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Biomedical Engineering
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VetMed: Affordable Muzzle to Assist in Mandibular Fracture Repair in Dogs

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BME 200/300: Biomedical Engineering Design

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Abstract

A common injury seen in canines is the fracture of the mandible. Currently, there are several different techniques used to treat these fractures, both invasive and non-invasive. The standard non-invasive method of treatment is a tape muzzle, as shown in Figure 1, that helps to stabilize the fracture up to and after surgery. However, the tape muzzle can cause further displacement of the fracture site due to the pivot point it generates. The surgery that follows is typically costly and most patient owners cannot afford this course of treatment. Our client, Dr. Thatcher, asked our team to utilize principles of cantilever bridge mechanics to design a nylon muzzle that provides adequate support and evenly distributes the bite forces in the jaw to aid in proper healing. We then needed to quantitatively prove that the new muzzle design is superior to the tape muzzle. After extensive research, the team developed three designs that met the design requirements specified by our client. These designs were then evaluated using a design matrix against criteria developed by the team. After evaluation, we decided to focus on the mesh design. Using this design, we created a model of a canine jaw in SolidWorks and carried out finite element analysis to analyze the stress distribution across the mandible. It was determined that peak stress decreased from 8.07 MPa with no support and 8.12 MPa with the tape muzzle to 0.821 MPa when fully supported. These calculations allowed us to prove a statistically significant effectiveness of the new muzzle design for canine mandibular fracture support.

Figure 1: Tape muzzle design

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1. Introduction

1.1: Motivation, Global and/or Societal Impact

Mandibular fractures in canines are a costly injury that have many forms of non-invasive and invasive treatment. These fractures are common and make up 1.5 to 3 percent of all fractures in canines [1]. With the current treatment options, oftentimes surgery and several anesthetic events are required in order to heal the fracture. These surgeries can range anywhere from 1000 to 2000 dollars, and in certain cases pet owners cannot afford to have their animal undergo surgery [2]. This can be detrimental to the canine leading either to improper fracture healing or in some cases euthanization.

Treatment options include internal fixation and wiring combined with a tape muzzle to stabilize the fracture. Currently, tape muzzles are the standard non-invasive treatment for mandibular fracture repairs in canines. Their main purpose is to stabilize the fracture up to and after surgery, but because of the placement, tape muzzles have been known to cause a pivot point around the fracture site that can lead to further displacement of the fracture. More common, commercially available, nylon muzzles on the other hand can provide an alternative to surgery or provide greater stability before and after surgery by distributing the bite forces of a canine mandible more evenly than that of a tape muzzle.

Our client, Dr. Thatcher, believes that nylon muzzles are the superior treatment option for mandibular fracture repairs in canines. Quantitatively proving that nylon muzzles more evenly distribute the bite forces in the jaw and reduce the stress by 50% at the fracture site could result in these nylon muzzles becoming the standard treatment for canine mandibular fractures. This would eliminate costly surgeries and improve the comfort and quality of life of the injured canine.

1.2: Existing Devices/Current Methods

The standard treatment for a mandibular fracture in canines is the tape muzzle. This method is meant to stabilize the fracture up to and after surgery by wrapping around the snout. The typical placement of this stabilizing device has the tape sitting directly over the fracture site with a gap of 0.5 cm to 1 cm between the top and bottom jaw [1].

There are nylon muzzles that are commercially available, most of them being meant for recreational use and not to treat fractures. There are thousands of patents for these commercial muzzles, most of them aimed to improve the comfort for the dog. One particular patent, number 5299531, aims to improve the breathability while ensuring the stability of the muzzle is not compromised [3]. While another patent, number US D659,303 S, has a more rigid body in order to improve the security of the muzzle [4]. These muzzles do provide more stability throughout the entire jaw; however, further research is needed in order to ensure the support offered by these muzzles is adequate to treat mandibular fractures.

Tape muzzles, which are the most widely used treatment option, create a pivot that can cause further displacement. Commercial muzzles, while they are useful in restraining canines, are not fit to be used in a medical setting. By looking at these factors there is a clear gap in treatment options leaving the opportunity for our team to develop a nylon muzzle that is suitable for medical treatments.

1.3: Problem Statement

In veterinary medicine there is a gap in treatment options for mandibular fracture repairs in canines. The current treatments available require costly surgeries and the tape muzzles that are used to stabilize the fracture up to and after surgery can displace the fracture further. In order to reduce costs and improve the quality of care, our client would like the team to design an improvement upon nylon muzzles using principles of cantilever and suspension bridge construction that can be used as an alternative to the standard treatment options. Using finite element analysis, the team will compare the stress that the improved nylon muzzle places on the fracture site compared to the standard tape muzzle. The muzzle must be able to withstand bite forces of 620.33-1,091.1 N and evenly distribute those forces throughout the jaw [5]. Through these tests the team must quantitatively prove that nylon muzzles are the superior treatment option when dealing with mandibular fracture repairs in canines by reduction of the stress in the mandible by approximately 50%.

