Project TrisPrint

Final Design Report

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DISCLAIMER

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EXECUTIVE SUMMARY

This report will describe the design, usage, components, properties, and final benchmarking of the TrisPrint 3D Printable Trismus Treatment device designed by Team Trismus from Northern Arizona University's Mechanical Engineering Department. The Trismus Capstone team aimed to design a 3D printable and open-source device intended to help relieve trismus symptoms via the active and passive stretching of the jaw, where other solutions have been either inaccessible or too expensive. TrisPrint features a leverage-based design, where a compliant spring provides active resistance to the jaw's natural closing motion and a graded surface to indicate jaw displacement. Comprised entirely of 3D printed Polycyclohexylenedimethylene Terephthalate glycol-modified (PCTG), this material allows for a flexible device that can easily be replicated by clinicians across the United States. This device aims to be safe, easily reproducible, and affordable for patients, with a total unit cost of $8.50 worth of filament per device.

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1 BACKGROUND

This project aims to develop a cost-effective, 3D-printable device to aid physical therapists in treating patients with Trismus, a condition caused by neck and throat cancer that limits jaw mobility.

Key Features:

- **Affordable and Accessible:** The device is designed for easy 3D printing in doctor's offices, with a production cost under $50. Open-source design files will further increase accessibility.
- **Multi-functional:** The device measures both mouth opening distance and bite force, providing valuable data for monitoring progress and tailoring physical therapy.
- **Safe for Use:** Patient safety is prioritized through careful material selection and design to minimize risks of injury.

Project Success:

The device will be considered as successful based on its ability to:

- Withstand expected bite force without breaking.
- Clearly indicate the amount of bite force applied.
- Comfortably fit within a limited mouth opening range.

1.1 Project Description

This project aims to develop a cost-effective 3D printable device to aid with physical therapy for neck and throat cancer patients diagnosed with Trismus. Trismus, or lockjaw, reduces a person's maximum mouth opening (MMO) which can impact a patient's quality of life by limiting the type of food they can consume and affecting their speech. The primary focus of this project was to create an accessible device readily available for 3D printing and assembly in any doctor's office, with a 'low' production cost but following further discussions with the clients, the project scope was expanded to encompass additional functionalities:

- **Measurement of Mouth Opening:** The device now incorporates a mechanism to quantify the patient's jaw opening distance during physical therapy sessions. This data can be crucial in monitoring progress and tailoring treatment plans. A built-in ruler has been implemented into the TrisPrint's design, allowing for the MMO to be measured in millimeters. Due to the nature of filament during the printing process, the team can guarantee the measurements to be accurate within +/- 0.35 mm.
- **Bite Force Measurement:** The ability to measure bite force remains a core function. Quantifying bite force can potentially provide valuable insights for physical therapists, allowing for more targeted interventions and improved treatment outcomes. This would also prevent excessive force from being applied to the teeth and jaw. The included compliant springs are designed to output 5 +/- 0.15 N of resistive force to the jaw during active stretching exercises, such as chewing motions.

The total cost of the device is $8.50 per assembly, which falls within the acceptable range of price (less than $50) for the device set by the clients. Based on printing tests and benchmarking, PCTG is the material of choice for this device to limit the potential for injury or material leeching onto the patient during normal operation.

1.2 Deliverables

This project aims to produce a multi-functional device that addresses the needs of physical therapists in evaluating and treating jaw-related conditions while meeting all course requirements and deliverables for the Capstone Class (ME 486C).

1.2.1 ME 486C Key Deliverables

Deliverables for ME 486C are based on successfully identifying and meeting client needs while practicing professionalism through submission of required documents and assignments such as presentations 1 – 3, final report, production of poster, and the final presentation at the NAU EFest. Additional course deliverables include maintaining a Gantt chart for project progress, submitting weekly timesheets, conducting client meetings on a weekly basis, produce the required amount of device copies for the client, and proof of testing the device. These deliverables allow our team to practice utilizing all material learned from previous classes and continue to apply them to this project to ensure that we hold the necessary skills and knowledge to design and implement a quality product our client would approve of.

1.2.2 Client Key Deliverables

Core Functionality:

- **Successful and Manufacturable Device:** A fully functional device that can be readily manufactured using FDM 3D printing technology. The design should prioritize printability and use materials compatible with most hobbyist level FDM 3D printers.
- **Safe for Use:** The device must be designed with the patient's safety in mind. Materials and construction should minimize any risks of injury to the mouth, teeth, or jaws during use.

Measurement Capabilities:

- **Measure Mouth Opening:** The device should incorporate a mechanism to accurately measure the distance a patient can open their mouth. This data is valuable for monitoring progress in physical therapy for jaw mobility.
- **Visually Quantify Bite Force:** The device should provide a clear and easy-to-interpret visual indication of the bite force applied by the patient. This functionality allows therapists to assess jaw strength and tailor treatment plans accordingly.

Cost and Accessibility:

- **Cost-Effective Production:** The design should be optimized for 3D printing with materials that keep the production cost under $50 per device. This affordability makes the device accessible for a wider range of healthcare providers.
- **Open-Source Design:** The design will be available to any doctor or healthcare provider as an open-source design. A patent for the device will be considered to prevent 'unsafe' alternations or modifications that could harm the patient, and a patent would prevent 'selling' of the device.

1.3 Success Metrics

This section outlines the success criteria for the device's ability to withstand bite force, visually quantify the force applied, and fit within the specified mouth opening range.

Bite Withstanding Capability:

- **Success Definition:** The design must successfully resist the maximum bite force expected of a patient (~60 N) while preventing excessive force from being applied to the patient's jaw and teeth.
- **Assessment Method:**
  - Testing: A simple force application experiment was performed on the mouthpieces of the device. A downward force equal to 60 N was applied on the bridge, with the expected result being slow deformation in the direction of the force.
  - Calculations: The maximum expected bite force was determined through research on the maximum bite force of a person. The design will be subjected to a force exceeding this value by a pre-determined safety factor.
  - Design Requirements: The design materials and structure must be able to handle the calculated force without permanent deformation or failure.

1. **Visual Bite Force Quantification:**

- **Success Definition:** The design should incorporate a visual indicator that allows for the clear and measurable assessment of the applied bite force.
- **Assessment Method:**
  - Testing: The compliant spring design was tested to ensure the force applied by the spring on the jaw is equal to 5 +/- 0.5 N.
  - Calculations: A correlation will be established between the visual indicator's response and the applied bite force through calibration with a force or pressure testing machine.
  - Design Requirements: The visual indicator should provide a clear and quantifiable response that is easily interpretable by the user. The compliant spring completes one full compression (both ends of the spring making physical contact), with the compression being equal to the previously mentioned 5 N.

2. **Mouth Opening Accommodation:**

- **Success Definition:** The design must comfortably fit within the patient's mouth opening range of approximately 5-6 mm.

- **Assessment Method:**
  - Testing: The final design was tested by placing them within a model replicating human jaw and mouth opening. Rubber bands were attached to the sides of the jaw to replicate the muscles on a patient's jaw.
  - Design Requirements: The design dimensions must ensure it can be placed within the specified mouth opening range without causing discomfort or hindering the patient's movement.

Overall Project Success:

The project will be considered successful if all three criteria are met. The design should effectively resist the target bite force, provide a clear visual indication of the force applied, and comfortably fit within the designated mouth opening range.

2 REQUIREMENTS

2.1 Customer Requirements (CRs)

CR1: Fully 3D Printable and Open Source:

The client has requested that the device is able to be fully 3D printed with detailed instructions and clear disclaimers towards what materials and printing tolerances are required for the device.

CR2: Medically Safe For User:

The device must be made entirely out of FDA / ISO compliant materials that, during normal operation, should not cause any short- or long-term damage to the patient.

CR3: Less Than $50 Per Unit:

The total cost of printing material required to print the device must be under $50.

CR4: Ability to Measure Progress:

To aid researchers and clinicians, the device should be able to measure muscle displacement as well as applied force to the jaw so that progress can be measured over time.

2.2 Engineering Requirements (ERs)

ER1: Quick Printing Speed:

The previous time from starting the print to assembly took approximately 17 hours. With the additional parts included to the total part count from the last iteration, the current time from start of print to assembly is 11 hours and 30 minutes.

ER2: Durable and Flexible:

The device must be rated for a certain tensile strength to function properly without breaking when in use. The device must also fail in a controlled manner for safe operation.

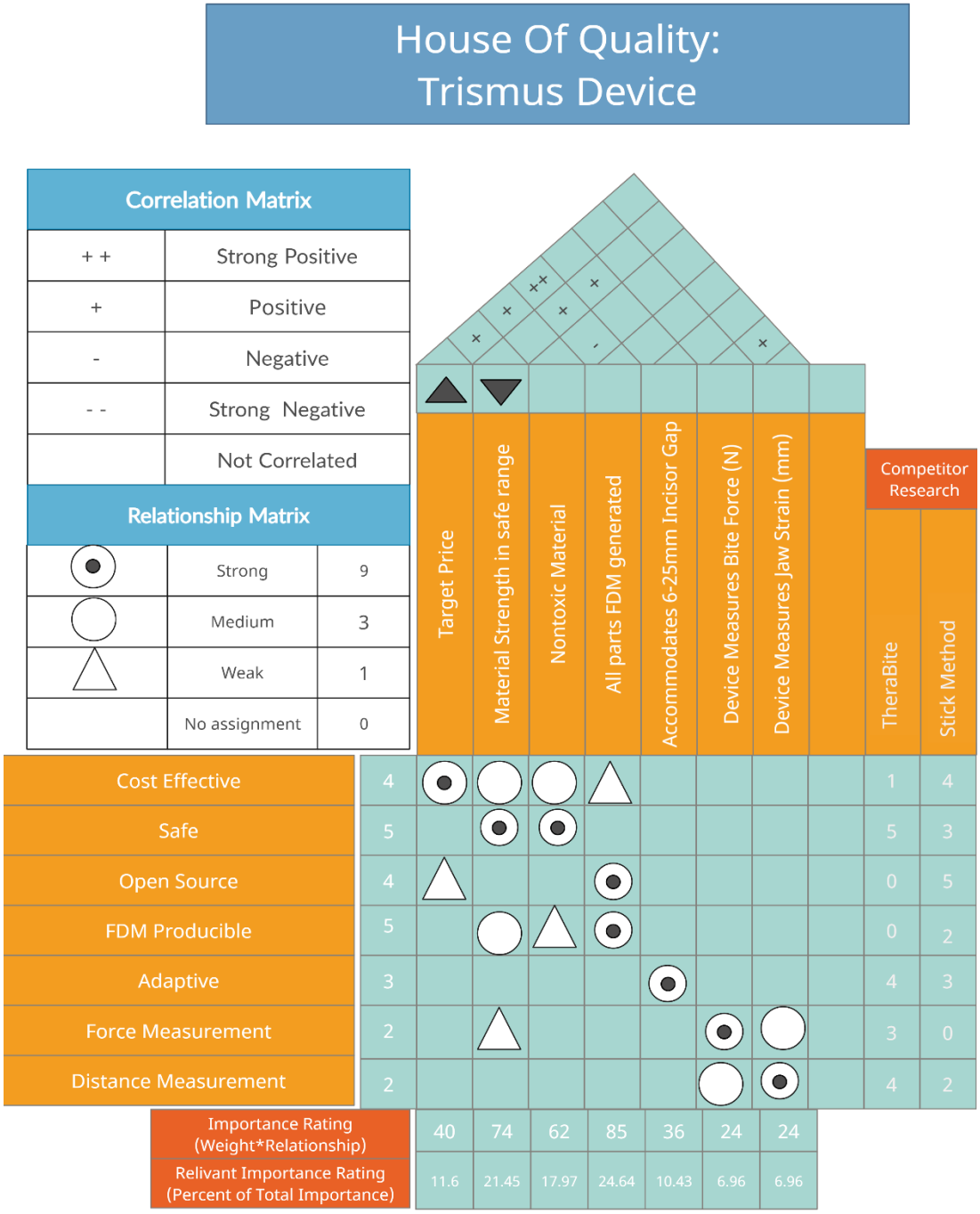
ER3: Easily Reproducible:

By refining the CAD model, as well as the instruction suite and print settings, the device should be able to be reproducible with limited need for modification of the model or printer being used.

ER4: Measurement System:

The device should be able to measure the patient's incisor displacement in mm to measure treatment progress. A secondary goal is to measure the applied force to jaw in N.

2.3 House of Quality (HoQ)



3 Research Within the Design Space

3.1 Benchmarking

- **TheraBite***: $579.99 (See Appendix B: Figure B1: Therabite)*

-<u>Description</u>*:*

Injection-molded, adjustable design with replaceable mouthpiece

-<u>Assessment</u>*:*

Adjustable with replacement bite pads

- UNIQUE Trismus*: $24 (See Appendix B: Figure B2: Unique)*

-<u>Description</u>*:*

Constructed with steel, uses a screw mechanism to force apart metal mouthpiece

-<u>Assessment</u>*:*

Extremely painful but more affordable

- In house Trismus Device: *Less than $5.00 (See Appendix B: Figure B3: In House Treatment)*

-<u>Description</u>*:*

Created by clinician, constructed from tongue depressors

-<u>Assessment</u>*:*

Non-reusable but low cost

3.2 Literature Review

3.2.1 Shilo Bailey

Exercise Intervention for the Treatment of Trismus in Head and Neck Cancer – A Prospective Two-Year Follow-up Study [3]

A study investigated if structured exercises with jaw mobilizing devices would improve mouth opening and quality of life in head and neck cancer patients who experience limited jaw opening (trismus) as a side effect of radiotherapy. Patients who exercised showed significantly better improvement in mouth opening and reported fewer trismus-related symptoms and better overall quality of life after two years compared to a control group, suggesting this exercise program to be an effective long-term treatment for trismus in these patients.

Trismus Therapy Devices: A Systematic Review [4]

A two-year study showed that head and neck cancer patients who did structured exercises with jaw mobilizing devices after radiation treatment had significantly better long-term jaw opening and fewer symptoms like trouble eating and speaking compared to patients who didn't exercise. This suggests these exercises can be a valuable treatment for radiation-induced jaw limitations, improving patients' quality of life.

Mobilization regimens for the prevention of jaw hypomobility in the radiated patient: A comparison of three techniques [5]

Researchers compared jaw exercises with tongue depressors or a Therabite device to improve jaw mobility in radiated head and neck cancer patients. After ten weeks, the Therabite group showed significantly greater improvement and continued to gain mobility throughout the study, while the other groups plateaued after four weeks. Patients using Therabite also reported feeling more in control and compliant with the exercises, suggesting it may be a more effective treatment for radiation-induced jaw limitations.

Feasibility study of intensive intervention using novel trismus device during adjuvant radiation for head and neck cancer: RestorabiteTM [6]

This pilot study investigated a new 3D-printed jaw stretching device called RestorabiteTM for patients with head and neck cancer who experience limited jaw opening (trismus) after surgery and before radiation therapy. The device applies a regulated force to improve jaw mobility and patients were followed for 6 months. The study showed good patient adherence, significant improvement in jaw opening, and improved quality of life. Future studies will explore improving adherence during radiation and determine the optimal force for individual patients.

Regulatory mechanisms of jawbone and tooth development [7]

Development in jaw muscle pathways and nerves is crucial for proper jaw function. Disruptions in these pathways can lead to conditions such as trismus, characterized by restricted mouth opening. Understanding and addressing these disruptions are essential for managing trismus and maintaining oral health.

New Approaches to Enhanced Remineralization of Tooth Enamel [8]

Restoring natural materials in teeth is essential for preserving their structural integrity and function. However, the process can alter the tooth's original properties, potentially affecting the amount of pressure required for biting and chewing.

Tooth Enamel and Its Dynamic Protein Matrix [9]

The effects of root repair on teeth are pivotal for ensuring long-term dental health. Severe trismus can impede proper healing or cause disruptions in the repair process, potentially compromising the integrity and stability of the tooth.

Tooth enamel remineralization [10]

The process of teeth remineralization is essential for maintaining their strength and resilience against decay. Trismus can disrupt this process and cause further oral issues, such as cavities and unnecessary enamel erosion.

Organic Matrix of Tooth Enamel [11]

Disruptions to oral hygiene caused by trismus can cause injury or potentially destroy the natural matrix of teeth. This is particularly bad for patients with diabetes or a naturally acidic mouth.

Abiotic tooth enamel [12]

Trismus directly affects the abiotic enamel restorations and may cause longevity issues with healthy teeth. Patients with weak or unhealthy teeth may lose them due to the lack of repair that can occur during trismus.

3.2.2 Nathan Bastidas

Biomaterials: An Introduction to Materials in Medicine [13]

This textbook highlight different materials in the biomedical field, primarily in the fields of implants and medicinal use. This, pair alongside the next source, give the team a great deal of knowledge that can be applied towards what materials we will be using for this project.

Biomaterials: An Introduction [14]

This additional textbook focuses on the biocompatibility of various materials, degradation and science. The source focuses on the major materials (ceramics, metals, and polymers) in a biomedical context, highlighting the various uses of these different materials and their strengths and weaknesses in their application. For this project, the chapters focusing on polymers are the most important, as many 3D printing filaments are considered polymers of some kind.

ISO Standards of Medical Devices [15]

The medical article displays the various categories of the ISO safety standards and how biomedical devices are classified under such a system. These safety standards give our team clear insight into how meticulous we must be when designing this product in order to have a device that will not cause any harm or biological damage to the patient.

Materials and applications of 3D printing technology in Dentistry: An Overview [16]

This document highlights the current state of 3D printing with regards to dental procedures and products. As our device deals with the inside of the human mouth, some details regarding the landscape of 3D printing with regards to the mouth could help provide some examples of different compatible materials to use.

Designing biomaterials for 3D printing [17]

This research paper details 3D printable biomaterials that can be used for a wide variety of manufacturing situations. As one of our most prominent objectives is for the device to not cause any long term harm (either through ingestion of toxic materials or potential contamination of the inside of the patient's mouth), seeing what biocompatible, 3D printable materials exist will allow us to complete that objective.

Biocompatible 3D resins for medical devices [18]

Similar to the previous source, this document gives us additional references regarding different 3D printing material that is considered biocompatible. However, this article focuses more on biocompatible resins rather than more common type known as filaments.

Siraya Tech Blu-Tough Resin [2]

This manufacturer's website gives the team technical data regarding an on-the-market product that we can use to print out our device. Siraya's Blu-Tough resin has gone through the ISO Standards to be considered a biocompatible material used in 3D resin printing.

