.33 mm, heights between 3.2 - 6.4 mm, and widths varying between 1.24 - 1.64 mm [8]. The overall size of the sectional matrix band will vary depending on the tooth (a wide range should be made), but the thickness of the device should remain between 0.0254 and 0.0508 mm.

i. **Weight:**

Depending on the material used for the sectional matrix band design (usually stainless steel or polytetraflouroethylene (PTFE)) and its size, the typical weight of a sectional matrix band is between 0.01 and 0.02 grams (although not clinically relevant).

j. **Materials:**

The materials that make up the device must be biocompatible while temporarily pushed between the teeth of the patient; it is not required to meet the stringent standards of permanent implants. The device must be made of materials that can withstand the forces and environment of the tooth (described in section f) while still being malleable by the dentist, so that it can be moved to fit any specific patient's tooth. Materials like stainless steel are commonly used to accomplish these requirements. The material must be able to withstand autoclaving at 121°C (250°F) for 30 minutes in accordance with CDC guidance [9].

k. **Aesthetics, Appearance, and Finish:**

The final design should feature a slightly curved appearance to easily fit the anatomy of the tooth which it lines, subsequently reducing the time spent shaping the restoration. The product should be made of either polished stainless steel or PTFE, which can further be coated with a teflon finish to provide a non-stick surface. The design should also feature a tab, which makes for easy manipulation by the dentist during insertion and removal.

2. **Production Characteristics**

a. **Quantity:**

The client has requested a single prototype to test the functionality of the device.

b. **Target Product Cost:**

To be competitive, the device would need to be in parity with similar dental matrices costing ~$0.50 - $1.00 [10]. However, because of the relative complexity of the device and the time savings that it should provide, the cost of the device must remain under $5 per unit to manufacture. The total budget for development and testing of the device must stay under $200 as provided by the client.

3. **Miscellaneous**
   a. **Standards and Specifications:**

Dental matrix bands are regulated by the FDA. The FDA classifies sectional matrices under “Dental Hand Instruments” which are class I devices that are 510(K) exempt. However, the FDA does not exempt the device from GMP, so this must be considered in the design for manufacturing. In addition to FDA regulations, ISO sets standards for sectional matrices under ISO standard 18556-2016. The standard classifies “intraoral spatulas” into two categories based on design and material properties. As designated by the standard, type 1 intraoral spatulas are oval shaped and are more rigid, while type 2 are more rectangular, flat, and flexible [11]. ISO also regulates the materials used in surface matrix bands under ISO standard 10993-1 *Biological Evaluation of Medical Devices,* which regulates biocompatibility of medical devices. The standard regulates testing for cytotoxicity, interactions with blood, irritation, and skin sensitivity, as well as identification and quantification of degradation products from medical devices [12]. Of these testing standards, irritation and skin sensitivity are the most relevant because of the minimal contact of the device. If further processing is required of the materials to increase ductility and malleability, the testing would likely fall under ASTM standard A666/A666M-24, which sets specifications for annealed or cold worked austenitic stainless steel sheet, strip, and flat bar [13]. This could be relevant because the thinness of the stock may limit the processing of the steel, especially for prototyping. It may be difficult to find medical grade (316L or 304) stainless steel at the required thickness with the correct annealing to allow for the ductility and malleability required for sectional matrices. Considering this, the ASTM standard for annealing austenitic stainless steel could be valuable in testing modified purchased materials.

   b. **Customer:**

The intended customer of this product is any dental office or dentist who performs Class 2 dental restorations on their patients. This device can also be used by dental schools to train students on interproximal restorations.

   c. **Patient-related concerns:**

Comfort is a large concern, which is related to the size of the matrix. On a patient-to-patient basis, patients with larger teeth may require a different sized matrix than patients with smaller teeth. This means that if there were to be a universal design, it must account for the different sizes of teeth, or it could be both uncomfortable and incapable of filling the teeth properly.

d. **Competition:**.