2. Background

2.1: Background Research

2.1.1: Relevant Physiology and Biology

In canines, mandibular fractures make up approximately 90% of maxillofacial trauma injuries (injuries relating to the jaw or face). These fractures most commonly occur at the mandibular carnassial tooth, also called the M1 tooth (labeled in Figure 2 below). The M1 tooth is the tooth with the largest volume, resulting in the largest force applied to the mandible during a bite [6]. Fracture under the M1 tooth can occur in two general patterns: favorable and unfavorable. Favorable patterns are characterized by the distal end of the mandible lying above the fracture, and the fracture being under compression as the masseter contracts. The masseter is the muscle that runs through the rear part of the jaw on each side and is responsible for opening and closing the jaw. An unfavorable fracture occurs in the opposite direction, and the fracture will pull apart during a bite [G. Thatcher, personal communication, September 25, 2020]. A cadaver mandible with the direction of force by the masseter and types of fracture patterns can be seen in Figure 2.

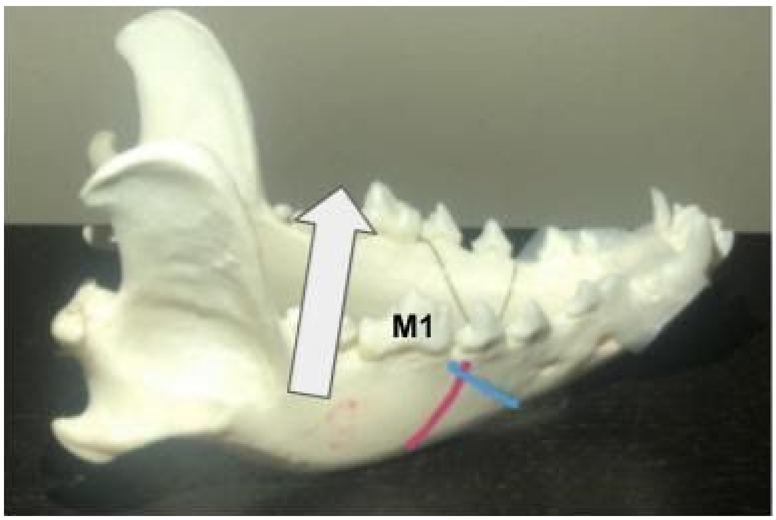


Figure 2: Canine mandible, with favorable fracture pattern in Blue and unfavorable pattern in Pink. White arrow represents the direction of contraction of the jaw. The fracture most often occurs at the M1 tooth.

Bite forces at the carnassial tooth, found through finite element analysis, can range from 620.33-1,091.1 N. The bite force for the dogs can vary based on the size and skull shape of the dog. Bite force will increase as the size of the dog increases. Also, long-headed dogs with dolichocephalic skull shapes (such as the greyhound) have increased bite force compared to broader wide-skulled dogs with brachycephalic skull shapes (such as the pug) [5].

2.1.2: Design Research

The current method to stabilize mandibular fractures before and after surgery is a tape muzzle. Our goal is to create an improvement from this method and provide quantitative evidence to support a new design. The tape muzzle has been taught to veterinary students, without its effectiveness in supporting the fracture being studied. The tape muzzle, seen in Figure 1, only provides rigid structure directly under the fracture site. Lack of support throughout the entire mandible could create a pivot point at the fracture, resulting in displacement of the fracture, increased healing time, and pain. The muzzle should have a 0.5 cm to 1.0 cm gap for drinking water and eating soft food, and since these are made individually, there may be difficulty for the owner to achieve this range. They are also only single use and must be replaced whenever they get dirty.

There are also commercially available muzzles, created to limit barking or biting of dogs. These types of muzzles are designed to be put on and taken off easily, and provide greater range of contact under the mandible. Our design will be created for the purpose of increased support along the mandible. We have researched commercially available muzzles and talked with our client to determine requirements to implement, and we have created three initial designs to be evaluated.

2.2: Client Information

Our client, Dr. Graham Thatcher, is part of the Surgical Sciences at University of Wisconsin- Madison's School of Veterinary Medicine. In his experience, he has encountered many maxillofacial injuries in canines. He has expressed his displeasure with current teachings of the tape muzzle design and would like scientific evidence that shows other designs providing superior support for healing.