Kinetics of Ternary Co-polycondensation for High-Performance PCTG Copolyester with Ester Interchange, Polycondensation, and Mass Transfer [19]

This report details the intricacies of PCTG, as well as it's direct comparisons to PETG. Additionally, the report discusses the chemical composition of PCTG, and it's effects on the material properties.

Balanced strength and toughness improvement in polylactide (PLA)/poly(1,4-cyclohexylene dimethylene terephthalate glycol) (PCTG) blends using various compatibilizers [20]

The report discusses the initial differences between PLA and PCTG as materials, detailing the potential blend of the two improving various mechanical properties of the material, such as tensile strength and elasticity.

Overview of Materials for PETG Copolyester [21]

This technical sheet gives average data for PETG material used in 3D printing. This data is collected from various manufacturers, with all the listed values being the mean of the different manufacturers' material properties. With this, our team can find an estimated strength of the device.

3.2.3 Cassina Olson

The Design and Manufacture of Medical Devices [1]

This book chapter cites a few commonly used biomedical materials and their biocompatibility in

humans as tested. It further explains the qualities that constitute a biomedical device versus a device interacted with by humans regularly and where people may posit to draw a line between them. It references the FDA for device classification and uses these guidelines as a basis for class 2 and class 3 medical devices.

Classify Your Medical Device [22]

This FDA source provides the specific qualities and requirements for a medical device to be classified as class 1, 2, or 3. This source defines class 1 devices as noninvasive, non-surgical, temporary, and containing no bioactive components. Under this system, the trismus device is considered a class 1 device alongside Band-Aids and gauze wrappings.

Trismus in Head and Neck Oncology: A Systematic Review [23]

This paper shows the effects of radiation on certain muscle groups and joints in the mandibular area. It continues to express the strains within the mouth and how to combat muscle strain and varying upper neck muscle losses from radiation.

The Degree and Time-Course Assessment of Radiation-Induced Trismus Occurring After Radiotherapy for Nasopharyngeal Cancer [24]

This book chapter analyzes the severity of trismus after different times in which the patient was exposed to radiation therapy and whether surgery was involved/required for the cancer cells/tumor. It further explored the possibility of beginning trismus treatment early and the effects of this on keeping patients from ever experiencing trismus symptoms that limit opening to under 6mm (about 0.24 in).

Mandibular Sites Prone to Fracture: Analysis of 174 Cases in a Nigerian Tertiary Hospital [25]

This experimental finding shows the sites in the jaw that fractured most often with forced mouth opening movement. This study is centered on people of African descent and provides a more ethnically inclusive basis for trismus treatment.

Evaluation of Jawbone Density and Morphology in Bruxers Using Panoramic Radiography [26]

This online source shows the findings of how bruxism may affect the jaw and tooth structure in a patient. These were conclusive because bruxism leaves a patient's dentin exposed and causes micro fractures that may greatly decrease the appropriate pressure for application on the mouth during trismus treatment.

Comparative Study of Mechanical Properties of Dental Restorative Materials and Dental Hard Tissues in Compressive Loads [27]

This source displays the findings of compressive experimental trials on various dental layers and popular dental replacement materials such as fillers, veneers, and crowns. Often, filling materials can weaken the integrity of the tooth and may cause concern for the applied pressure on a tooth during trismus treatment.

Comparison of Mechanical Property and Role Between Enamel and Dentin in the Human Teeth [28]

This scientific literature describes the different aspects and materials of the tooth and jaw and popular substitutions in dentistry that may alter the necessary pressure needed for a patient

regarding the trismus device. From this, the team can consider testing hydroxyapatite as it is the most common substance in teeth/bones and replacements.

Adverse Effects of Orthodontic Treatment: A Clinical Perspective [29]

This research was conducted to determine the effects of orthodontic trauma on patients with varying backgrounds such as those with preexisting trauma, missing teeth, and genetic predisposition. These findings may result in the team needing to alter the mouthpiece or add a different design for the mouthpiece in addition to the original ones. People with these predispositions may have tooth or jaw fracturing, tooth movement within the mouth, and in some cases, pain with decalcification or enamel loss.

Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects [30]

This peer reviewed article considers the effects of different plastics within the mouth and how microplastics affect humans. This thorough article outlines plastics that are safer for humans and compares those to plastics that a person should rarely, if ever, be in contact with. This will inform the team of which materials to use if the material needed is unavailable or unsuccessful.

3.2.4 Carter Rhoades

Fatigue Analysis of FDM Materials [31]

This source provides an overview of fatigue in 3D printed materials. The information in this article is useful because it helps us determine how long each part might last, as well as some considerations to lessen the effect of fatigue on 3D printed objects.

Biocompatible 3D printing resins for medical applications: A review of marketed intended use, biocompatibility certification, and post-processing guidance [32]

This source provides an overview of a biocompatible variant of SLA resin, its uses, and how to process parts out of the printing area. This may prove useful for our project if we require the use of SLA printed mouthpieces that conform to a scan of the patient's mouth.

Special materials used in FDM Rapid Prototyping Technology Application [33]

This Source provides an overview of various specialty or uncommon 3D printer materials. Some materials may be stronger than others but significantly harder to print, this source explains the various tradeoffs between various filaments.

Trismus [34]

This source discusses the broader Trismus condition. It explains the causes, the physical symptoms, including musculature nomenclature, and treatment of this affliction. This is useful for our project because it discusses the main ailment we want to treat.

Persistent trismus following mandibular third molar extraction and its management: A case report and literature review [35]

The study talks about a patient who suffered from trismus 45 days after a tooth extraction. They received treatment and the article explains this in detail. This is relevant to our project because it explains possible treatments and implies potential design considerations.

A Preliminary Report on the Efficacy of a Dynamic Jaw Opening Device (Dynasplint Trismus System) as Part of the Multimodal Treatment of Trismus in Patients with Head and Neck Cancer [36]

This source explains the Dynasplint system and its process. It concludes by establishing the functionality of the treatment with final treatment results. This is useful for our project because it demonstrates a good benchmark process to compare our device to in terms of MID.

Trismus: Etiology, Differential Diagnosis and Treatment [37]

One more article that discusses the overall condition of trismus, and its treatments, this is a useful tool to use for our project to reference the symptoms of trismus.

Treating trismus with dynamic splinting: A cohort, case series [38]

Explained a case study of 40 participants who used the DTS system to improve their symptoms of trismus after cancer related trauma. This article is useful because it explains the functionality of a preexisting design.

TheraBite exercises to treat trismus secondary to head and neck cancer [39]

This source evaluates the effect of TheraBite exercises on mouth opening and analyzes factors influencing this effect in a patient record evaluation. This is a useful benchmark for our results to compare to.

Prediction of post-treatment trismus in head and neck cancer patients [40]

This article provides an overview of a study done on trismus patients quality of life vs a healthy control group. This is based on a variety of factors to quantify the patient's quality of life. This may help us to inform our HOQ quantitative values for abstract concepts such as comfort.

3.3 Mathematical Modeling

3.3.1 Maximum Bite Force Calculations - Shilo Bailey

Assumptions:

- Maximum 'bite' force is "produced at horizontal and vertical joint force directions".
- Temporomandibular Joins is a simple lever model.
- Average Jaw Weight:
  - Head Wt = 10 – 11 lbs
  - Jaw is approximately 20% of head weight/maws.
  - Assumed Jaw Wt = 2lbs
- Maximum Bite Force: F = 275lbf or 1.22kN
- For Patients with 0 – 5 mm mouth opening can be considered as static

Equation Used: Static Equilibrium, , $\sum F_y = 0$

$$\sum F_y = F_{\max bite} - W_{jaw} - F_{device} = 0$$

$$F_{device} = F_{\max bite} - W_{jaw} = F_{\max bite} - m_{jaw} * g$$

$$F_{device} = 275lbf - 2lbs * 32.1\frac{ft}{s^2}$$

$$F_{device} = 210.8lbf = 937N$$

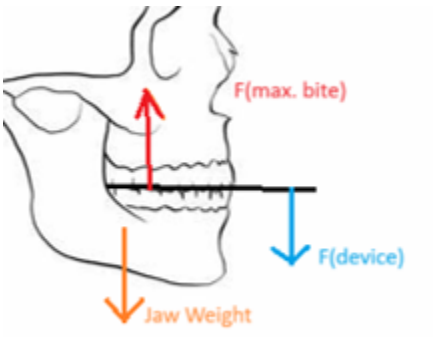


Figure 3.3.1: Jaw Forces on Device

3.3.2 Manufacturing and 3D Printing - Nathan Bastidas

System 1: Initial Theoretical Print Speed and Process:

With various assumptions made during this project's initial planning process, which will be discussed further in this initial entry, we found a mathematical formula to help predict the time

necessary to print out our device. As the Trismus Treatment device must be fully 3D printed, a swifter print time will allow clients more time to produce more units for their patients over time. In terms of software various slicers, programs designed to convert 3D models into printable instructions, were considered for this project. For our initial modeling, we settled on using Ultimaker Cura as our slicer software. A Creality Ender 3 was set as the printer inside the software, as that is one of the most affordable and accessible printers in the current market. Finally, considering the choice of an Ender 3 as our printer, FDM printing was chosen as the printing format due to its low price of entry and relative simplicity for those who have no experience in 3D printing.

Additionally, the following mechanical properties were assumed for generic PETG [21]:

- Chemical Resistance (FDA-Compliant)
- Yield Strength: ~47.9 - 52.9 MPa
- Tensile Strength: ~60-66 MPa
- Density: ~1.26e3 - 1.28e3 kg/m^3
- Avg. Print Speed: 60-80 mm/s

With these values, we were able to estimate an average print time of ~17 hours/assembly with the following equations.

- $MaxSpeed_{Rec.} = (Flow\ Rate_{Max})/(Height_{Layer} * Extrusion_{Width})$
- $Flow\ Rate = Nozzle\ Size\ (mm) \cdot (Height_{Layer} \cdot print\ Speed)$

System 2: Updated Printing Procedures with Known Variables:

With our first set of materials purchased, we were able to secure data given by the manufacturer to gain a more accurate timeframe for manufacturing. PETG from Polymaker's Polylite line was purchased and used for material testing and our initial prototypes. The following data was given to us by the manufacturer:

- Youngs Modulus: 2.17 GPa
- Tensile Strength (XY): 51 MPa
- Tensile Strength (Z): 43 MPa
- Density: 1.25 g/cm^3
- Avg. Print Speed: 30-50 mm/s
- Bending Strength (XY: 3-Point Test): 70 MPa
- Bending Modulus: 1.899 GPa

Using our initial equations, as well as printer and slicer assumptions, we were able to estimate that with a 20% infill with this material, we would be at roughly ~11 hours / assembly.

3.3.3 Pressure Measurements in MATLAB - Cassina Olson

System 1: General Pressure in MATLAB

Using the pressure from a fully toothed mouth [cite], dividing by the number of teeth [cite], and multiplying each tooth by a ratio for pressure differences experienced by each tooth [cite], the following graphs were yielded, showing the minimum force needed to open a mouth starting at 0.6mm (about 0.02 in). These were separated by molar and incisor pressures as the calculation findings differed by a wide margin. The first set of photos show a typical person with full teeth present, and the second set of photos show a person missing 75% of teeth in the mouth. These findings confirm that, without teeth, patients will need less pressure applied to the mouth to safely undergo treatment.

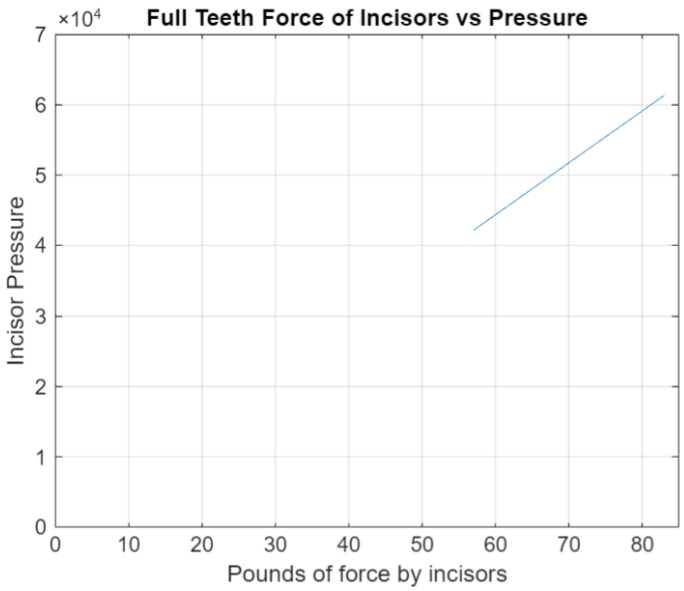


Fig 3.3.3.1: Full Teeth Incisors v Pressure

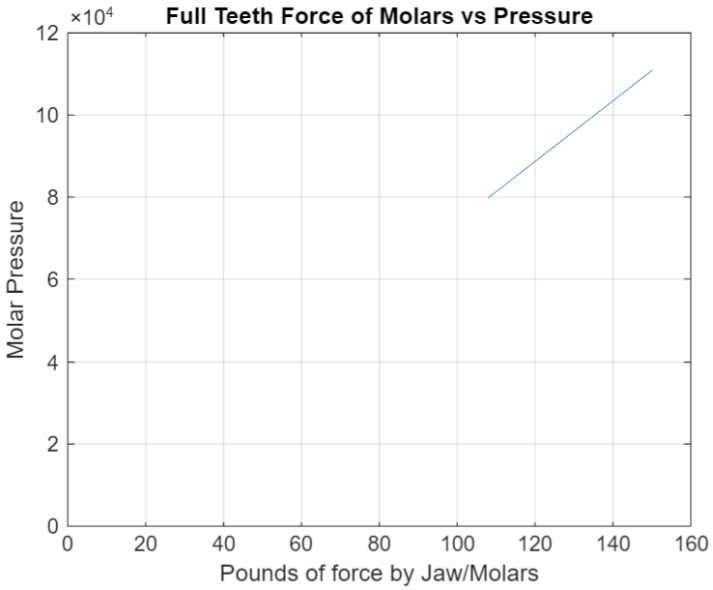


Figure 3.3.2: Full Teeth Molars v Pressure

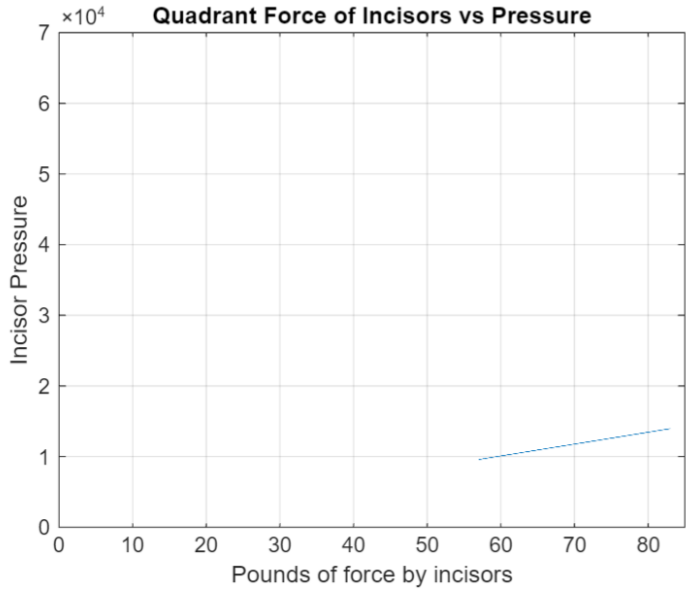


Figure 3.3.3: Quadrant Teeth Incisors v Pressure

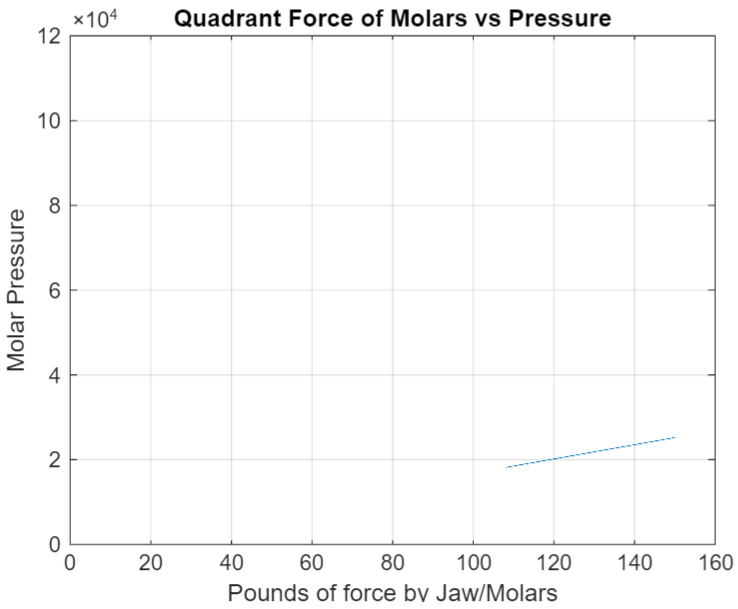


Figure 3.3.4: Quadrant Teeth Molars v Pressure

System 2: Pressure Mapping in MATLAB/Simulink

Using the same procedure and metrics as above, but with a remodeled compression map, the following graph was yielded. This represents an ideal patient with a full mouth of teeth as the front mouthpiece applies pressure to the front teeth only. The second map shows what the pressure map may look like with an updated, mouthguard-like mouthpiece that utilizes the back teeth rather than the front teeth for pressure application. The second map shows the areas with the most stress as highlighted in yellow, with the molars bearing the most pressure and the front teeth (or lack of teeth) bearing the least. As the mouth was designed as a sinusoidal function in MATLAB, there is excess data shown which may benefit the team to see what a bite that is too large or small for the apparatus would endure during treatment.