One of the leading competitors in the market is the Halo Sectional Matrix Kit, which contains bands that are held in place by nitinol rings and glass-filled nylon tines [14]. A downside to this product is that the kit used to install this sectional matrix on the teeth is about $700, which is far higher than the client's budget. A current device on the market that is used to fill cavities is the Triodent V3 Ring [15]. This device is capable of filling cavities, but when used, it isn't capable of filling adjacent cavities without leaving too large of a gap.

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Appendix B

Testing Procedure

Outlined below are the steps of the filling procedure along with figures depicting each step during our testing.

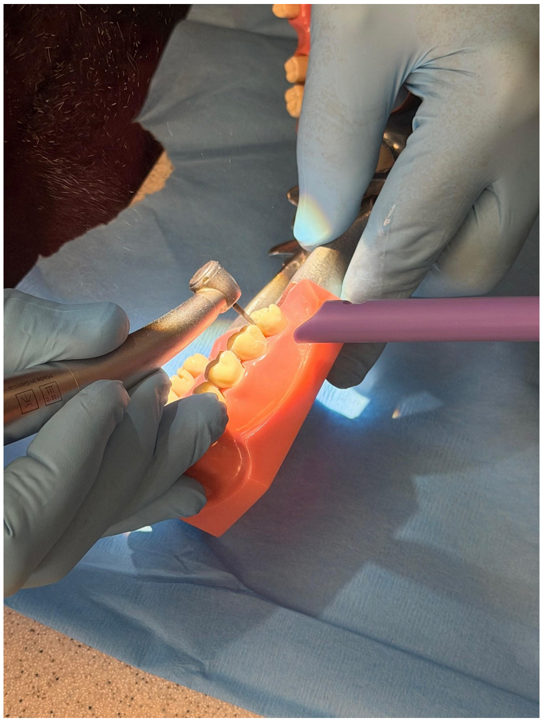


Figure 21: Removal of Decay

Decayed tooth structure is removed to prepare a clean cavity for restoration.

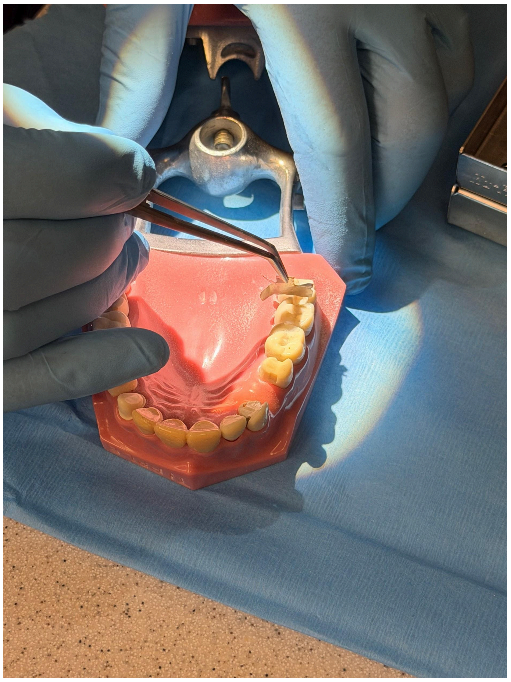


Figure 22: Matrix Placement

The matrix band is positioned to recreate the missing tooth wall and contain filling material.

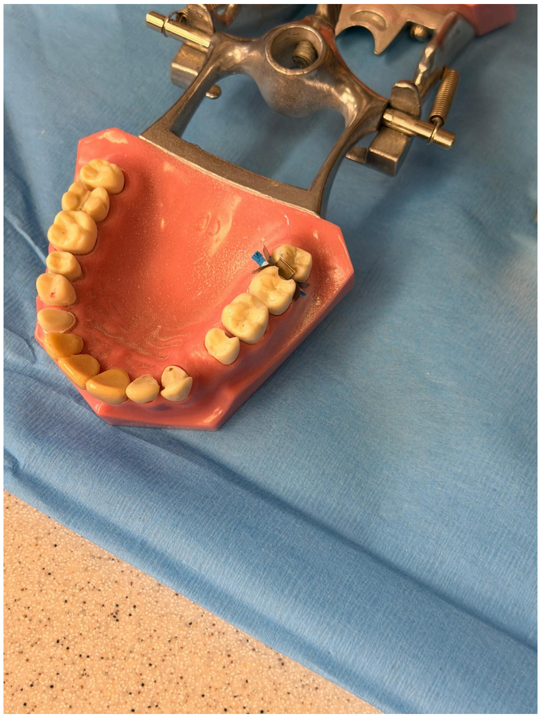


Figure 23: Wedge placement

A wedge is inserted interproximally to secure the matrix and improve tooth separation.