2.3: Design Specifications

Currently, the tape muzzle used in the treatment and recovery of mandibular fracture repair in dogs is insufficient in evenly distributing the biting forces throughout the mandible. Our alternative muzzle design must support the fractured mandible, while preventing stress concentration or displacement near the existing fracture site at the M1 tooth. A model must accompany the new muzzle design that validates a decrease in stress when compared to the existing tape muzzle options.

The main purpose of the design is to support and distribute the forces throughout most of the mandible's length, in contrast to the fulcrum point that is formed where the tape of the tape muzzle is wrapped around the dog's jaw. Compressive forces of the jaw can reach up to 5000 N depending on size, breed, and location within the mouth [7], and the bite force of the M1 tooth ranges from 620.33-1,091.1 N [5]. The dog must be able to carry out necessary functions such as eating soft food, drinking water, and panting. A gap of 0.5 cm to 1.0 cm (1.5 cm maximum) is sufficient in allowing the dog to perform these actions. The design needs to account for common complications of muzzles including moist dermatitis, aspiration of food, and hyperthermia due to possible impairment of panting [8]. The muzzle also must not disrupt blood flow to oral tissues, so the fracture can properly heal. The material used should be comfortable and minimize irritation to the dog's skin. The muzzle should be washable, so it is easy to clear away any build-up of dirt or bacteria that could lead to infection.

The design must support the jaw without loss of strength for at least 6 weeks when the jaw is stable. Canine dental fractures are reported to have functionally healed within as little as 2-3 weeks, with average healing time of 5.5 weeks [1]. Fractures often return to 90% of their original stiffness within 6 weeks [9], at which time the dog is able to resume normal activities without risking further damage to the mandible. The design should be able to accommodate dog's of different breeds, shapes, and sizes. It will be made in three different size variations (small, medium, and large), all of which will feature a breathable, lightweight, adjustable strap to allow the muzzle to properly fit and support the jaws of many different dogs.

3. Preliminary Designs

3.1: Zipper Muzzle

The first design considered was a nylon sleeve featuring zippers along the sides of the mouth (Figure 3). It bears a great resemblance to many commercial nylon slip on muzzles, save for the added zippers. The zippers can open and allow more movement. There will also be a thin mesh layer underneath the zippers in order to add more support and prevent fur from catching on the zippers (Figure 3). If the muzzle is to be a long term treatment alternative to more expensive surgical procedures, the extra movement will allow convenient drinking and eating.

The typical nylon sleeve muzzle's support has also been improved through the addition of sewn in battens. Due to the request of the client for further support in mandibular fractures, there will be 3D printed battens running laterally through the nylon, reminiscent of the battens in a corset or sail. To aid in comfort and prevent wearing on the dogs skin, the team has considered padding the areas with foam. However, that may lead to a possible breathability issue.

The main material of this muzzle will be nylon due to its relatively strong and elastic fibers. Nylon would be able to withstand abrasions and more force than other synthetic materials such as polyester [10]. Though the nylon does have less moisture-wicking capabilities, it is washable.

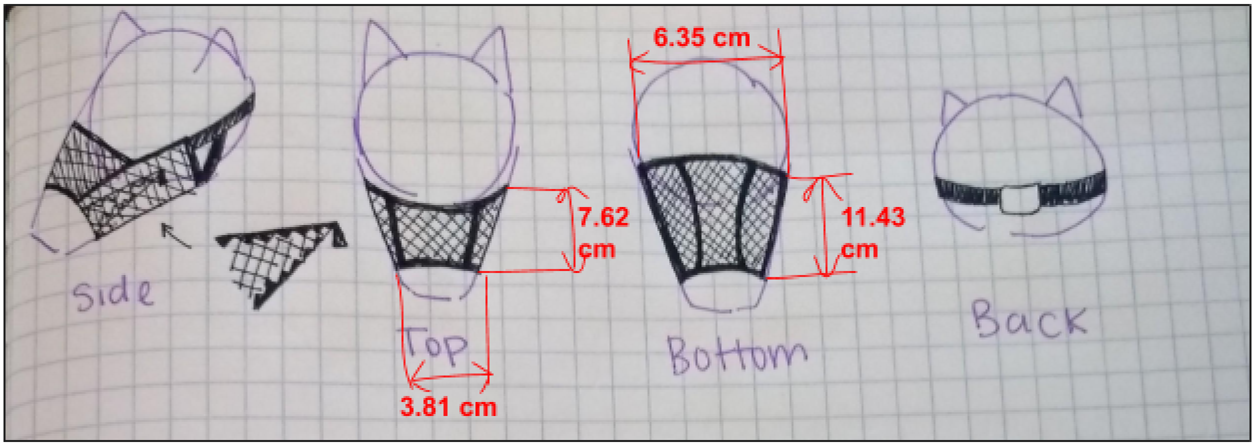


Figure 3: Preliminary zipper muzzle design. Views from left to right: side, top, bottom, and back. Measurements are based on mandible provided by the client.