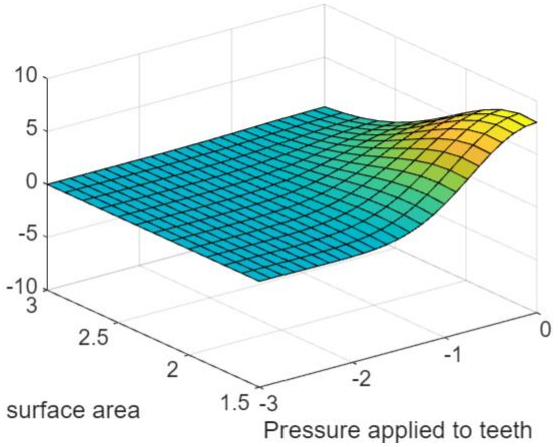


Fig 3.3.3.5: Frontal Bite Mouthguard as Surface Plot for Pressure

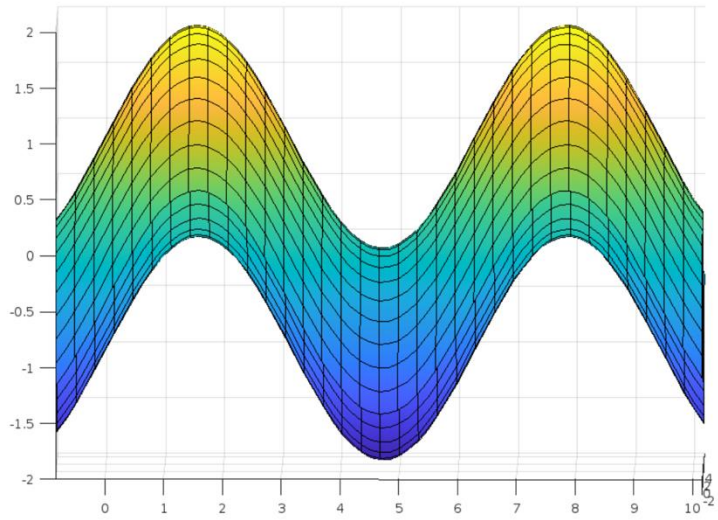


Fig 3.3.3.6: Side Bite Mouthguard as Surface Plot for Pressure

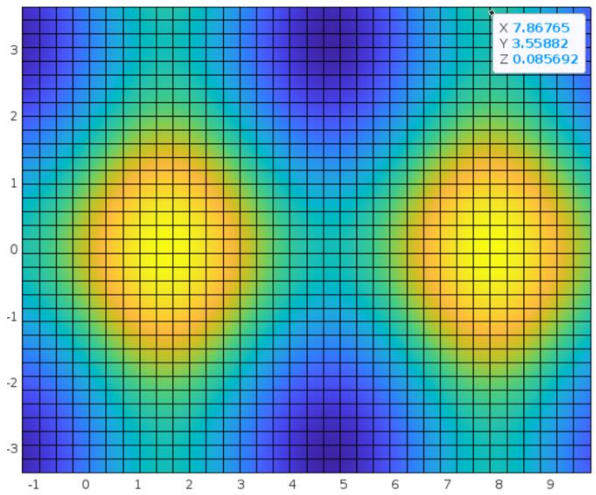


Fig 3.3.3.7: Side Bite Mouthguard as colormap for Pressure

Equations used:

- $Force = mass \cdot area$
- $[X, Y, Z] = sphere$

(Core MATLAB code to model the mouth as a sphere that ends in two sinusoidal curves to show pressure changes)

3.3.4 SolidWorks Compliant Spring Simulation - Carter Rhoades

This Is a mathematical model of the Top portion of the device. The static simulation is done in SolidWorks and is testing the deformation of the Compliant Spring. The program uses FEA to complete its assessment. This simulation was performed under the worst stress conditions, where the max bite force of the average human, 305N, was applied to the top and bottom mouthpieces. This was done to see the maximum possible displacement of the spring in context of the greater design. The result of this Simulation implies that the Spring needs to possess more bending points to spread out the load.

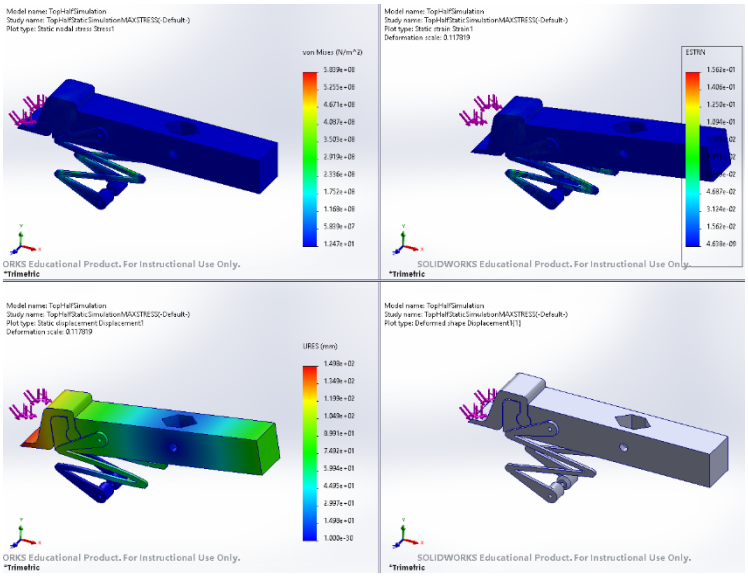
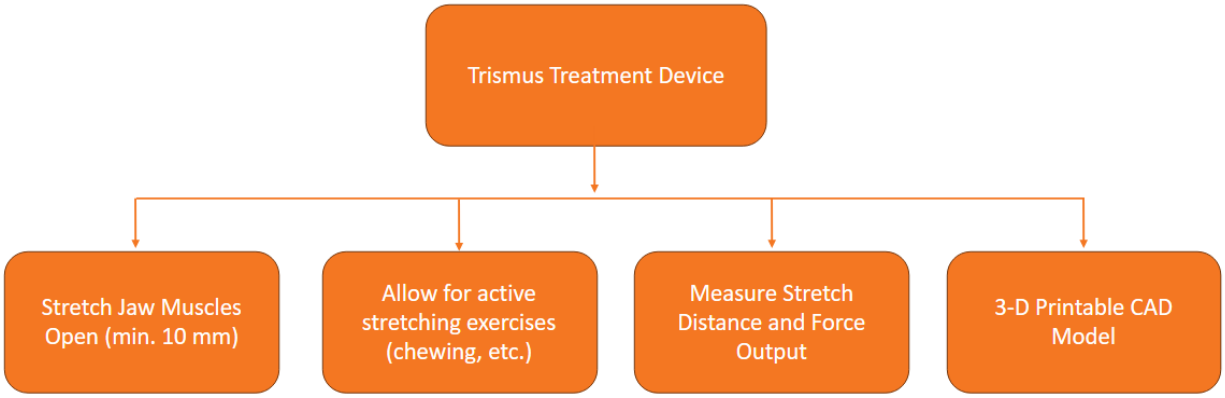


Fig 3.3.4.1 Static simulation of top half of deice under maximum force

4 Design Concepts

4.1 Functional Decomposition

The design of the device must fulfill four main functions. The first is to stretch the jaw muscles of the patient by 10 mm (Successful treatment). The second is to allow for active stretching exercises, simulating chewing motions. The third function is to measure the patient's progress with each treatment. And the last function is to be open source and printable by any clinician possessing a mid-range hobbyist 3D printer.



Stretch Jaw Muscles

The first requirement is to stretch patients' jaw muscles open to a minimum of 10mm (about 0.39 in) safely and with minimal fracture to the jaw and teeth as many patients may have lower bone density or weakened structural support in and around the jaw due to radiation.

Active and Passive Stretching

The second requirement is to create a singular device that can provide active and passive stretching, meaning that the device can force open a jaw, but also be altered easily to a state in which the patient can freely bite down and apply pressure to the device in a compliant mode. This will allow for the rebuilding of muscle and can contribute to a quicker recovery with regular use.

Measurements

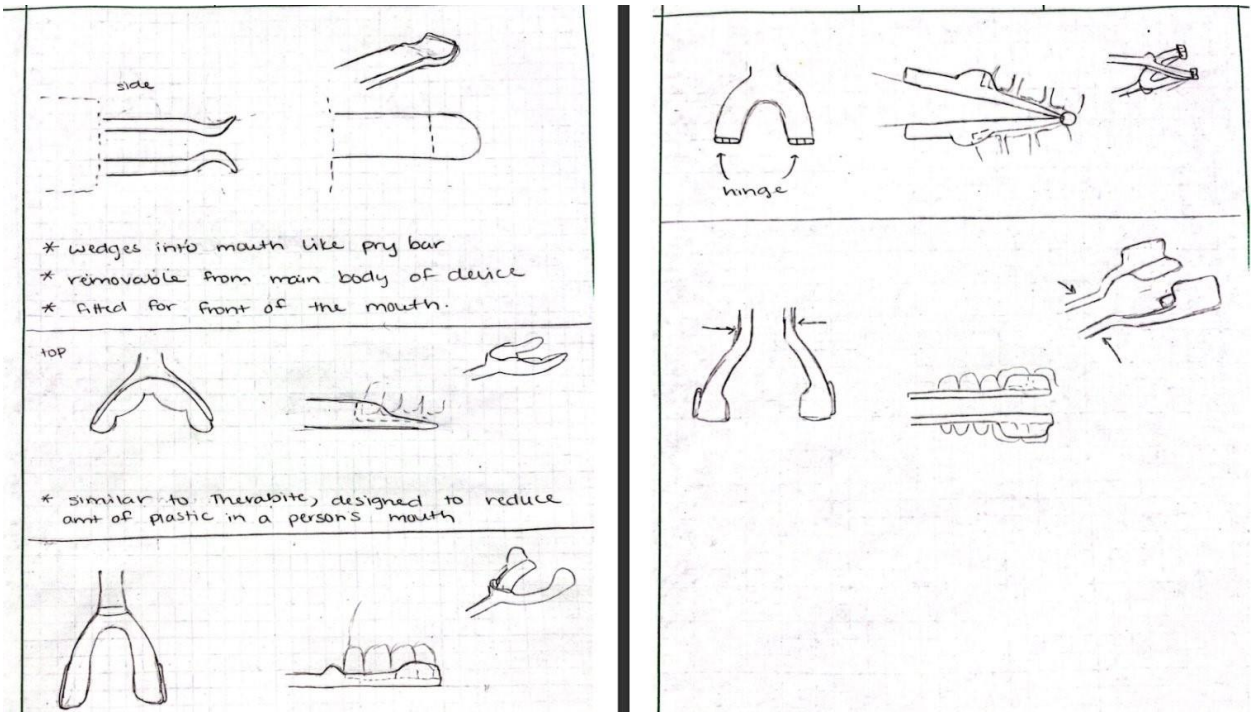
The third requirement allows for doctors to measure the recovery speed and maintain an optimum pressure on the device to not fracture any part of the patients' mouths and not delay recovery for fear of fracture. The stretch distance measurement apparatus is also intended to show the patients' progress in an outpatient setting for easily readable results and safe self-administration.

3D Printable CAD

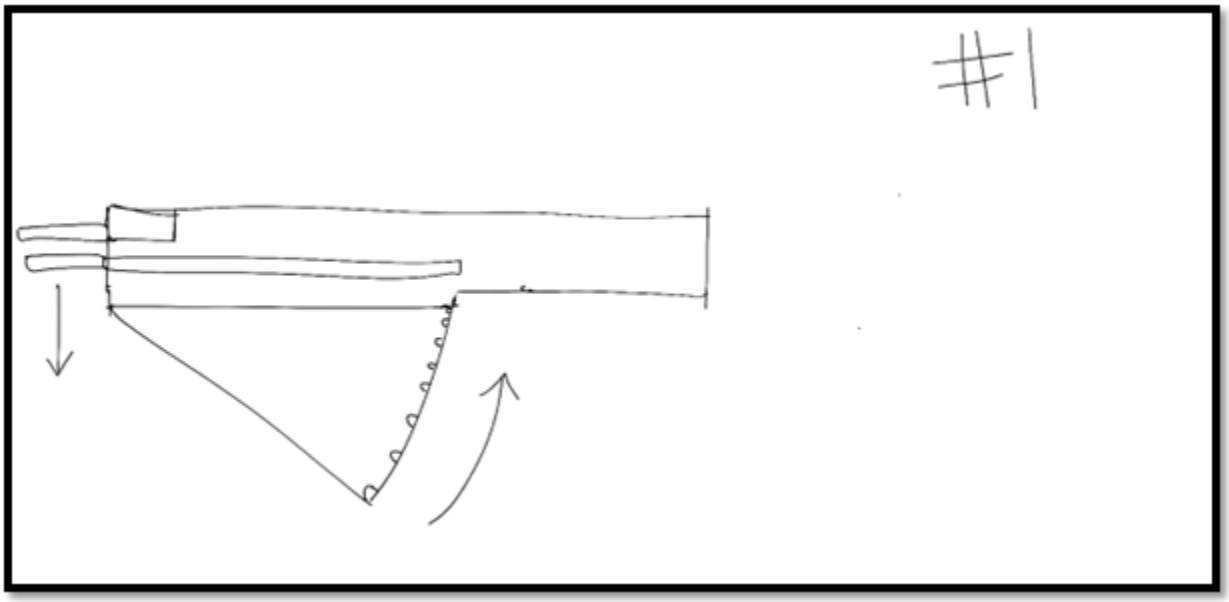
The final portion expresses both a sponsor and engineering requirement as the entire file to print this device must be accessible and easy to import for printing in a medical facility. The CAD package must have few to no risks to a medical professional, be easily assembled, and present no medical or health risks to the patient, including device fracture, gouging, and choking.

4.2 Concept Generation

4.2.1 Mouthpiece — Shilo Bailey

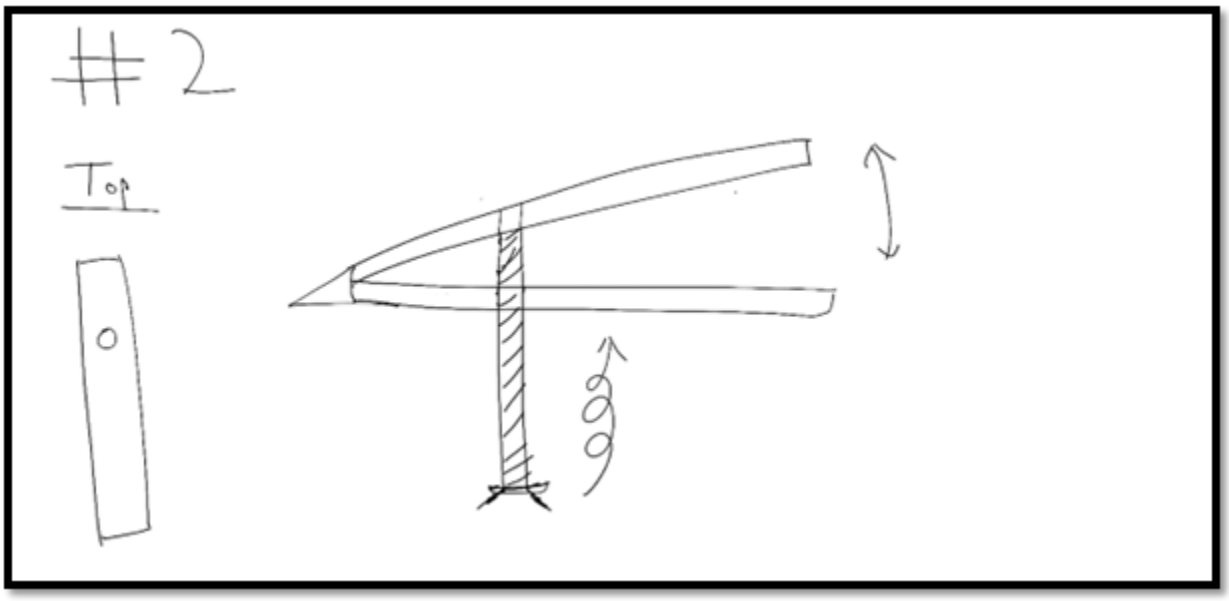


4.2.2 Mechanical Designs — Nathan Bastidas

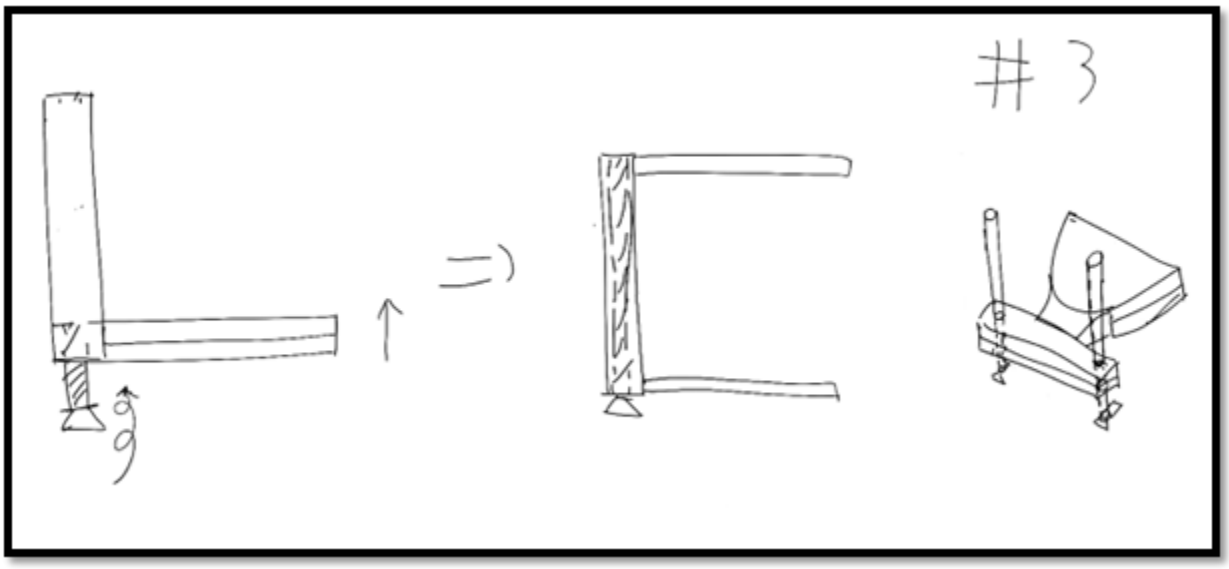


Design #1: A squeeze-lever type mechanism with various grooves made on the side of the lever. As the lever is pressed into the device with a squeezing hand gesture, the bottom mouthpiece will click into place inside the groove, locking the bottom mouthpiece at a new distance. Each groove

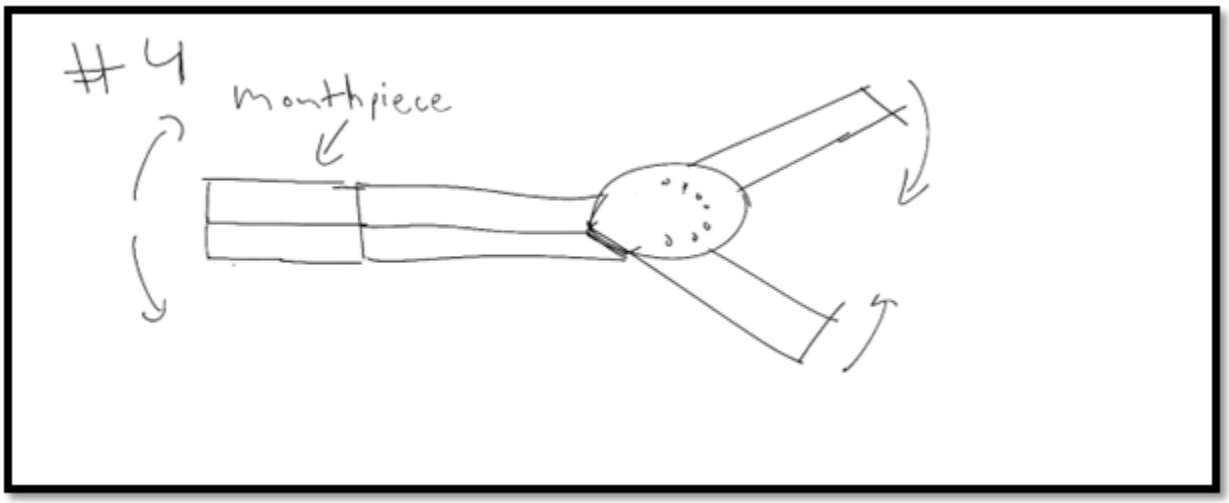
is designed to increase in space over time, that way the device naturally locks at a specified distance but has enough wiggle room between each groove to actively chew against the device for active stretching exercises.