Figure 24: Clamp placement

The clamp stabilizes the matrix system and maintains proper positioning during restoration.

Figure 25: Etching, priming, and adding bonding agent.

The tooth surface is conditioned and a bonding agent applied to improve composite adhesion.

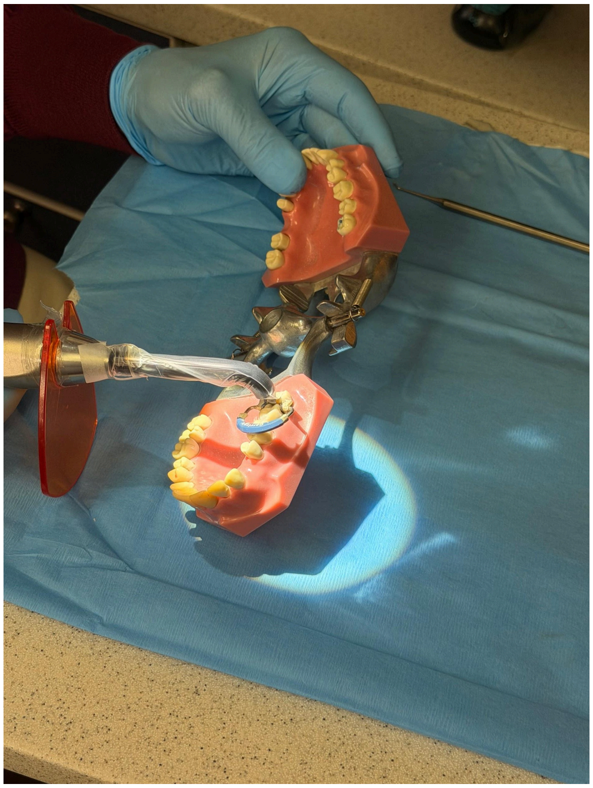


Figure 26: Blue light curing

Blue light is used to harden the bonding agent.

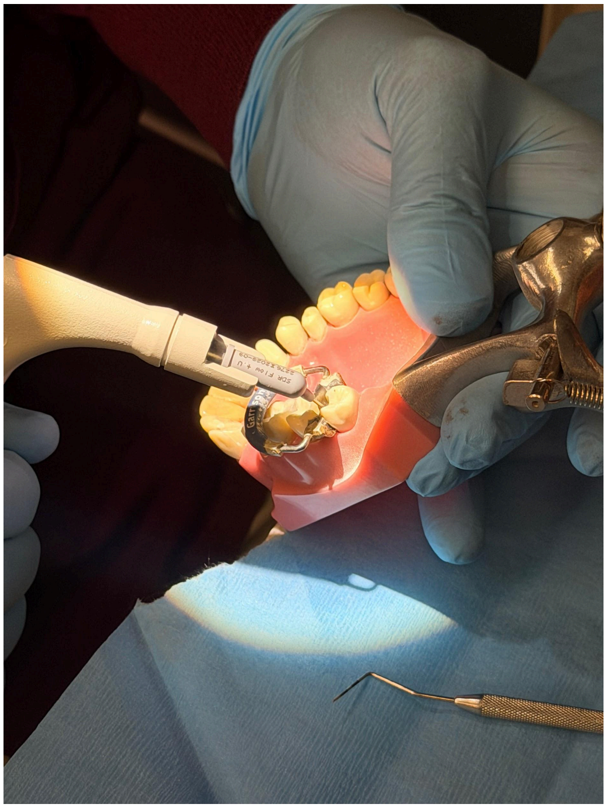


Figure 27: Composite Placement

Composite resin is placed into the cavity and shaped to restore tooth anatomy.

Figure 28: Blue Light Curing

Blue light is used to harden the composite resin material.