3.2: Mesh and Nylon Muzzle

The second design used a combination of mesh and nylon materials. There will be two main panels of material; a reinforced nylon bottom panel and mesh top panel. The nylon piece will be laterally reinforced with batten supports running through the fabric. The mesh panel will be stitched to nylon straps. If possible, the nylon straps would have flexible battens also running through for added support. There will be an overhead strap which buckles to the back of the head (Figure 4). The size of the muzzle will vary with dog skull sizes though the maximum circumference will be no more than 12 inches (i.e. 30.48 cm). The muzzle is designed primarily for the use of long snouted dogs such as a labrador and are unsuitable for flat-nosed dogs.

The mesh's primary function is to allow better breathability for the dog. It will allow proper ventilation and prevent any build up underneath the muzzle that may lead to infections. The extra ventilation will also help counteract nylon's poor moisture wicking. The bite force of a dog is majorly affected by body weight and skull size. There is a lesser effect due to oral pain as well [5]. Thus as the dog heals and there is less oral pain due to the fracture, the mesh may not hold up to the forces. The nylon straps will help in supporting the muzzle even if the mesh were to rip. Further testing in SolidWorks will be needed in order to find the failure point of the mesh and nylon straps.

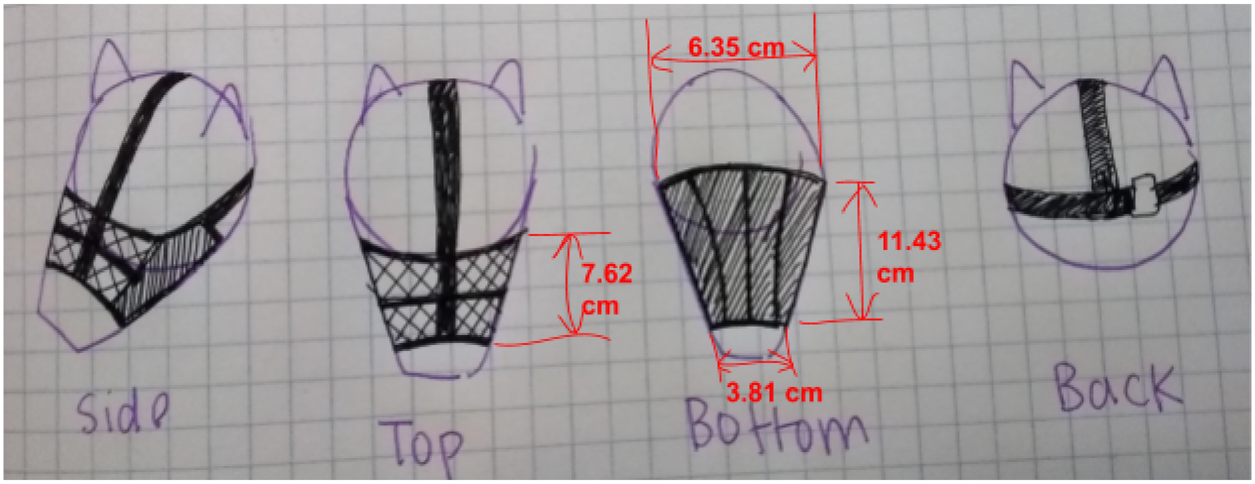


Figure 4: Preliminary mesh muzzle design. View from left to right: side, top, bottom,and back. Measurements are based on mandible provided by the client.

3.3: Molar Muzzle

The third design was the Molar Muzzle. There would be an over-the-top of the head strap oriented horizontally between the ears and the eyes, with a batten reinforced underside and single straps over the muzzle and behind the back of the head with a buckle. The underside of the muzzle would have significant gaps in its structure near the areas of where the molar fracture site would be, enabling this design to disperse the force evenly throughout the rest of the muzzle while avoiding force directly on the fracture site. There would be three distinct sizes of the muzzle, with the largest not being greater than 12 inches (i.e. 30.48 cm) in diameter.

The nylon used has an increased strength over that of tape, while also offering a greater ability to be adjusted. The over the top straps will stabilize both the mandible and the muzzle on the canine patient, which is further reinforced by the behind the skull buckle strap. The battens located on the underside of the muzzle will help to disperse the force evenly throughout the mandible bar the molar areas of the mandible. The thought process behind this was that if there was a fracture in that position, it would be wise to avoid putting significant force directly onto it. However, according to the client this design will likely only be beneficial for unfavorable fractures (Figure 2). This design would remove such a large amount of stress from the fracture site, that the bone would be unable to properly set. Bone healing is accelerated when both ends of the fracture are in contact with each other [12].