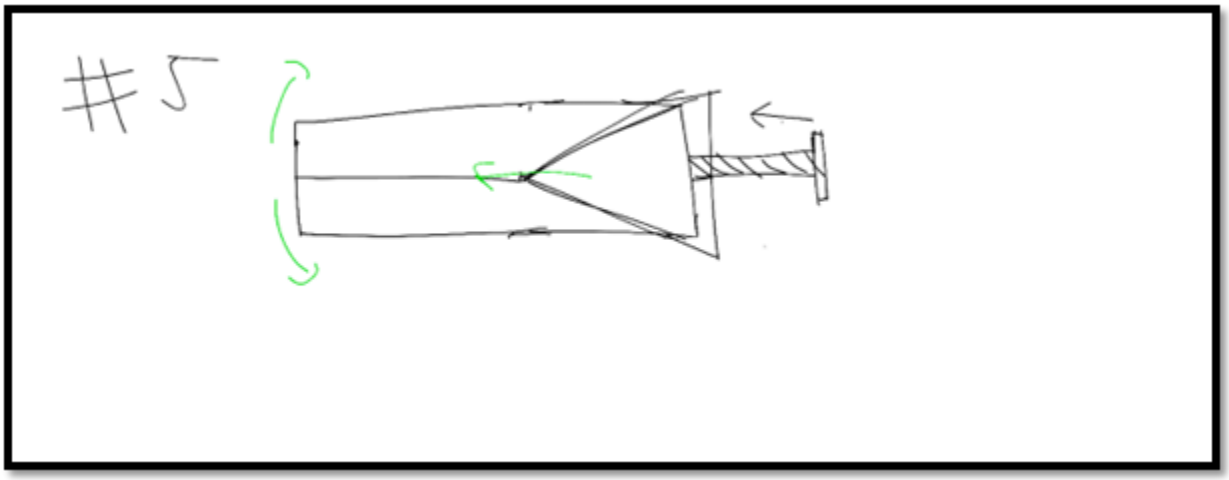
Design #2: This design utilizes a single screw point that can be adjusted manually by turning the knob on the bottom of the device. As it is turned, it causes the two mouthpieces to separate at an angle, allowing for a potentially greater spread. With this design, it could be modified to be more spring-like in nature, allowing for an easier time blending active and passive stretching exercises.



Design #3: Similar to design #2, this design uses two screw points that elevate part of the mouthguard, similar to an elevating platform. This design could be utilized for patients that have different levels of stretching for each side of their jaw.

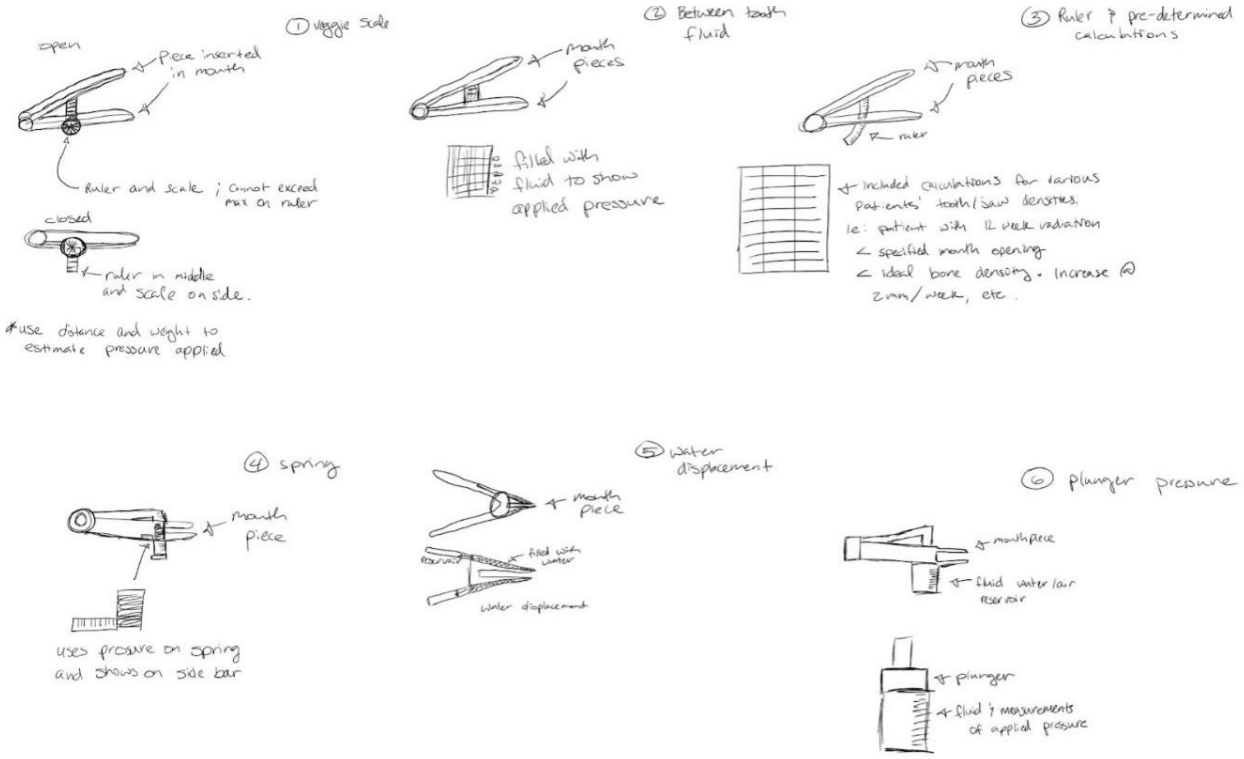


Design #4: This design uses a scissor-type mechanism to open the jaw. Each half of the mouthpiece would be linked to one part of the handle, allowing for a scissoring motion. In the center would be an adjustable lock, like design #1 where different grooves of varying distances would be able to lock the device in place for passive stretching over time.



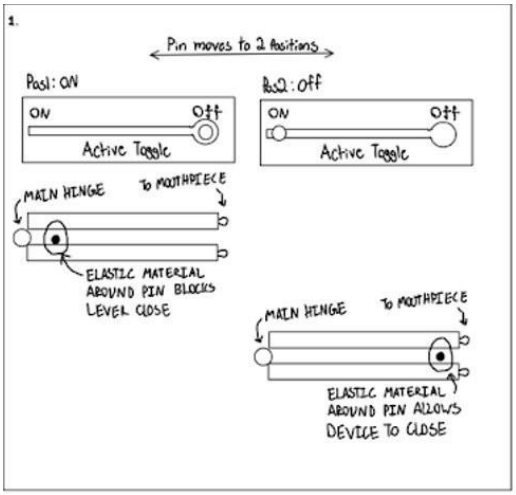
Design #5: The most unique variant, design #5 utilizes a single screw point on the back end of the device that is linked to a triangular wedge that rests between the two mouthpieces. At rest, the wedge sits flush with the two pieces. In use, the screw in the back can be turned, pushing the wedge forward between the two mouthpieces, causing them to spread.

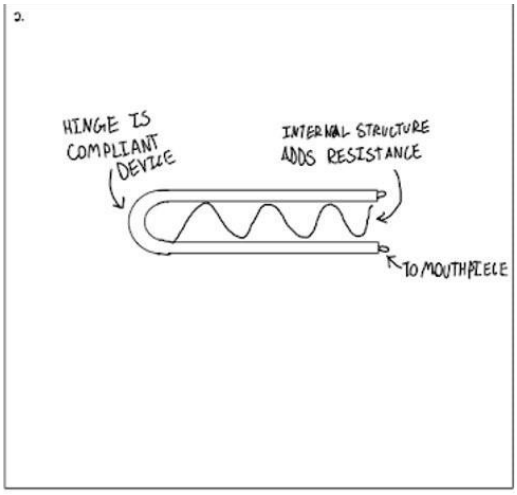
4.2.3 Pressure Measurements — Cassina Olson

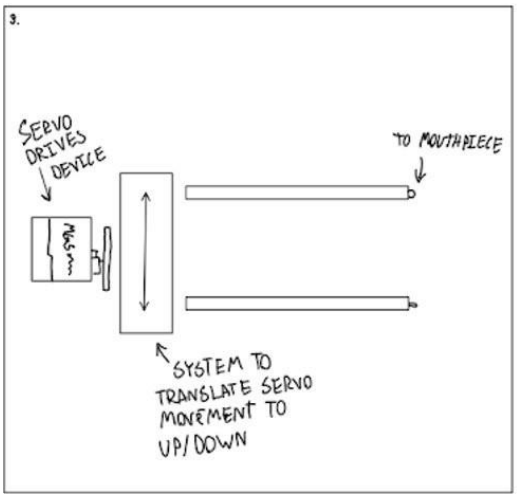


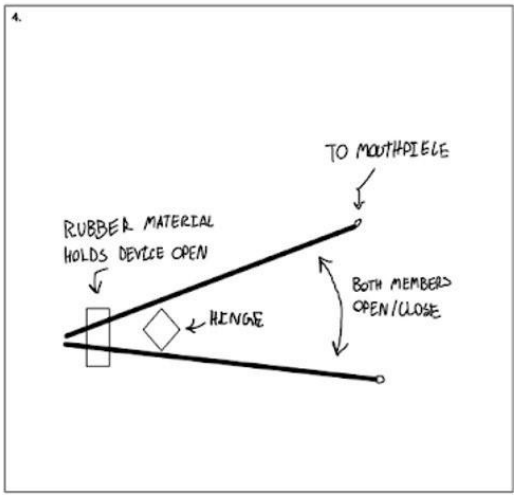
The first design shows pressure measurements through a purchased part that measures weight. This is like a veggie scale and would require a separate ruler to measure the mouth stretch distance. The second design has a tube filled with liquid and as the device is compressed, it will show the amount of pressure applied but may break under the strength of the jaw. The third design only incorporates a ruler, and premade measurements based on different preset charts which is easier in design but provides no actual solution for pressure measurements. The fourth design uses a spring to measure the pressure applied to the device from the mouth which will be difficult to design and include but would achieve precise pressure measurements. The fifth design uses silicone pads filled with water and a reservoir to measure pressure by water displacement which will work well, but tap water may contain contaminants, so the consumer must purchase distilled water to fill the reservoir. The sixth and final design incorporates both parts of the second design into one single part. The plunger pushes down on the fluid and as the plunger gets further down, the more pressure is shown to be applied. The markings on the outside of the plunger also indicate distance and force. The only issue is that it may be difficult to incorporate different styles of the device such as one that separates at the mouthpiece.

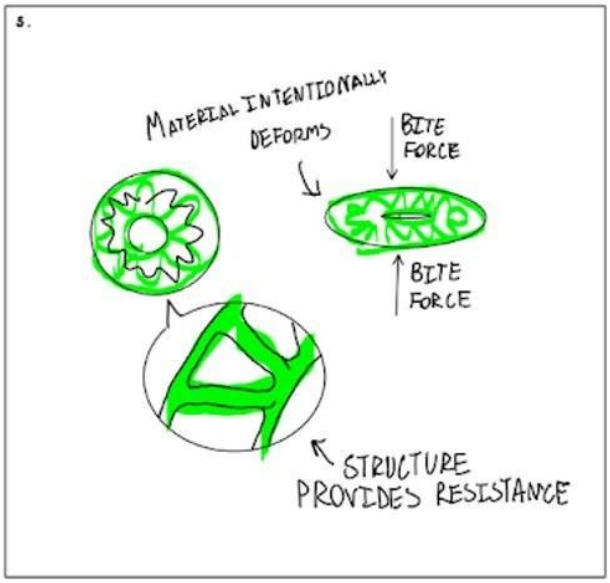
4.2.4 Shell Material and Active Resistance Systems — Carter Rhodes

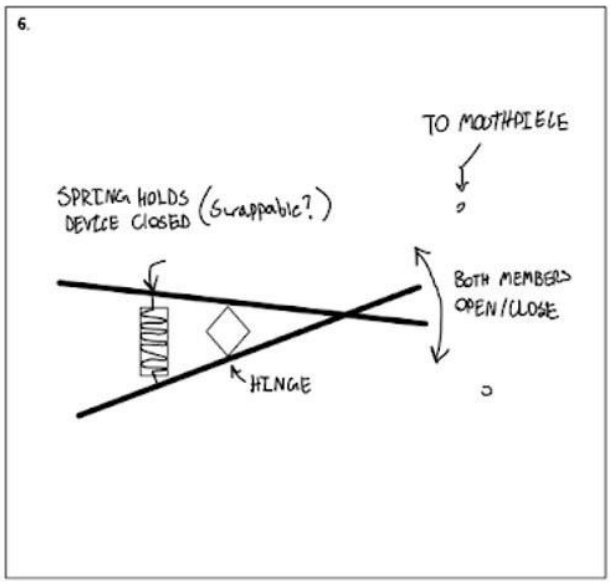


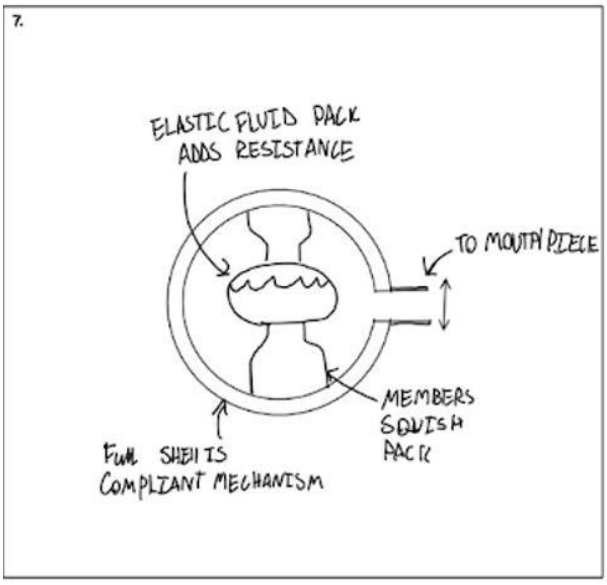












4.2.4.1 "Toggle Switch":

Pro: Easy actuation of active resistance.
Con: Requires multi-material printer or non-printed material for soft resistance around printed pin.

4.2.4.2 "Internal Spring":

Pro: Compliant spring printed with device.
Con: No active resistance actuation.

4.2.4.3 "Servo Controlled":

Pro: Precise resistance force control.
Con: Disqualified as class 2 device (Requires electronics).

4.2.4.4 "Band Resistance":

Pro: Simple design with toggleable resistance (Removable elastic).
Con: May require non-printed, albeit cheap, parts.

4.2.4.5 "Chewing Gum":

Pro: Useful solely for jaw exercise.
Con: Requires separate device for active resistance.

4.2.4.6 "Compliant Spring":

Pro: Swappable Compliant Springs change resistance by geometric design.
Con: More parts needed as well as multiple materials due to variable compliant spring types.

4.2.4.7 "Water Orb":

Pro: Device is inherently strong due to geometry.
Con: Maintaining watertightness of internal fluid pack may be challenging with FDM printing.

4.3 Selection Criteria

The selection criteria include cost as it must be under $50 to produce each device, ease of printability as quantifiable by the number of times a reprint must occur or how many of and how often the 3D printer parts must be replaced, and safety as defined by strength testing able to withstand 1.5 times estimated average applied pressure and body safe printing materials as defined by the FDA or other regulatory administrations. The force measurement aspect must show an accuracy within +/- 0.5mm (about 0.02 in) of measurement and +/- 0.5 N of pressure for the device which can be seen and adjusted through testing.

Patient safety is defined as a lack of fracture within a mouth and positive patient feedback when compared to patients who use other devices or do not use a device for medical assistance. This criterion was determined to require a much longer timeframe to fulfill and much patient paperwork regarding safety, usage, and doctor recommendations.

Ease of printability is classified as having to remove or destroy equal or less than 1 in 10 consecutively printed and assembled apparatuses. It is also quantified as having to replace 1 or fewer parts of the 3D printer for every 10 fully printed devices and base structures.

Cost is defined as less than $50 per printed device. This does not account for misprints, printer failures, the cost of a 3D printer, or labor costs to print and assemble. It is only constituted of the cost of printing filament and one nozzle replacement for every 10 full device prints.

4.4 Concept Selection

Using the above criteria, the following decision matrix was created, giving each requirement a weight and rating each design against a current competitor to see which design captures all the design requirements best. As shown, the TheraBite brand trismus device failed in cost, printability and force measurements which ranked higher in weight, giving it a score of 2.55 when weighted and leaving much to be desired which the team took to create a better fit. Based on the ratings and multiplied weights, alternative design 5 excelled with a weighted score of 7.5. The next best options were alternate design 1 with a weighted score of 6.5 and design 3 with an equal weighted score. However, the team looked to create a version that included each of the best aspects from each model to create a device that would, in theory, rank a full 10 when weighted.