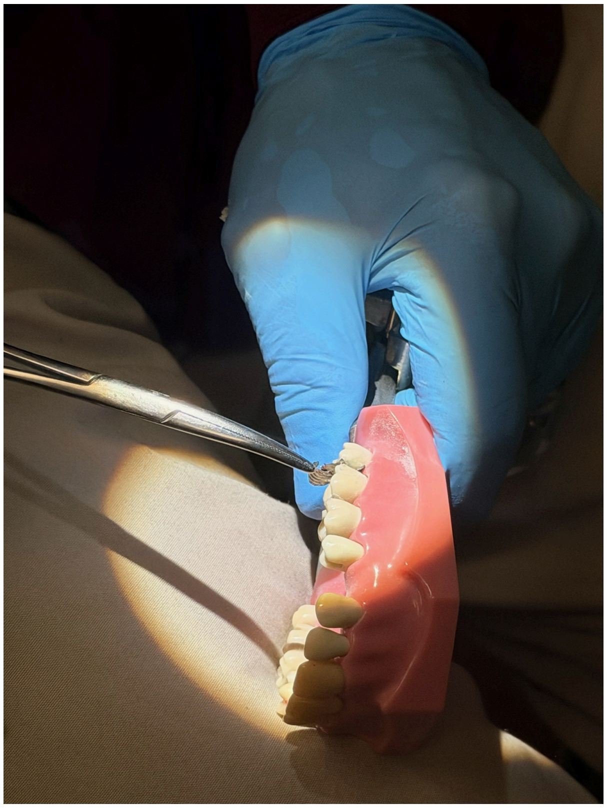


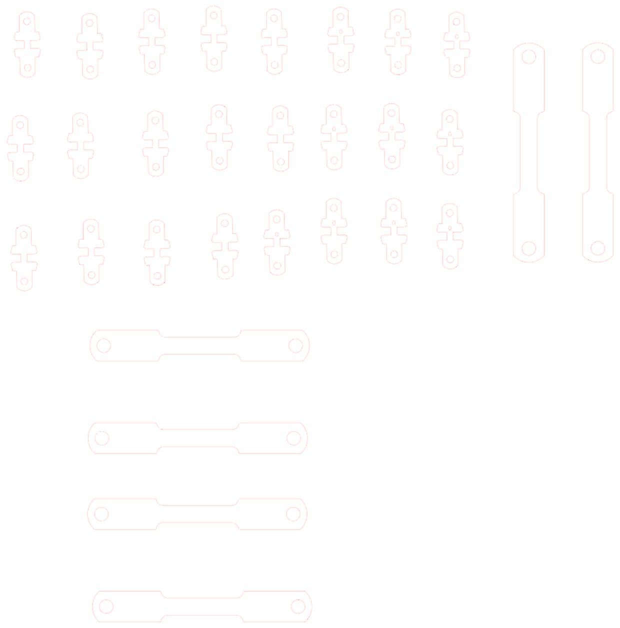
Figure 29: Matrix Removal

The matrix system is carefully removed after curing to reveal the final restoration.

Figure 30: Post processing

Excess material is removed, contours refined, and the restoration polished for final fit and function.