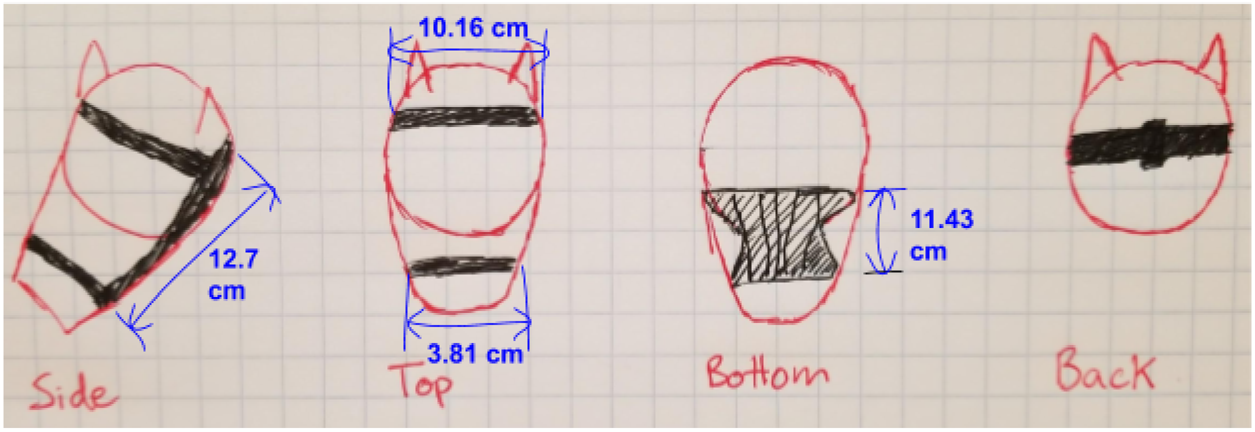


Figure 5: Preliminary molar muzzle design. Views from left to right: side, top, bottom, and back. Measurements are based on mandible provided by the client.

4. Preliminary Design Evaluation

4.1: Design Matrix

Table 1. Design matrix comparing the three designs

Designs Criteria (*weight)	Design One Zipper		Design Two Molar		Design Three Mesh		Existing Design Tape	
Safety (25)	9/10	22.5	4/10	10	9/10	22.5	3/10	7.5
Support (25)	8/10	20	6/10	15	8/10	20	0/10	0
Ergonomics (15)	7/10	10.5	5/10	7.5	8/10	12	1/10	1.5
Size (15)	8/10	12	6/10	9	7/10	10.5	5/10	7.5
Material (10)	9/10	9	9/10	9	9/10	9	2/10	2
Cost (5)	6/10	3	8/10	4	8/10	4	10/10	5
Usability (5)	8/10	4	5/10	2.5	7/10	3.5	3/10	1.5
Total (100)	**81**		**57**		**81.5**		**23.5**	

*Note: When referring to weight it is always *x/100*

Our design criterion weighed our three designs against the current tape muzzle. Safety and Support are the most important to the construction of our product. Safety is a major concern as it takes into consideration the inherent ability for the canine to be able to actually drink water and eat food in order to survive. Alongside this, factors such as not restricting blood flow to the mandible or the rest of the head and the ability to be machine washed as to aid in the prevention of bacterial growth in the space between fur and muzzle. The zipper design and the mesh design ranked the highest out of the three due to both of these designs including some type of nylon mesh that would reduce contact surfaces while remaining highly adjustable for the canine. The molar design is still inherently safe, but did not rank as high as a result of full pieces of nylon being used rather than mesh. Tape was ranked poorest out of all designs, since it often has problems with infection and is not adjustable so improper implementation can have harsh side effects.

Support was weighed on account of the ability of the muzzle to offer full and proper support of relevant force throughout the mandible, limiting side effects as much as possible. Once again, the Zipper and Mesh designs ranked highest in our criterion, offering relatively equal support between the two of them. The molar design, while initially ranking higher, was ranked lower than both of the other two new designs. This is due to some input that we received from our client, in that if the fracture is at a "favorable" angle, the design to distribute the forces elsewhere might actually end up hindering the healing of the fracture site. Simultaneously, if the fracture is at an "unfavorable" angle, this design likely offers superior support than that seen in a standard muzzle. A new design must be able to assist in healing for both fracture types. The tape offers relatively low if any support throughout the mandible and therefore received a zero.