Criteria	Weight	Current Solution :TheraBite		Alternate Design 1	
		Rating (0-10)	Weighted Rating	Rating (0-10)	Weighted Rating
Cost (Lower cost scores higher)	30%	1	0.3	7	2.1
Printability	15%	0	0	6	0.9
Print In Place	5%	0	0	8	0.4
Safe	20%	5	1	5	1
Open Source	5%	0	0	9	0.45
Adaptability	10%	8	0.8	6	0.6
Force Measurement?	15%	3	0.45	7	1.05
Total Percentage:	100%	Total Option A:	2.55	Total Option B:	6.5

Alternate Design 2		Alternate Design 3		Alternate Design 4		Alternate Design 5	
Rating (0-10)	Weighted Rating	Rating (0-10)	Weighted Rating	Rating (0-10)	Weighted Rating	Rating (0-10)	Weighted Rating
6	1.8	7	2.1	4	1.2	9	2.7
5	0.75	6	0.9	5	0.75	8	1.2
3	0.15	2	0.1	2	0.1	7	0.35
5	1	5	1	5	1	5	1
8	0.4	8	0.4	5	0.25	9	0.45
7	0.7	8	0.8	6	0.6	6	0.6
6	0.9	8	1.2	3	0.45	8	1.2
Total Option C:	5.7	Total Option D:	6.5	Total Option E:	4.35	Total Option F:	7.5

Best Fit: Design #5					
Top 5 Combinations (More on page 2)					
System:	Pressure Measurement	Mouth Piece	Active Resistance	Mechanical	Drafter:
Alt Design 1	Ruled Measurements	PryBar	RubberBand	SqueezeLever	NAT
Alt Design 2	Plunger Pressure	MouthGuard	TogglePin	SingleScrew	CAS
Alt Design 3	Spring Force	Molar-Anchored	Spring	DoubleScrew	SHI
Alt Design 4	Water Displacement	MouthGuard	FullCompliant(#7)	ScissorMechanism	CTR
Alt Design 5	Leverage Device	PryBar	TogglePin	Wedge	CTR

Fig 4.4.1: Concept Decision Matrix

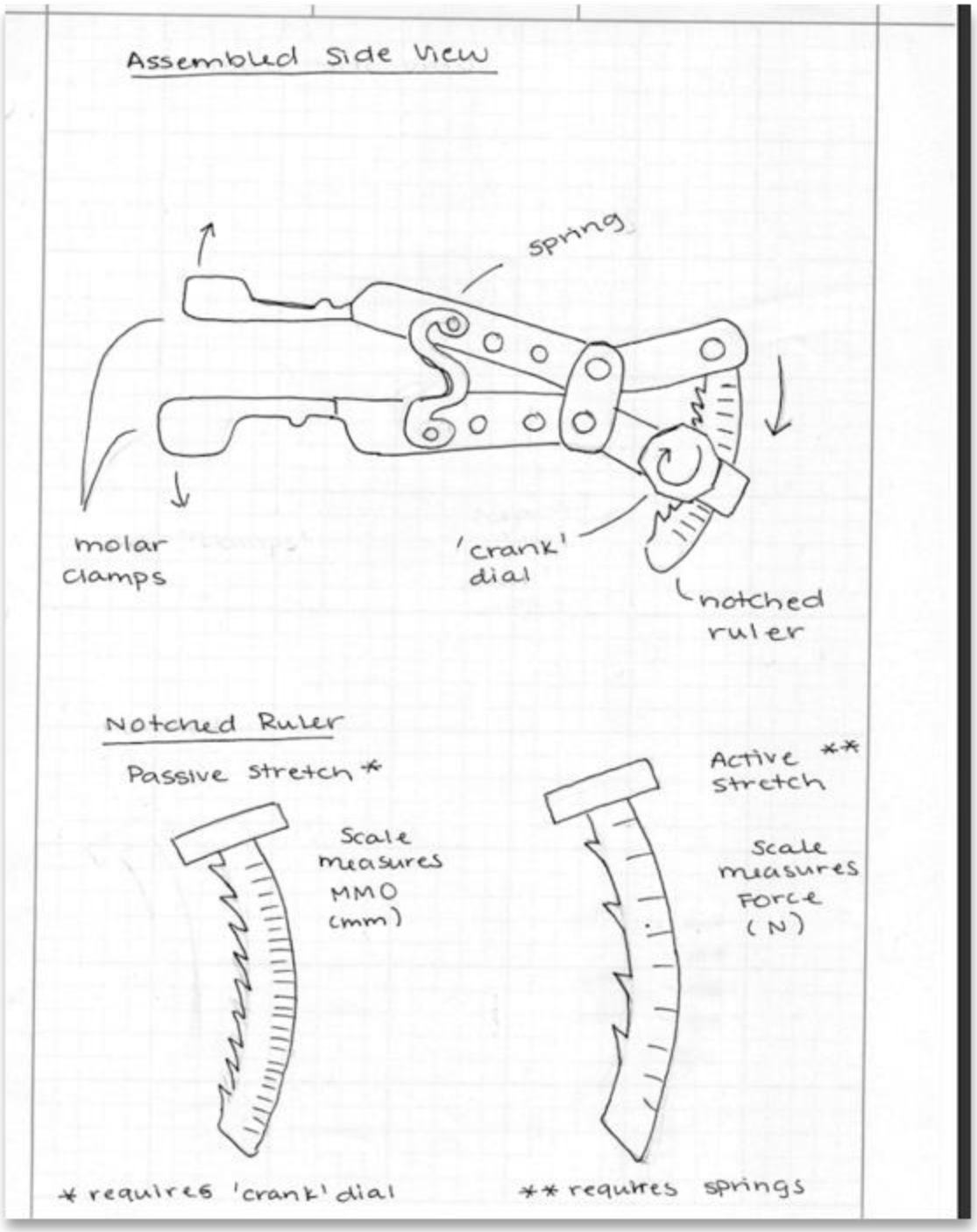


Fig 4.4.2: Selected Design (Alternative Design 3)

5 Schedule and Budget

5.1 Schedule

Below is the current Gantt Chart as of 4/12/2024 showing completed and current deliverables, most deliverable components are assigned based on each member's role.

The Team Charter required all team members to work collaboratively and create a charter that would outline the team's rules to ensure all deliverables are completed and to enforce the importance of communication between team members.

Team Charter				
Clarify Expectations and Sign	Shilo Bailey	100%	1/25/24	1/26/24
Clarify Expectations and Sign	Nathan Bastidas	100%	1/25/24	1/26/24
Clarify Expectations and Sign	Cassina Olson	100%	1/25/24	1/26/24
Clarify Expectations and Sign	Carter Rhoades	100%	1/25/24	1/26/24
Clarify Expectations and Sign	Team	100%	1/25/24	1/26/24

Fig 5.1.1: Team Charter Gantt

Presentation 1 required the team to begin reviewing journal articles for benchmarking, identify customer and engineering requirements, create a QFD based on the requirements, and begin mathematical modeling.

Presentation 1				
Budget/TVM/IVP	Shilo Bailey	100%	1/29/24	2/5/24
QFD / Format	Nathan Bastidas	100%	1/29/24	2/5/24
Intro/hook/problem/benchmark/	Cassina Olson	100%	1/29/24	2/5/24
C and E requirements/ scheduling	Carter Rhoades	100%	1/29/24	2/5/24
Lit reviews; mathematical modelling	Team	100%	1/29/24	2/5/24

Fig 5.1.2: Presentation 1 Gantt

For Presentation 2 the team completed concept generation and evaluations which were then presented to the client for review and approval. Engineering calculations were also completed to identify components of the device which would be used to quantify the bite force applied to the device and measure the mouth opening.

Presentation 2				
Suite of Potential Solutions	Team	100%	2/12/24	2/26/24
BoM/Concept Eval.	Nathan Bastidas	100%	2/12/24	2/26/24
Intro/project desc./concept generation	Cassina Olson	100%	2/12/24	2/26/24
Engineering Calculations/CAD (Spring,Body)	Carter Rhoades	100%	2/12/24	2/26/24
Schedule/Budget/CAD (Ruler, Mouth Guard)	Shilo Bailey	100%	2/12/24	2/26/24

Fig 5.1.3: Presentation 2 Gantt

For Report 1, all previous deliverables were gathered and formatted into a report and each chapter was delegated to a team member for completion.

Report 1				
Ch 1	Shilo Bailey	100%	2/24/24	3/16/24
Ch 3	Nathan Bastidas	100%	2/24/24	3/16/24
Ch 4	Cassina Olson	100%	2/24/24	3/16/24
Ch 2	Carter Rhoades	100%	2/24/24	3/16/24
Lit reviews; mathematical modelling	Team	100%	2/24/24	3/16/24

Fig 5.1.4: Report 1 Gantt

For the Website Check, each team member uploaded deliverables and documents for each delegated portion of the website and ensured it was accessible via desktop and mobile devices.

Website Check 1

Documents	Shilo Bailey	100%	2/23/24	3/15/24
Project Description	Nathan Bastidas	100%	2/23/24	3/15/24
Gallery	Cassina Olson	100%	2/23/24	3/15/24
About Us	Carter Rhoades	100%	2/23/24	3/15/24
Pictures	Team	100%	2/23/24	3/15/24

Fig 5.1.5: Website Check 1 Gantt

The Analytical Analysis Memo required the team to analyze different components for the device ranging from material properties to stresses applied to the jaw. All analyses were then compiled into a memo.

Analytical Analysis Memo				
Jaw Stresses	Shilo Bailey	100%	3/1/24	3/22/24
Material Stress	Nathan Bastidas	100%	3/1/24	3/22/24
Dental	Cassina Olson	100%	3/1/24	3/22/24
Lever Tolerances	Carter Rhoades	100%	3/1/24	3/22/24
Formatting	Team	100%	3/1/24	3/22/24

Fig 5.1.6: Analytical Analysis Memo Gantt

For Presentation 3, the team continued to move forward with the design process and began 3D printing the 1st prototype after discussing design concepts and concerns with the client. A demonstration of the 1st prototype was conducted in class after the presentation was completed.

Presentation 3/1st Prototype				
Schedule & Budget / CAD Model	Shilo Bailey	100%	3/11/24	4/1/24
Design Requirements / Engineering	Nathan Bastidas	100%	3/11/24	4/1/24

Design Validation / Project Description	Cassina Olson	100%	3/11/24	4/1/24
Design Description / CAD Model	Carter Rhoades	100%	3/11/24	4/1/24
Come up with FMEA ideas	Team	100%	3/11/24	4/1/24

Fig 5.1.7: Presentation 3/ 1st Prototype Gantt

For Report 2, all previous deliverables were gathered and formatted into a report and each report component was delegated to a team member for completion.

Report 2				
Schedule & Budget / Background	Shilo Bailey	100%	4/2/24	4/23/24
Requirements / Conclusions	Nathan Bastidas	100%	4/2/24	4/23/24
Research Within Design Space	Cassina Olson	100%	4/2/24	4/23/24
Design Concepts / Design Validation	Carter Rhoades	100%	4/2/24	4/23/24
References, Appendices	Team	100%	4/2/24	4/23/24

Fig 5.1.8: Report 2 Gantt

The Final CAD/BOM will include SolidWorks parts and drawings of each component of the device and be compiled into a Bill of Materials.

Final CAD/BOM				
Mechanics of Notched Ruler	Shilo Bailey	100%	4/5/24	4/26/24
Molar Mouthpiece	Nathan Bastidas	100%	4/5/24	4/26/24
Molar Mouthpiece	Cassina Olson	100%	4/5/24	4/26/24
Mechanics of Notched Ruler	Carter Rhoades	100%	4/5/24	4/26/24
Submission / Drawings	Team	100%	4/5/24	4/26/24

Fig 5.1.9: Final CAD/BOM Gantt

The 2nd prototype demonstration will be completed by 4/29/24 and each team member will discuss their delegated component of the device.

2nd Prototype Demo				
Explain Notched Ruler	Shilo Bailey	100%	4/8/24	4/29/24
Explain Mouthpiece	Nathan Bastidas	100%	4/8/24	4/29/24
Explain Mouthpiece	Cassina Olson	100%	4/8/24	4/29/24
Explain Compliant Spring	Carter Rhoades	100%	4/8/24	4/29/24
Task	Team	100%	4/8/24	4/29/24

Fig 5.1.10: 2nd Prototype Demo Gantt

The Project Management memo/report will be completed by 5/3/24 and each team member will complete their delegated component.

Project Management				
Purchasing Plan	Shilo Bailey	100%	4/12/24	5/3/24
Reflection	Nathan Bastidas	100%	4/12/24	5/3/24
Gantt Chart	Cassina Olson	100%	4/12/24	5/3/24
Manufacturing Plan	Carter Rhoades	100%	4/12/24	5/3/24
Formatting	Team	100%	4/12/24	5/3/24

Fig 5.1.11: Project Management Gantt

Website Check 2 will be completed by all team members before the end of the semester to ensure that all documents and deliverables from the semester are showcased on the Capstone Trismus website.

Website Check 2

Add more	Shilo Bailey	100%	4/14/24	5/5/24
Submit	Nathan Bastidas	100%	4/14/24	5/5/24
Add more	Cassina Olson	100%	4/14/24	5/5/24
Add more	Carter Rhoades	100%	4/14/24	5/5/24
Add more	Team	100%	4/14/24	5/5/24

Fig 5.1.12: Website Check 2 Gantt

Below is a draft of the Gantt chart for ME486C including main deliverables and tentative due dates. The Gantt chart will be updated as more information regarding deliverables is provided.

TASK	ASSIGNED TO	PROGRESS	START	END
Project Management				
	Shilo Bailey	0%	1/25/24	8/28/24
	Nathan Bastidas	0%	1/25/24	8/28/24
	Cassina Olson	0%	1/25/24	8/28/24
	Carter Rhoades	0%	1/25/24	8/28/24
	Team	0%	1/25/24	8/28/24
Engineering Calculations				
	Shilo Bailey	0%	8/28/24	9/4/24
	Nathan Bastidas	0%	8/28/24	9/4/24
	Cassina Olson	0%	8/28/24	9/4/24
	Carter Rhoades	0%	8/28/24	9/4/24
	Team	0%	8/28/24	9/4/24
Website Check 1				
	Team	0%	9/25/24	10/9/24
	Nathan Bastidas	0%	9/25/24	10/9/24
	Cassina Olson	0%	9/25/24	10/9/24
	Carter Rhoades	0%	9/25/24	10/9/24
	Shilo Bailey	0%	9/25/24	10/9/24
Finalized Testing Plan				
	Shilo Bailey	0%	10/9/24	10/30/24

	Nathan Bastidas	0%	10/9/24	10/30/24
	Cassina Olson	0%	10/9/24	10/30/24
	Carter Rhoades	0%	10/9/24	10/30/24
	Team	0%	10/9/24	10/30/24
Final CAD Packet				
	Shilo Bailey	0%	10/30/24	11/20/24
	Nathan Bastidas	0%	10/30/24	11/20/24
	Cassina Olson	0%	10/30/24	11/20/24
	Carter Rhoades	0%	10/30/24	11/20/24
	Team	0%	10/30/24	11/20/24
Final Report & Final Website Check				
	Shilo Bailey	0%	11/6/24	11/27/24
	Nathan Bastidas	0%	11/6/24	11/27/24
	Cassina Olson	0%	11/6/24	11/27/24
	Carter Rhoades	0%	11/6/24	11/27/24
	Team	0%	11/6/24	11/27/24
Client Handoff				
	Shilo Bailey	0%	11/20/24	12/11/24
	Nathan Bastidas	0%	11/20/24	12/11/24
	Cassina Olson	0%	11/20/24	12/11/24
	Carter Rhoades	0%	11/20/24	12/11/24
	Team	0%	11/20/24	12/11/24

Fig 5.1.13: Full Gantt Chart

A full Gantt Chart for the 2024 Spring Semester can be found in Appendix C: Spring 2024 Gantt.

5.2 Budget

The Total budget of the project was $300, where $200 was provided by the client, and $100 was funded by the team using various fundraising methods. The main expense for this project was the cost of each roll of filament. Two rolls of PETG were used for the initial prototypes, and four rolls of the finalized material, PCTG, were used to produce multiple copies of the design as requested by the client. The filament orders were fulfilled by amazon, however the PETG was manufactured by the Polymaker company, and the PCTG was manufactured by the Essentium company. A final breakdown of cost verses funding shows that a total of $33.20 was left remaining after the conclusion of the project. This breakdown can be found in Figure 5.2.1: Project Final Budget.

Fundraising		Expenses						
Catagory	Amount	Catagory	Description	Cost Per Item	Quantity	Cost of Purchase	Date	Vendor
Client Funding	$200.00	Filament	PETG	$24.44	2	$48.88	3/6/24	PolyMaker
Team Funding	$100.00	Filament	PCTG	$54.48	1	$54.48	4/25/24	Essentium
Total Funding	$300.00	Filament	PCTG	$54.48	1	$54.48	9/5/24	Essentium
		Filament	PCTG	$54.48	1	$54.48	10/3/24	Essentium
		Filament	PCTG	$54.48	1	$54.48	10/10/24	Essentium
					Total Expense:	$266.80		
					Total Budget:	$300.00		
					Remaining Funds:	$33.20		

Figure 5.2.1: Project Final Budget

5.3 Bill of Materials (BoM)

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	PRINT TIME (seconds)	QTY PER DEVICE	QTY PCTG	PRINT LINE TYPE	PCTG FILAMENT PER	PCTG PRICE TOTAL
1	101	Mouthpiece	PCTG	2871	2	24	Inner wall	29.54	$1.58
2	102	Top Arm	PCTG	7200	1	13	Outer Wall	27.85	$1.49
3	103	Bottom Arm	PCTG	11400	1	13	Overhang Wall	0.18	$0.01
4	104	Ruler	PCTG	6180	1	13	Sparse Infill	43.24	$2.31
5	105	Gear	PCTG	701	1	13	Internal Solid Infill	23.89	$1.27
6	106	Knob	PCTG	6600	1	13	Top Surface	4.41	$0.24
7	107	Ruler Pin	PCTG	330	1	13	Bottom Surface	3.06	$0.16
8	108	Gear Clip	PCTG	1064	1	13	Bridge	5.52	$0.29
9	109	Compliant Spring	PCTG	1742	2	17	Gap Infill	0.03	$0.00
10	110	Wasted Support	PCTG	1425	1	16	Support	4.32	$0.23
11	111	Handle	PCTG	3623	1	6	Outer Wall	16.92	$0.90
12	112	Handle Pin	PCTG	120	1	6	Bottom Surface	0.13	$0.01
			TOTAL	43256	14	160	Support Interface	0.18	$0.01
			PRINT TIME (hrs)	12.02			Custom	0.07	$0.00

VENDOR	PCTG DEVICES PRINTED	11.43
Essentium PCTG	TOTAL COST PER PCTG	$8.50
	TOTAL SPENT PCTG	$97.12
	TOTAL MATERIAL (ROLLS) RECIEVED	4
	REMAINING MATERIAL REQUIRED	0
	TOTAL PARTS NECESSARY	14
	TOTAL PARTS PER DEVICE	14
	DEVICES MADE FROM 1 ROLL	4.71
	ASSEMBLED	100%
	TOTAL DEVICES NEEDED	12
	TOTAL DEVICES PRINTED	4

Figure 5.3.1: BOM for PCTG

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	PRINT TIME (seconds)	QTY PER DEVICE	QTY PETG	PRINT LINE TYPE	PETG FILAMENT PER	PETG PRICE PER
1	101	Mouthpiece	PETG	2871	2	10	Inner wall	29.54	$0.87
2	102	Top Arm	PETG	7200	1	5	Outer Wall	27.85	$0.82
3	103	Bottom Arm	PETG	11400	1	5	Overhang Wall	0.18	$0.01
4	104	Ruler	PETG	6180	1	5	Sparse Infill	43.24	$1.27
5	105	Gear	PETG	701	1	5	Internal Solid Infill	23.89	$0.70
6	106	Knob	PETG	6600	1	4	Top Surface	4.41	$0.13
7	107	Ruler Pin	PETG	330	1	2	Bottom Surface	3.06	$0.09
8	108	Gear Clip	PETG	1064	1	2	Bridge	5.52	$0.16
9	109	Compliant Spring	PETG	1742	2	11	Gap Infill	0.03	$0.00
10	110	Wasted Support	PETG	1425	1	5	Support	4.88	$0.14
11	111	Handle	PETG	3623	1	0	Outer Wall	0	$0.00
12	112	Handle Pin	PETG	120	1	0	Bottom Surface	0	$0.00
			TOTAL	43256	14	54	Support Interface	0.18	$0.01
			PRINT TIME (hrs)	12.02			Custom	0.07	$0.00

VENDOR	PETG DEVICES PRINTED	3.857142857
PolyLite PETG	TOTAL COST PER PETG	$4.19
	TOTAL SPENT PETG	$16.16

Figure 5.3.2: BOM for PETG

Our team originally chose PETG as the product filament, but due to delamination, PCTG was purchased and used. Approximately 4 full devices can be produced with a single 750g roll of PCTG. The current objective is to print 12 full devices for client use, of which 4 have been printed to date. This is deemed ‘on time’ for the team objective as each print takes about 12 hours to print.