Appendix C: Files for Laser Cutter

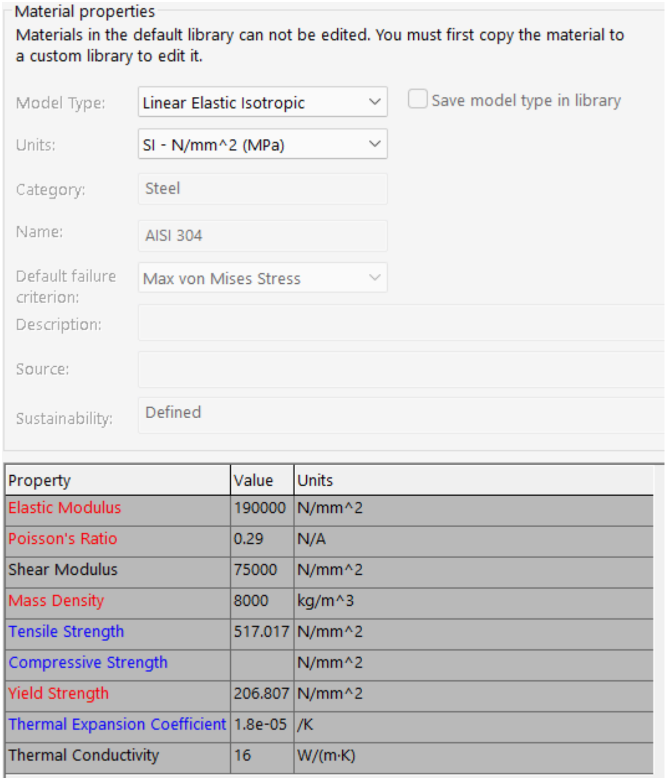


Note: The template is difficult to see because the line weight is so small, zooming in helps

Appendix D: Full Final Fabrication Procedure

1. Convert 3D SolidWorks model into 2D flattened surface
    a. Rolled back model to one sided 3D model
    b. Flattened surface using surface flatten tool
    c. Mirrored to create two surfaces
    d. Connected two surfaces with boundary surface
2. Prepare files for laser cutting templates
    a. Added tabs with holes for locating
    b. Created SolidWorks drawing file and layout all pieces to be cut
        i. A
    c. Exported as .pdf to Adobe illustrator
    d. Converted line color to RGD #FF0000 and line weight to 0.0001 mm
    e. Exported as .ai file
3. Print .ai file to Universal Laser System ILS9.150D-150 machine
    a. Placed ⅛ in HDF on cutting bed
    b. Calibrated laser
    c. Cut material
4. Prototype flat fabrication
    a. Covered both sides of metal shim stock with blue painters tape
    b. Glued one template onto tape
    c. Rough cut with scissors
    d. Drilled out alignment holes and part hole
    e. Used bolts and nuts attach second template to opposite side of shim stock and tighten
    f. Cut away extra tape using razor blade to improve visibility during grinding
    g. Used dremel ½” drum sander bit to remove as much material as possible
    h. Finished with 5/64” tip diamond wheel grinder to remove material up to template
    i. Took off one template
    j. Used dremel cut off wheel to rough cut off tab
    k. Finished bottom surface off part with ½” drum sander and diamond wheel grinder
    l. Repeated for all parts
5. 3D model fabrication
    a. Printed mold
    b. Placed flat matrix between mold halves and compressed
    c. Measured matrix to find halfway point which was marked
    d. Used a razor blade to maintain square folding and folded matrix to create final geometry

Appendix E: AISI 304 stainless steel from SolidWorks material library



Material properties

Materials in the default library can not be edited. You must first copy the material to a custom library to edit it.

Model Type: Linear Elastic Isotropic

☐ Save model type in library

Units: SI - N/mm^2 (MPa)

Category: Steel

Name: AISI 304

Default failure criterion: Max von Mises Stress

Description:

Source:

Sustainability: Defined

Property	Value	Units
Elastic Modulus	190000	N/mm^2
Poisson's Ratio	0.29	N/A
Shear Modulus	75000	N/mm^2
Mass Density	8000	kg/m^3
Tensile Strength	517.017	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	206.807	N/mm^2
Thermal Expansion Coefficient	1.8e-05	/K
Thermal Conductivity	16	W/(m·K)

Appendix E: Expense Table

Item	**Description**	**Manufacturer**	**Vendor**	**Vendor Cat#**	**Date**	**QTY**	**Cost Each**	**Total**
Fabrication Materials								
316 Stainless Steel	316 Stainless Steel Shim Stock	Trinity	Mcmaster Carr	2317K51	9/29/2025	1	$22.55	$22.55
301 Half Hard Steel	301 Half Hard Steel Shim Stock	Trinity	Mcmaster Carr	2316K327	11/19/2025	2	$8.94	$17.88
304 Full Hard Steel	304 Full Hard Steel Shim Stock	Trinity	Mcmaster Carr	9784K623	11/19/2025	2	$10.04	$20.08
260 Brass	260 Brass Shim Stock	Trinity	Mcmaster Carr	9011K821	3/09/2026	1	$19.53	$19.53
Total Spent								**$80.04**