Next in our criterion was Ergonomics, which takes into account the ability for the muzzle to be adjustable, breathable, and lightweight while taking into account support, comfort, and range of motion. The mesh design won out this criteria due to its focus on the nylon mesh, which would be far more breathable for the canine than any of the other 3 designs. The zipper design was ranked second since it also included some mesh details, but is primarily covered by the zipper. The molar design, having neither mesh nor zipper came in third, since it still offered support, comfort, and range of motion, but was likely not as breathable as the other two designs or as lightweight. The tape, since it offers no adjustability prevents almost all movement of the jaw in the patient and therefore scored the lowest on ergonomics.

Size of the muzzle was ranked equal in importance to ergonomics, and takes into account that the muzzle should not be oversized, remain flush to the surface it is on, and also should not have any major components sticking a significant distance off of the canine's skull, while also including adaptability, The zipper design accumulated the most points as it is the only design to offer not only adjustability in the back, but also adjustability in the front as well. The mesh design then ranked since it is flush with much less material used than the molar design, which was ranked below the mesh design. The tape muzzle, while being the smallest and closest to the canine out of all the designs, was downgraded for not taking adaptability into consideration.

We then weighed material as the next most important aspect. Materials should be non-toxic as well as non-abrasive, avoid metals as they are typically heavier and more rigid, and allow airflow for breathing and prevention of overheating. Since all three designs are going to be made of nylon, all ranked the same, although some designs will feature metal aspects such as a zipper, these are not vital parts of construction and do not weigh very heavily into consideration for this aspect of our criterion. Yet again, the tape was ranked the lowest since it neither allows for airflow and can be abrasive.

We then placed cost at a low weight because most of the materials we will be using are relatively inexpensive. With this accounted for, tape is obviously the cheapest option, with the molar and mesh designs then coming in second. The zipper design, due to its inclusion of a zipper, makes it the most expensive design that is featured and therefore caused it to be ranked the lowest.

Tied with cost was usability, also known as the ability for the product to be used by the owner of the canine patient. The design should not be overly difficult to get off or put on, nor should the adjustability of it be over complex, while remaining relatively easy to clean. The Zipper design was ranked the highest since the zipper would make it the easiest to get on and off of the canine. Then, the mesh design that features the vertically aligned over the head strap. The molar design was ranked the lowest since its horizontal head strap would likely cause trouble for the owner to put on. Tape was yet again ranked the lowest as it is not easy to put on.

4.2: Proposed Final Design

Our proposed final design is the Mesh design. The Mesh design ranked highest in 4 separate criterion categories while the Zipper ranked highest in 5, with the Mesh design only coming out on top by 0.5 points after weighting. Accordingly, we were considering a combination of the two designs. In the end, we decided not to add the zipper to our final design because it could easily cause complications in fabrication, and we wanted to be sure we could construct a final product. One addition to the proposed design was a thin layer of foam within the muzzle for comfort.

5. Fabrication

The final muzzle design featured top and bottom nylon panels and two side mesh panels (Figure 7). The mesh was chosen to increase the breathability of the muzzle for long-term use. However, the fabric chosen was a nylon-spandex blend and ended up too stretchy. This may result in future performance and support problems. Due to time constraints, the team went with the nylon-spandex fabric, but in the future would like to use a heavier weight fabric. Furthermore, nylon straps and a buckle were used to secure the muzzle to the dog. For added support, the muzzle also had 3D printed acrylic supports running laterally through the top and bottom nylon panels. Though the team initially decided on using polypropylene for the supports, due to time constraints and prices, the team moved forward with acrylic. For added comfort, foam was added around the supports of the muzzle. A full compilation of materials and prices can be found in Appendix E.

Figure 6. Final muzzle on skull.

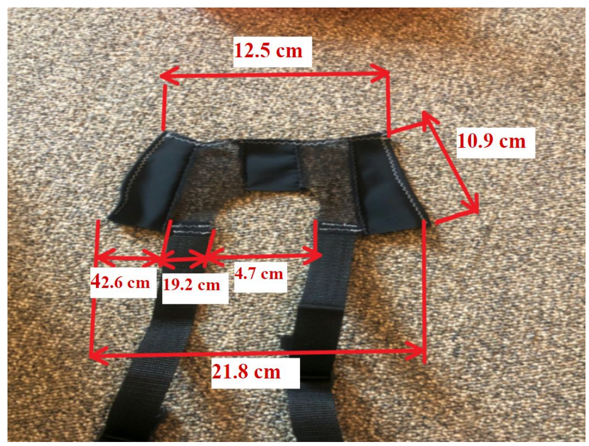


Figure 7. Flat layout of final muzzle with dimensions.