6 Design Validation and Initial Prototyping

6.1 Failure Modes and Effects Analysis (FMEA)

Testing Procedures

- Stress / Strain / Shear stress testing on the material
- Cyclic loading to find lifetime use of the device
- Test effectiveness of building instructions / guide
- Customer feedback
- Pressure threshold to snap compliant spring / removable pin on device
- Pressure comparisons to a digital reading over lifetime testing

Equipment, Resources, and Space

- Apparatus to test stress/strain of PETG printed sheet for base calculations and for finished device testing
- Apparatus for full cyclic loading and counter to determine product longevity
- Polling and descriptions for instruction cohesiveness and product comfort
- Pressure test on ease of fracturing device when necessary, via pin/spring
- Digital pressure monitor/ sensing equipment

FAILURE MODE AND EFFECTS ANALYSIS

Item: Trismus Device | Responsibility: Team Trismus | FMEA number: Unknown
Model: Current | Prepared by: Team Trismus | Page : 1 of 1
Core Team: Team Trismus | FMEA Date (Orig): 3/31/24 | Rev: 1

Process/ Function/ Item	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
												Actions Taken	Sev	Occ	Det	RPN
Compliant Spring	Too strong/weak	Cannot press down on the device/ Spring Fracture	7	C	Improper machine set up /Improper assembly /Improper tolerances	0	Operator training and instructions	0	0	Create training guide and directions / Consider a stopping point or device failure upon reaching a particular pressure amount	Testing and manufacturing managers. Completion goal at second prototype	Instruction planning and testing tolerances	7	0	0	0
Pressure Measuring Tool	Locking / Fracture	False measurements / injure patient / device user	5	U	Improper machine set up	0	None	0	0	Create training guide and directions / Design Considerations	Testing and manufacturing managers. Completion goal at second prototype	Instruction planning and testing tolerances	5	0	0	0
Handle Pressing Down	Fracture	Injure patient / device user	7	U	Improper machining / improper assembly	0	None	0	0	Consider a stopping point or device failure upon reaching a particular pressure amount	Testing and manufacturing managers. Completion goal at second prototype	Instruction planning and testing tolerances	7	0	0	0

Mouthpiece	Locking	Injure patient / fear	9	H	Improper machine set up /Improper assembly /Improper tolerances	0	None	0	0	Operator training and instructions	Testing and manufacturing managers. Completion goal at second prototype	Instruction planning and testing tolerances	9	0	0	0
Grip Comfort	Locking / Fracture	Skin abrasions / injure device user	4	U	Improper machining / improper assembly	0	None	0	0	Design considerations / multiple designs for comfort	Testing and manufacturing managers. Completion goal at second prototype	Testing tolerances andusre feedback	4	0	0	0
Mouthpiece Comfort	Excessive size / subpar size	Skin abrasions / injure device user	5	U	Improper machining / improper assembly	0	None	0	0	Design considerations / multiple designs for comfort	Testing and manufacturing managers. Completion goal at second prototype	Testing tolerances andusre feedback	5	0	0	0
3D Printing filament too thin/thick	fracture / inability to use device	Cannot assemble / Injure Patient	5	C	Improper machine set up	0	None	0	0	Operator training and instructions	Testing and manufacturing managers. Completion goal at second prototype	Instruction planning and testing tolerances	5	0	0	0

Fig 6.1: FMEA Chart

6.2 Initial Prototyping

6.2.1 Prototype 1: Motion and Scale (See Appendix A: Figure A1)

Testing: Ensure new clearances and motion within device are functioning correctly

Result: The spring does not deform in a repeatable way or fit into the device, The ruled surface is oriented incorrectly, The Structure of the device appears stable

Interpretation: The next Prototype will be properly scaled to fit/ Tolerances & Clearances

6.2.2 Prototype 2: Gear Motion (See Appendix A: Figure A2)

Testing: Test motion of new ruled surface, full size prototype to determine ergonomics and usefulness of turn dial design.

Result: Motion theoretically works well, print quality provides unwanted resistance / looseness to movement. New spring design deforms in a predictable way.

Interpretation: The next version will have a straight arm for both the top and bottom members to increase printability, the next design will also include a larger turn dial for ease of grip. Via Client feedback, the mouthpieces will also be changed to be larger.

6.2.3 Prototype 3: Full Tolerance and Motion (See Appendix A: Figure A3)

Testing: Ensure full functionality with tighter tolerancing and modified body shape based on team and client feedback.

Result: The print, after some tolerancing, was consistently printing parts that are secure without compromising functionality.

Interpretation: Include a printable handle and redesign gear and pinion track for opening function.

6.3 Other Engineering Calculations

Since the concept selection phase, several engineering calculations have been performed. These

include stress, strain, and shear stress testing on materials to determine the failure point of components like the spring and mouthpiece. Equipment such as an elongation machine and testing apparatus for stress/strain and cyclic loading were used to validate performance. Feedback from the client was gathered to refine the ergonomics of the product. Additionally, gear size calculations were done to consider proper functionality, performance, and failure.

6.4 Future Testing Potential

Future testing includes the first set of human trials, this would be done after approval is received from the IRB submitted earlier in the semester. This test would focus on the ergonomic design of the device and feedback provided by the patients to improve the device. Such improvements could be related to the comfort of the mouth pieces or the handle. Feedback from the physician/physical therapist would also be beneficial to ensure the device provides the proper amount of stretching and resistance.

7 Final Hardware

7.1 Final Physical Design

The final design for the TrisPrint device is shown below, followed by two images of the CAD assembly drawing and the final 3D printed device. Additional sub-systems include the handle that is now pinned on the bottom of the ruler. The main subsystems featured are the ruler on the side of the device, gear housing and turn handle, and the holes on the top and bottom bodies that allow for the springs to be inserted and removed.

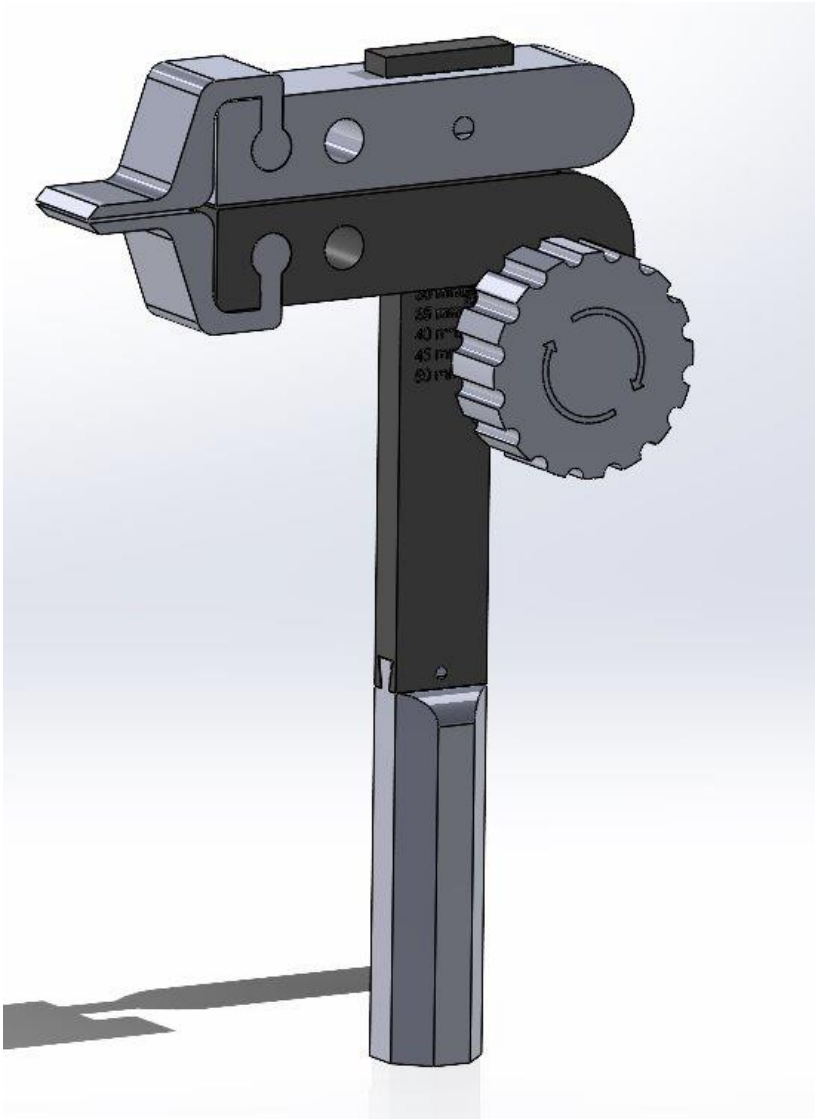
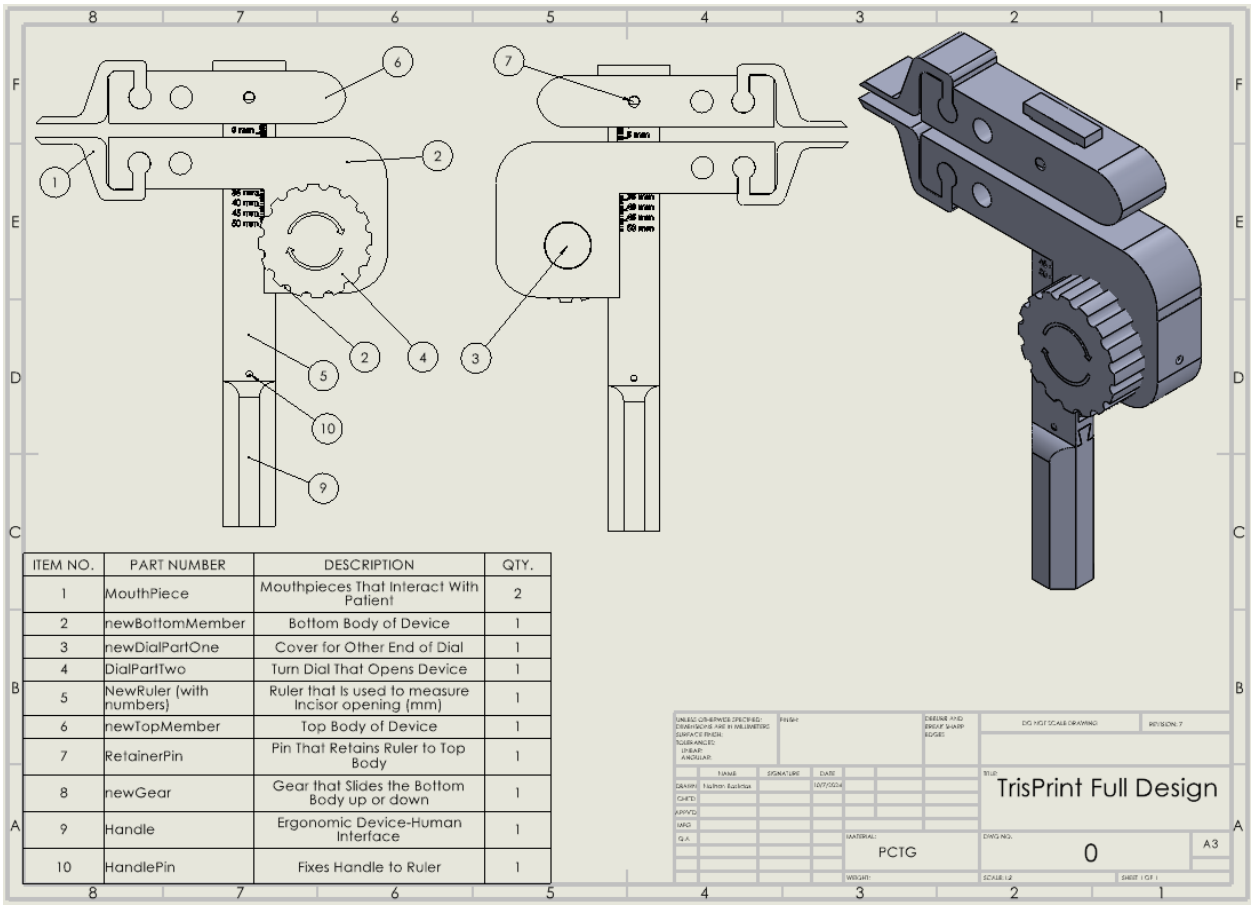


Figure 7.1.1: Final CAD



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MouthPiece	Mouthpieces That Interact With Patient	2
2	newBottomMember	Bottom Body of Device	1
3	newDialPartOne	Cover for Other End of Dial	1
4	DialPartTwo	Turn Dial That Opens Device	1
5	NewRuler (with numbers)	Ruler that is used to measure Incisor opening (mm)	1
6	newTopMember	Top Body of Device	1
7	RetainerPin	Pin That Retains Ruler to Top Body	1
8	newGear	Gear that Slides the Bottom Body up or down	1
9	Handle	Ergonomic Device-Human Interface	1
10	HandlePin	Fixes Handle to Ruler	1

Figure 7.1.2: Final CAD Drawings

Figure 7.1.3: Final Product

8 Final Testing

8.1 Top level testing summary table

Table 8.1: Top Level Testing Summary

Experiment #	Summary	Results
Ex1: Mouthpiece Bending Stress Point	The mouthpiece of the device will have a downward force of 50 N applied to the bridge to ensure the part fails by bending downwards.	Mouthpiece Failure : 55.4 N
Ex2: Spring Failure Test	The springs will be stretched out until failure to ensure breaking point via elongation is less than 5 N.	Spring Failure: 7 N (avg)
Ex3: Gear Tooth Shear Test	One tooth of the gear inside the device will have a downward force of 60 N applied to it to ensure the tooth shears at that force (measured in MPa).	Gear Tooth exceeds 60 N requirement
Ex4: Printing Calibration Tests	Two different commercial, entry level FDM printers (Creality's Ender 3 and the Bambu Lab A1) will be used for test printing to ensure little to no modification to the printer or STL files is required to print and assemble the device.	Minor calibrations to file needed, no printer modification necessary.
Ex5: Measurement Calibration / Tolerance Tests	Multiple rulers of the device will be printed and be compared to other standard measurements devices (rulers, calipers, etc.) to ensure the spacing on the print is accurate within that +/- 0.5 mm tolerance. The compressive springs will be attached to a test bench to ensure each compression is equal to 5 N by measuring the deflection of the spring based on a certain amount of weight.	Tolerance for Ruler: +/- 0.39 mm Tolerance for Spring: +/- 0.15 N

8.2 Detailed Testing Plan

8.2.1 Test 1: Mouthpiece Bending Stress Point

8.2.1.1 Summary

The focus for this test is to ensure the mouthpiece bridge will bend in a controlled manner when a load of 60 N is applied to it. This is to ensure the contact point between the device and the patient fails before causing any potential damage to the patient's teeth due to excessive bite

force. A load of 60 N was chosen as this is the most common amount of force applied by the jaw of Trismus patients before they reported issues with dental damage and pain. [1]

8.2.1.2 Procedure

The base of the mouthpiece is mounted to a testing bench that will secure it in place. Weights will be tied around the bridge of the mouthpiece to apply a total load of 60 Newtons.

8.2.1.3 Results

The result the team is looking for is for the mouthpiece to creep and bend once that load is reached, as shown in Figure 8.2.1. The total load applied before failure was calculated to be 55.4 N.

Fig 8.2.1: Mouthpiece after failure

8.2.2 Test 2: Spring Elongation Test

8.2.2.1 Summary

The focus of this test is to see the final stretching point of the compliant springs. This is to ensure the breaking point is within a certain value and to visualize the swiftness of the snap. Ideally, the failure point should not occur in a violent manner to ensure patient safety.

8.2.2.2 Procedure

A set of 7 springs were tested on an elongation machine, with the machine slowly spreading both ends apart. Data was recorded on a computer that was linked to the elongation machine, giving us the data for each trial. An example of this procedure can be seen below.

Fig 8.2.2: Spring at static position

Fig 8.2.3: Spring during elongation

8.2.2.3 Results

The results of the tests can be seen below in the following graph. The compiled data shows an average of 7 N being required to snap the compliant spring.