The muzzle was constructed in a conical shape. Three panels of nylon and 2 of mesh were cut out for the muzzle. The panels were sewn in alternating mesh and nylon. (Figure 8) The straps were sewn onto the mesh side panels in order to hook around the head securely and buckle in the back. The foam padding was also sewn directly over top the supports. The supports were 3D printed with the help of the Makerspace. All of the sewing was done by machine provided by one of the team members.

In order to obtain accurate dimensions for the muzzle, the team 3D scanned a skull provided by the client. Dr. Thatcher provided two medium-sized dog skulls for measurements and possible physical testing. Due to time and COVID restriction, no physical testing was done on the skulls provided. The 3D scans were then cleaned and processed in Meshmixer in preparation for finite element analysis (FEA) in SolidWorks (Figure 9). However, the files were too complex to perform FEA on and the team decided on creating an original simplified mandible design in SolidWorks.

Figure 8: 3D scan of mandible.

6. Testing

Initial calculations were performed by simplifying the mandible as a beam, and applying forces at each tooth to represent a biting force. The support forces are denoted as distributed loads across the bottom of the beam. The transition from mandible to simplified beam for the no support can be seen in Figure 9.

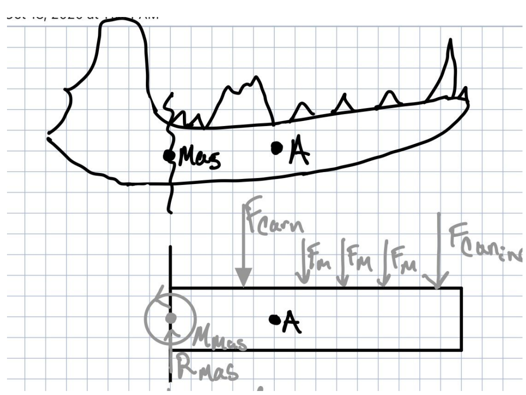
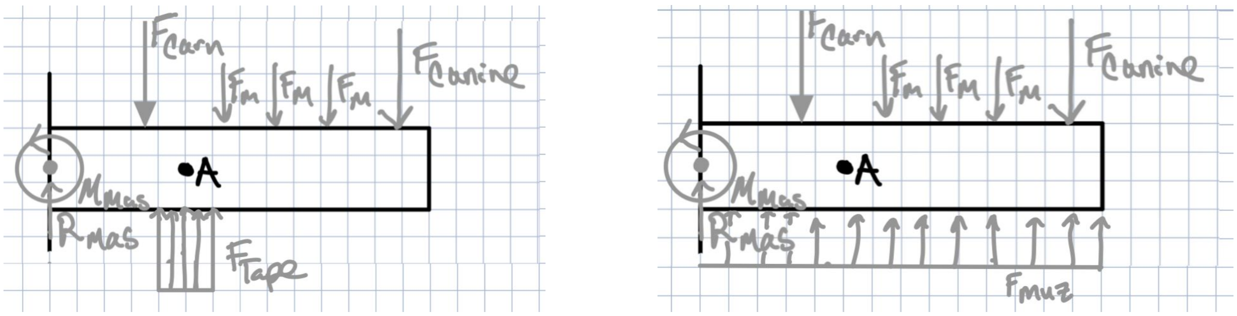


Figure 9: Jaw to simple beam estimation

The beam is simplified to having a cantilever joint at the masseter, which is the muscle which contracts the jaw. Under these forces, the jaw should be in static equilibrium. The beam has a uniform cross-sectional area of 1.75cm^2. Point A is the fracture site in the mandible, and the forces on each tooth relates to the forces given by S. E. Kim, et. al. Figure 10 displays the simplified beam for the tape support and fully supported designs.



a) *b)*

Figure 10: Beam simplifications for a) tape support and b) full support

These simple beams were used to calculate the shear, moment, and maximum stress point at the vertical line containing point A. The results can be seen in Table 2.

Table 2: Hand calculation results for shear, moment, and maximum stress at fracture

	Support Type		
	No Support	Tape	Full
Shear (N)	2224.8	566.85	106.3
Moment (Nm)	6.669	45.98	5.785
Max Stress (MPa)	74.66	51.46	6.48

These calculations display a much lower stress on the fracture when using a full support, compared to tape and no support. Full calculations can be found in Appendix B. Next, SolidWorks FEA will be done on a model to further confirm these results.

In order to quantitatively test that the nylon muzzle is superior to the standard tape muzzle the team performed FEA on a simplified canine mandible in SolidWorks. The simplified model loosely resembled the overall shape of one side of the mandible. The fracture was represented by an extruded cut near where the M1 tooth lies. The mechanical properties of bone were also inputted as a new material into SolidWorks and applied to the model [11]. These values are summarized in Table 2 below.