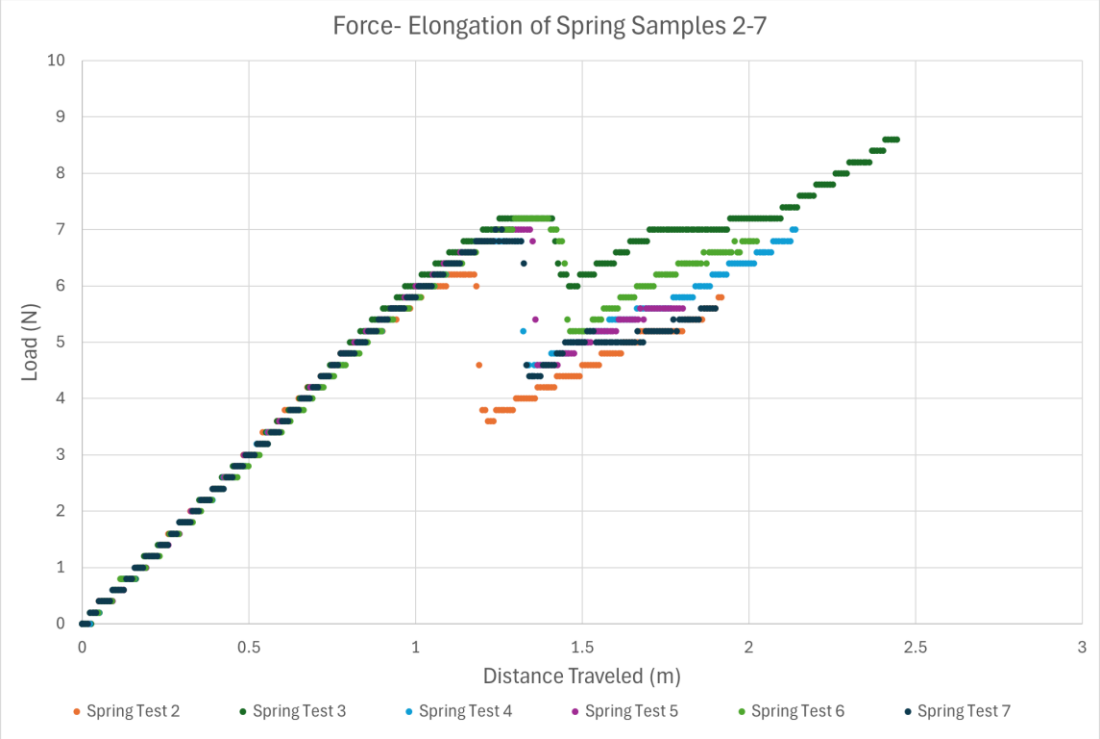


Fig 8.2.4: Force – Elongation Graph

8.2.3 Test 3: Gear Shear Test

8.2.3.1 Summary

The gear shear test is a calculation-based test as failure of the mouthpiece was considered as having met the device failure requirements.

8.2.3.2 Procedure

Calculations were performed at 30 N of force for both the bottom and top part of the mouthpieces and yielded the results that the gear would survive and not shear under the ultimate tensile stress from the horizontal print findings (33.15 MPa).

8.2.3.3 Results

Our client has determined that due to the results of the mouthpiece failure, it is okay for the gear to not shear under 60 Newtons of force.

8.2.4 Test 4: Printing Calibration Test

8.2.4.1 Summary

To ensure any clinician across the United States can print the device with ease, we will be using various 3D printers that are advertised as hobbyist machines or for personal use to print out multiple copies of the device. This is to ensure that clinicians do not need to spend a lot of money for a high-end device and can instead print with an affordable FDM printer with no need for modifications.

8.2.4.2 Procedure

The team will print out 3 batches of TrisPrint devices on separate machines, a Bambu Lab A1, and a Creality Ender 3. Both machines are great entry level FDM printers that are widely available online through their respective retailers. Each batch will be printed using the same STL files and will be thoroughly inspected for quality assurance purposes, a focus on parts tolerance and print quality being the main points of inspection.

8.2.4.3 Results

The device was able to be printed on both devices, with minimal tweaking to the files or printer being required. Issues that initially stemmed from printing gave us great insight into tips and suggestions if a print fails as well as what a failed print looks like. This information will be featured in the operations / assembly manual.

8.2.5 Test 5: Measurement Calibration / Tolerance Test

8.2.5.1 Summary

To ensure clinicians can get proper measurements, the built-in measurement ruler and compressible springs will be tested to ensure their listed readings are accurate within +/- 0.5 mm and +/- 0.5 N respectively. The ruler has a range of 50 mm, with a resolution of 0.5 mm. The compressible springs are designed to emit 5 N worth of resistance to the jaw during active stretch exercises, allowing the patient to slowly regain muscle strength and flexibility in the jaw.

8.2.5.2 Procedure

Multiple rulers of the device will be printed and be compared to other standard measurements devices (rulers, calipers, etc.) to ensure the spacing on the print is accurate within that +/- 0.5 mm tolerance. The compressive springs will be attached to a test bench to ensure each compression is equal to 5 N by measuring the deflection of the spring based on a certain amount of weight.

8.2.5.3 Results

The results of this test indicate that our forms of measurement for our clinicians are accurate within that +/- 0.35mm and +/- 0.15 N tolerance range.

Fig 8.2.5: Ruler Measurements vs Caliper Measurement

8.2.6 Additional Test 1: Material Tensile Test

8.2.6.1 Summary

Using the same elongation machine from test 2, 7 sets of "dog bone" elongation test samples were pulled apart to see the difference in yield stress based on the layer lines of the print. The first set of 7 were printed vertically, while the second set were printed horizontally.

8.2.6.2 Procedure

Each set of 7 test samples were placed into the elongation machine and pulled apart until failure. The computer recorded the data and allowed us to plot out the failure point of the material and compare it to the given data from the manufacturer's specification sheet.

8.2.6.3 Results

The results of this test indicate that the horizontal layer lines were stronger overall, lasting until roughly ~340 N until failure. The vertical tests failed at the 120 N mark. When solving for the ultimate yield strength, we saw that the yield strength after being printed horizontally was roughly 75% the listed yield strength from the manufacturer (33.1 MPa from the tests and 44 MPa from the technical data sheet).

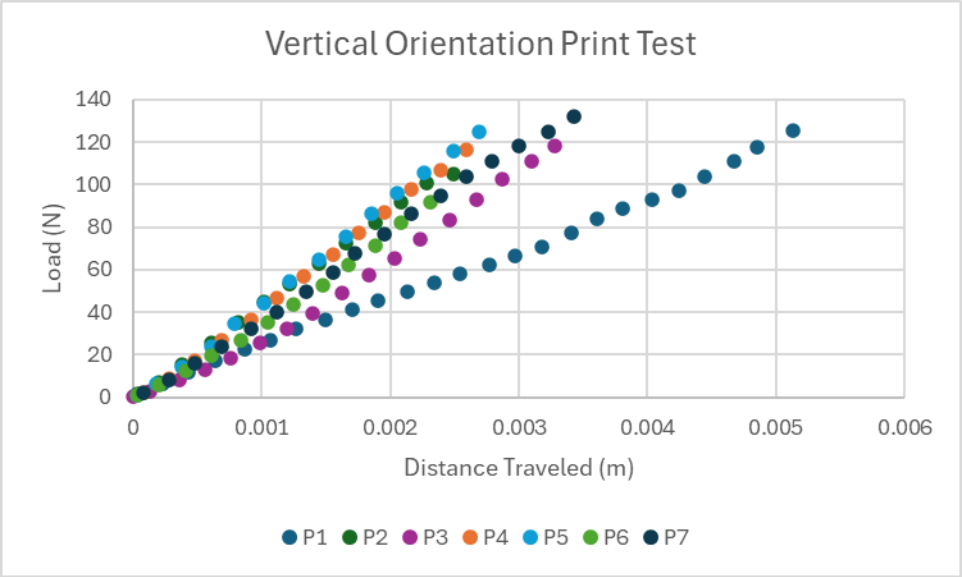


Fig 8.2.6: Vertical Orientation Test Results

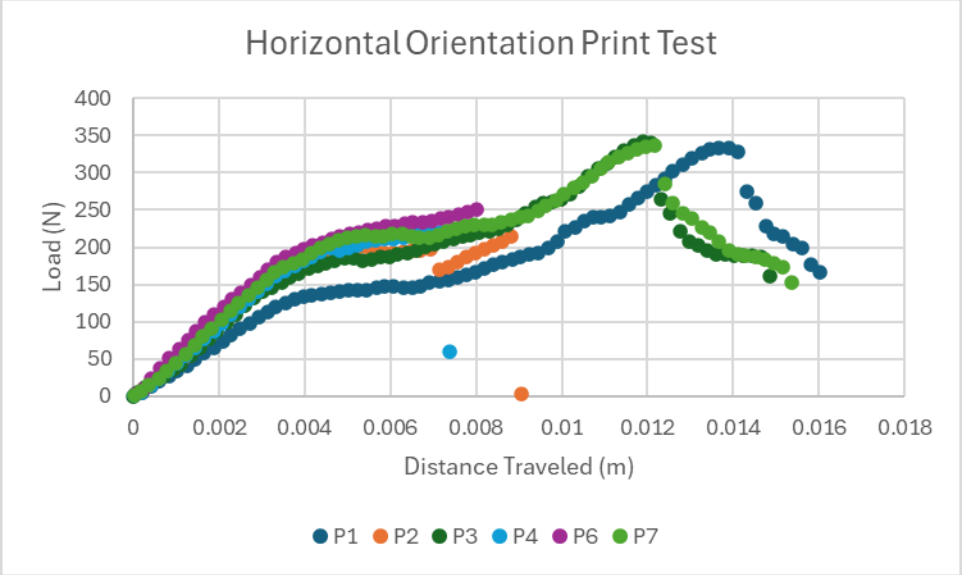


Fig 8.2.7: Horizontal Orientation Test Results

8.2.7 Additional Test 2: Model Skull

8.2.7.1 Summary

A 3D printed skull had 4 screws attached to both sides of the temples and jawbone which allowed us to attach rubber bands between the two points. This allowed us to replicate the sensation of the jaw muscles on the skull to get a better understanding of how a patient would use the device.

8.2.7.2 Procedure

4 screws were inserted into the previously mentioned 4 points on the skull. The rubber bands that were attached to each side applied roughly 2 N worth of force. The jaw was opened up to a 6 mm incisor gap before the device was inserted.

8.2.7.3 Results

The tests gave the team a good feel for device ergonomics and functionality with a makeshift patient. The device was able to withstand 30 N that the jaw was applying during normal operation.

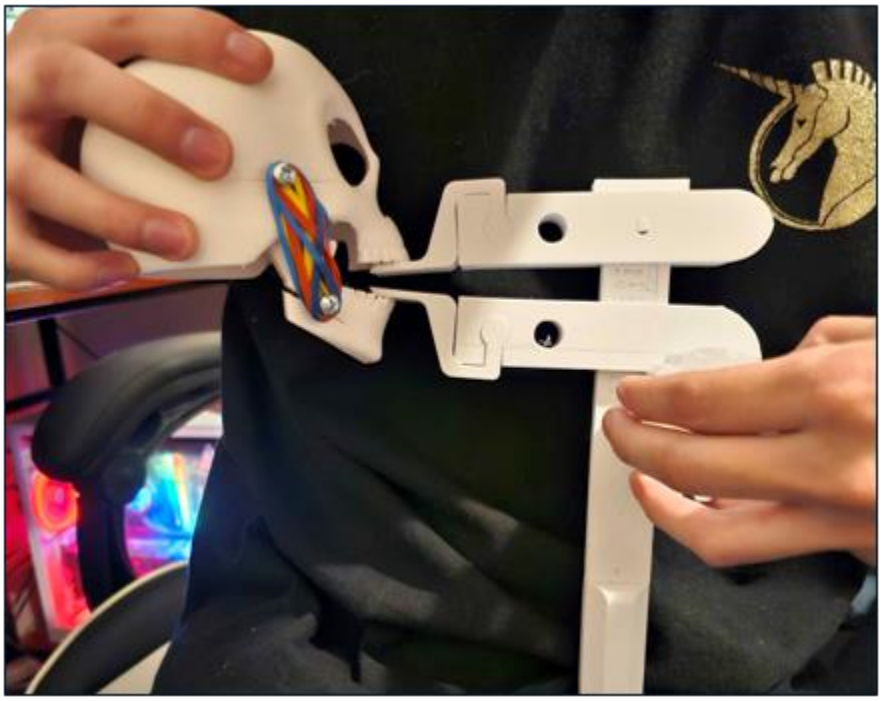


Fig 8.2.8: Skull and Device Demonstration

9 Future work

The next major step for this project would be to start the initial set of patient trials. Steps towards this next major goal have been initiated, though due to time constraints we were unfortunately unable to begin patient trials. Ideally, the patient trials would assist in receiving major feedback with regards to the device's feel, functionality, and any overall changes that could be made towards the TrisPrint device.

The steps that have been taken include the submission of the invention form for Dignity Health and the final report for the IRB (Institutional Review Board) that would oversee the clinical trials. Due to the nature of the approval process, we were not able to fit these clinical trials into the latter end of this year long project.

10 CONCLUSIONS

The Trismus treatment device is designed with Dr. Rebecca Bartlett and Carolyn Abraham from Dignity Health Phoenix. This device is to be entirely 3D printed, allowing for easy replication and reproduction of the design, safe (with regards to material use and strength tolerances) for the patient and the device, and have each unit cost $50 or less to produce. The device must be able to measure incisor displacement and force application from the jaw to the device. With these features, clinicians and researchers will be able to replicate an affordable device for patient research and treatment.

Our final solution is to utilize PCTG filament to print out the entire CAD package and publish the files and instructions alongside a full report of the device. This way, clinicians across the United States can find this article with the included files and instructions and be able to replicate it with relative ease for their patients. The provided instructions will showcase how to set up a 3D printer, materials necessary, printing instructions, assembly instructions, and part tolerances and materials tested to be considered safe in this device's use. A disclaimer stating that further modification of the device beyond its intended and tested tolerances is at the risk of the clinician/researcher and not the designers will be added to encourage safe use.

11 REFERENCES

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12 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report.]

12.1 Appendix A: Prototypes and CAD Modeling

Figure A1: Prototype 1- Motion and Scale

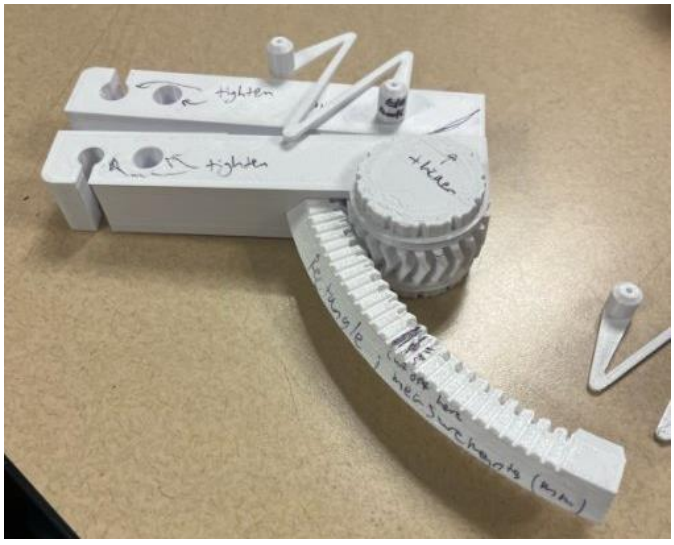


Figure A2: Prototype 2 - Gear Motion

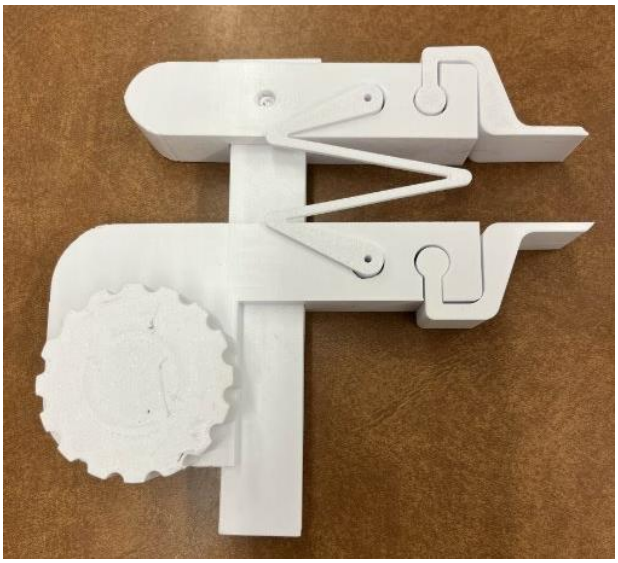


Figure A3: Prototype 3 - Full Tolerance and Motion

12.2 Appendix B: Initial Designs and Benchmarking

Figure B1: Therabite

Figure B2: Unique

Figure B3: In House Treatment

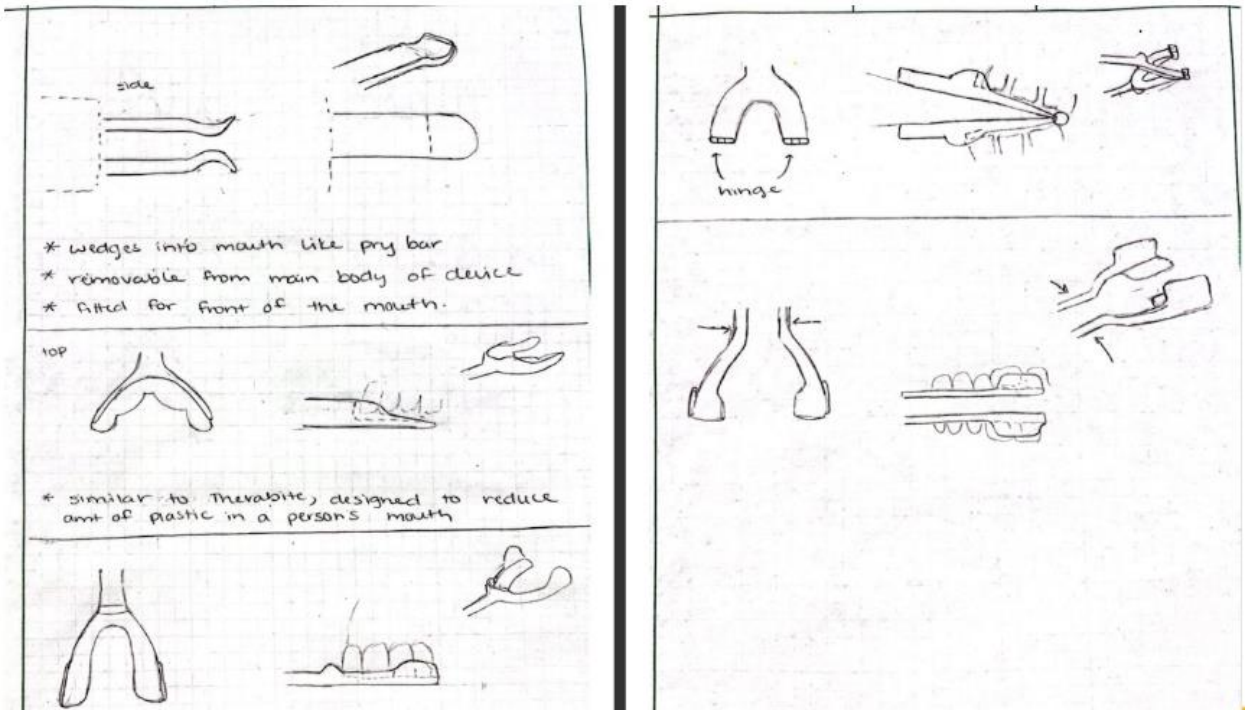


Figure B4: Mouthpiece Initial Designs

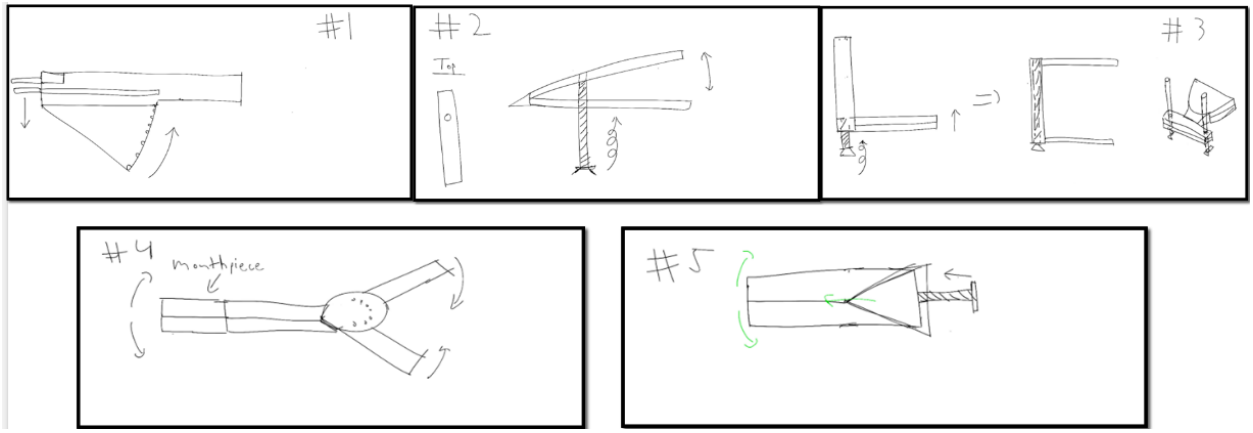


Figure B5: Mechanical Motion Initial Designs

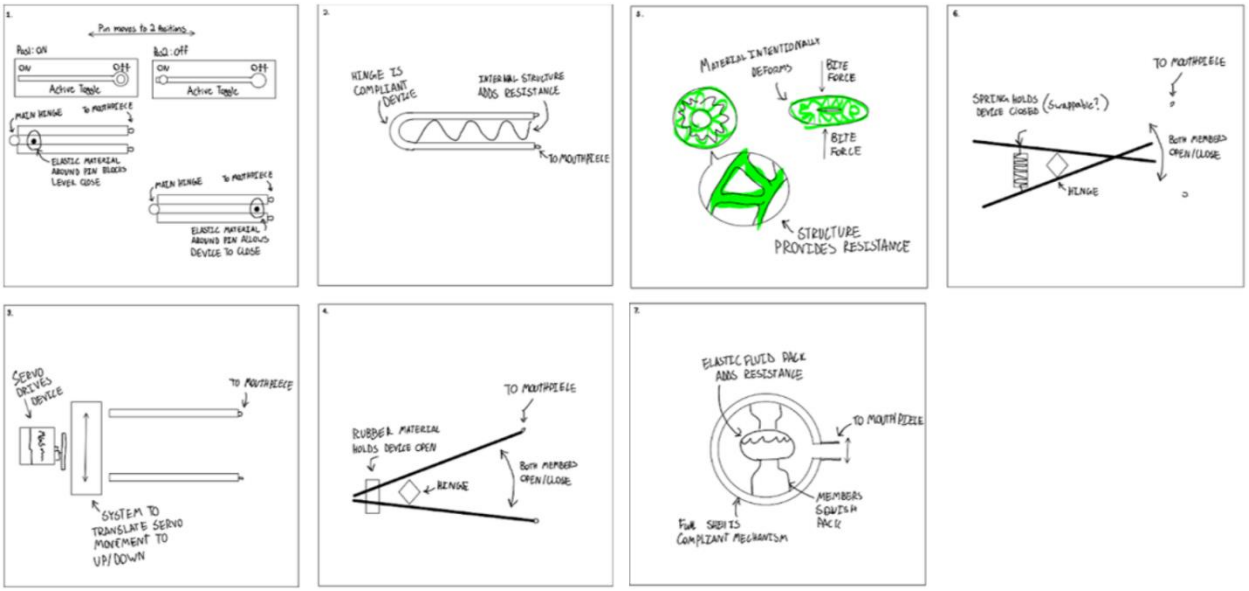
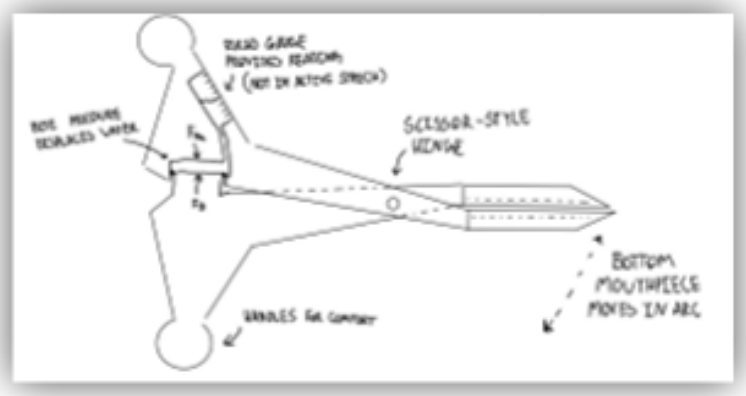
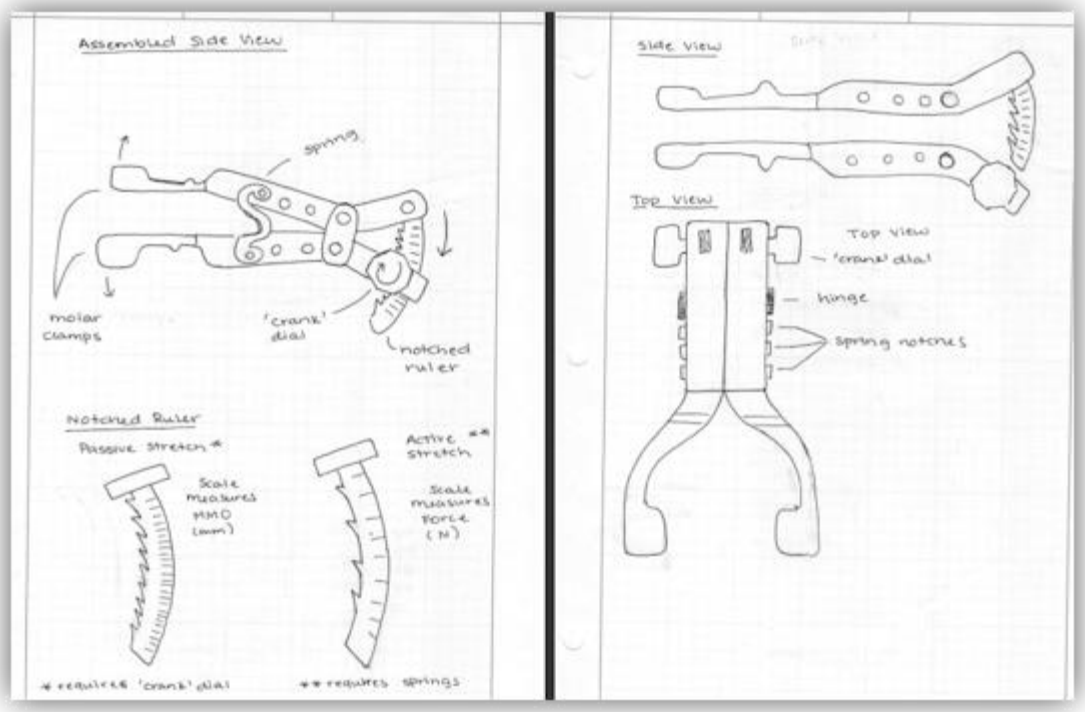
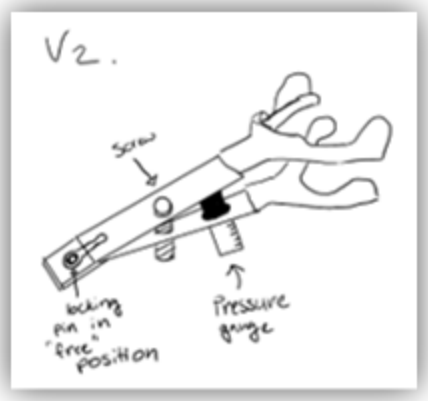
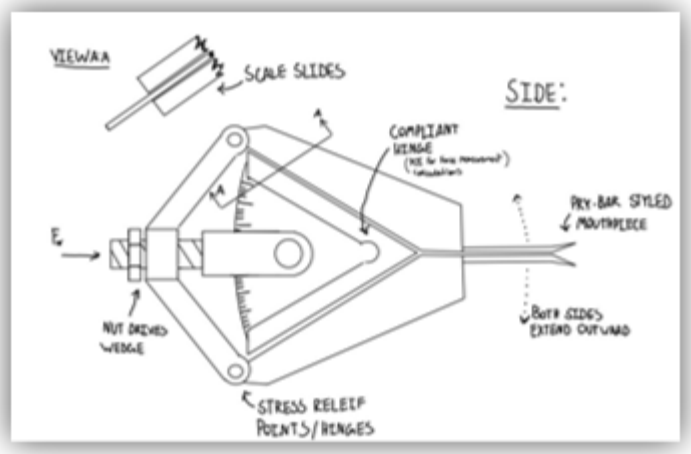


Figure B6: Active Resistance Initial Designs




Assembled Side View
spring
molar clamps
'crank' dial
notched ruler
Notched Ruler
Passive stretch *
Scale measures MMO (mm)
Active stretch **
Scale measures force (N)
* requires 'crank' dial
** requires springs
Side View
Top View
Top View
'crank' dial
hinge
spring notches


V2.
screw
locking pin in 'free' position
Pressure gauge


VIEW AA
SCALE SLIDES
SIDE:
COMPLIANT HINGE
PRY-BAR STYLED MOUTHPIECE
NUT DRIVEN WEDGE
BOTH SIDES EXTEND OUTWARD
STRESS RELIEF POINTS/HINGES

12.3 Appendix C: Spring 2024 Gantt Chart

Project Management				
Purchasing Plan	Shilo Bailey	100%	8/26/24	8/31/24
Reflection	Nathan Bastidas	100%	8/26/24	8/31/24
Gantt Chart/Top Level Finances	Cassina Olson	100%	8/26/24	8/31/24
Manufacturing Plan	Carter Rhoades	100%	8/26/24	8/31/24
Clarify Expectations and Sign	Team	100%	8/26/24	8/31/24
First Client Meeting	Team	100%	9/4/24	9/4/24
Engineering Calculations				
Budget/TVM/IVP	Shilo Bailey	100%	9/10/24	9/18/24
QFD / Format	Nathan Bastidas	100%	9/10/24	9/18/24
Intro/hook/problem/benchmark/	Cassina Olson	100%	9/10/24	9/18/24
C and E requirements/ scheduling	Carter Rhoades	100%	9/10/24	9/18/24
Lit reviews; mathematical modelling	Team	100%	9/10/24	9/18/24
Hardware Status Update 33%				
Suite of Potential Solutions (Alt Designs)	Team	100%	9/18/24	9/30/24
BoM/Concept Eval.	Nathan Bastidas	100%	9/18/24	9/30/24
Intro/project desc./concept generation (on alt designs)	Cassina Olson	100%	9/18/24	9/30/24
Engineering Calculations/CAD (Spring,Body)	Carter Rhoades	100%	9/18/24	9/30/24
Schedule/Budget/CAD (Ruler, Mouth Guard)	Shilo Bailey	100%	9/18/24	9/30/24
Website Check 1				
Ch 1	Shilo Bailey	100%	9/18/24	3/16/24
Ch 3	Nathan Bastidas	100%	9/18/24	3/16/24
Ch 4	Cassina Olson	100%	9/18/24	3/16/24
Ch 2	Carter Rhoades	100%	9/18/24	3/16/24
Lit reviews; mathematical modelling	Team	100%	9/18/24	3/16/24
Hardware Status Update 67%				
Documents	Shilo Bailey	100%	10/1/24	10/17/24
Project Description	Nathan Bastidas	100%	10/1/24	10/17/24
Gallery	Cassina Olson	100%	10/1/24	10/17/24
About Us	Carter Rhoades	100%	10/1/24	10/17/24
Pictures	Team	100%	10/1/24	10/17/24
UGrads				
Jaw Stresses	Shilo Bailey	100%	10/7/24	10/24/24
Material Stress	Nathan Bastidas	100%	10/3/24	10/24/24
Dental	Cassina Olson	100%	10/3/24	10/24/24
Lever Tolerances	Carter Rhoades	100%	10/3/24	10/24/24
Formatting	Team	100%	10/3/24	10/24/24

Draft of Poster				
Schedule & Budget / CAD Model	Shilo Bailey	100%	10/10/24	10/31/24
Design Requirements / Engineering	Nathan Bastidas	100%	10/10/24	10/31/24
Design Validation / Project Description	Cassina Olson	100%	10/10/24	10/31/24
Design Description / CAD Model	Carter Rhoades	100%	10/10/24	10/31/24
Come up with FMEA ideas	Team	100%	10/10/24	10/31/24
Finalized Testing Plan				
Schedule & Budget / Background	Shilo Bailey	100%	10/11/24	11/1/24
Requirements / Conclusions	Nathan Bastidas	100%	10/11/24	11/1/24
Research Within Design Space	Cassina Olson	100%	10/11/24	11/1/24
Design Concepts / Design Validation	Carter Rhoades	100%	10/11/24	11/1/24
References, Appendices	Team	100%	10/11/24	11/1/24
Hardware Status Update 100%				
Mechanics of Notched Ruler	Shilo Bailey	100%	10/17/24	11/7/24
Molar Mouthpiece	Nathan Bastidas	100%	10/17/24	11/7/24
Molar Mouthpiece	Cassina Olson	100%	10/17/24	11/7/24
Mechanics of Notched Ruler	Carter Rhoades	100%	10/17/24	11/7/24
Submission / Drawings	Team	100%	10/17/24	11/7/24
Final Poster and Final PPT				
Explain CAD	Shilo Bailey	100%	10/27/24	11/17/24
Methods and Results	Nathan Bastidas	100%	10/27/24	11/17/24
Explain Mouthpiece	Cassina Olson	100%	10/27/24	11/17/24
Explain CAD	Carter Rhoades	100%	10/27/24	11/17/24
	Team	100%	10/27/24	11/17/24
Initial Testing Results				
Set up Testing Benches	Shilo Bailey	100%	10/31/24	11/21/24
Experiment Testing	Nathan Bastidas	100%	10/31/24	11/21/24
Experiment Testing	Cassina Olson	100%	10/31/24	11/21/24
Results / Part Preparation	Carter Rhoades	100%	10/31/24	11/21/24
Formatting	Team	100%	10/31/24	11/21/24
Final CAD Packet				
Toleranced Parts	Shilo Bailey	100%	11/1/24	11/22/24
Solidworks Files and STLs	Nathan Bastidas	100%	11/1/24	11/22/24
Solidworks Files and STLs	Cassina Olson	100%	11/1/24	11/22/24
Solidworks Drawings	Carter Rhoades	100%	11/1/24	11/22/24
	Team	100%	11/1/24	11/22/24

Final Testing Results				
Aquire Testing Appartus	Shilo Bailey	100%	11/6/24	11/27/24
Results / Part Preparation	Nathan Bastidas	100%	11/6/24	11/27/24
Results	Cassina Olson	100%	11/6/24	11/27/24
Clarify Effects of 3D printing on test parts	Carter Rhoades	100%	11/6/24	11/27/24
Formatting	Team	100%	11/6/24	11/27/24
Final Report				
Budget/TVM/IVP	Shilo Bailey	100%	11/12/24	12/3/24
QFD / Format	Nathan Bastidas	100%	11/12/24	12/3/24
Intro/hook/problem/benchmark/	Cassina Olson	100%	11/12/24	12/3/24
C and E requirements/ scheduling	Carter Rhoades	100%	11/12/24	12/3/24
Lit reviews; mathematical modelling	Team	100%	11/12/24	12/3/24
Final Website Check				
Formatting and Design	Team	100%	11/13/24	12/4/24
Update Documents	Nathan Bastidas	100%	11/13/24	12/4/24
Update Text	Cassina Olson	100%	11/13/24	12/4/24
Update CAD on website	Carter Rhoades	100%	11/13/24	12/4/24
Update Screenshots	Shilo Bailey	100%	11/13/24	12/4/24
Operation/Assembly Manual				
CAD	Shilo Bailey	100%	11/13/24	12/4/24
quality assurance/ data confirmation	Nathan Bastidas	100%	11/13/24	12/4/24
Warnings/disclaimers/description	Cassina Olson	100%	11/13/24	12/4/24
CAD	Carter Rhoades	100%	11/13/24	12/4/24
			11/13/24	12/4/24
Final Product Demo				
Explain CAD	Shilo Bailey	100%	11/13/24	12/4/24
Methods and Results	Nathan Bastidas	100%	11/13/24	12/4/24
Methods and Results	Cassina Olson	100%	11/13/24	12/4/24
Explain CAD	Carter Rhoades	100%	11/13/24	12/4/24
	Team	100%	11/13/24	12/4/24
Expo PPT and Poster Pres/Delivery				
Jaw Stresses	Shilo Bailey	100%	11/13/24	12/4/24
Material Stress	Nathan Bastidas	100%	11/13/24	12/4/24
Dental	Cassina Olson	100%	11/13/24	12/4/24
Lever Tolerances	Carter Rhoades	100%	11/13/24	12/4/24
Formatting	Team	100%	11/13/24	12/4/24

Client Handoff				
Clarify Expectations and Sign	Shilo Bailey	0%	12/1/24	12/4/24
Clarify Expectations and Sign	Nathan Bastidas	0%	12/1/24	12/4/24
Clarify Expectations and Sign	Cassina Olson	0%	12/1/24	12/4/24
Clarify Expectations and Sign	Carter Rhoades	0%	12/1/24	12/4/24
Clarify Expectations and Sign	Team	0%	12/1/24	12/4/24