Table 3: Mechanical Properties of Bone

Shear Modulus	3300 N/mm²
Elastic Modulus	5650 N/mm²
Poisson's Ratio	0.62
Mass Density	2000 kg/m³
Tensile Strength	53 N/mm²
Compressive Strength	65.2 N/mm²
Yield Strength	44.1 N/mm²

After creating the model in SolidWorks finite element analysis could then be performed to simulate the stress concentrations at the fracture site for no support, tape support and full nylon muzzle support. In each test, the model was fixed at the joint location and 855 newtons, an average of the typical bite force range, was applied across the top of the mandible [5]. For the two tests with support, 855 newtons were applied where each muzzle's support is located, equal and opposite to that of the bite force. The tape muzzle provides support centered directly below the fracture site, while the nylon muzzle provides support across the entire bottom of the mandible.

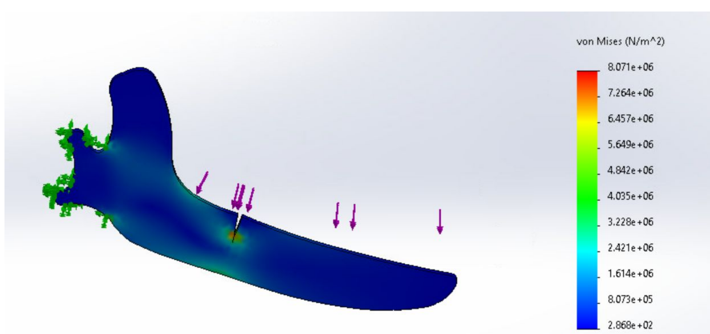


Figure 11: FEA of mandible with no support

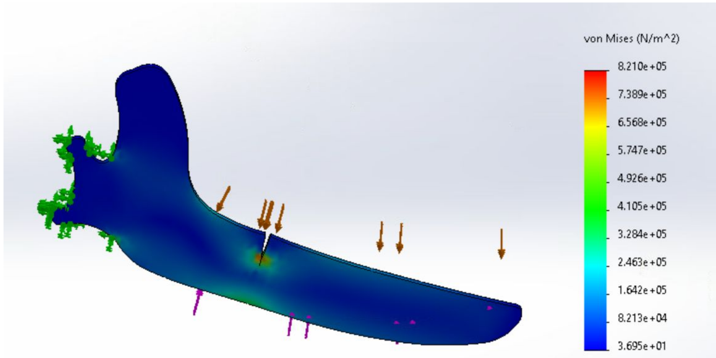


Figure 12: FEA of mandible with full support

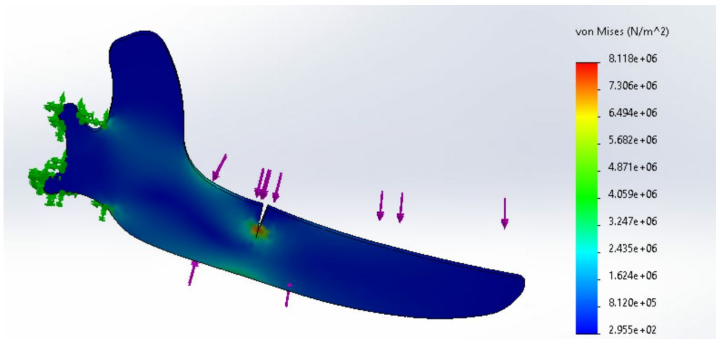


Figure 13: FEA of mandible with tape support

After the fixtures and forces were set, the simulation was conducted. Each simulation automatically generated a scale that depicts the stress values seen throughout the mandible, the top value being the maximum stress calculated. Using the probe tool ten points were randomly selected around the fracture site for further analysis. The values selected represent the varying stress values around the fracture site, with the areas of higher stress directed more closely to the apex of the fracture. A detailed testing protocol can be found in appendix F.

7. Results

Initial results on the jaw model were completed in SolidWorks. The data collected with the probe tool is immediately used for finding a sum, maximum and minimum values, mean, and root square mean. The maximum values are seen on the scales of Figures 7-9, and are noteworthy, as the stress is maximum at the fracture site. The maximum stress for each support type, along with the average stress for points samples around the fracture site are summarized in Table 4.

Table 4: Summary table for Maximum and Average Stress in SolidWorks Model

	Support Type		
	No Support	Tape	Full
Maximum Stress (MPa)	8.07	8.12	0.821
Average Stress (MPa)	5.35	5.41	0.483

When comparing the different types of jaw support undergoing the bite force in FEA, there was a large drop between the full support versus the other conditions. The full support experienced an 89.8% decrease compared to no support, and a 89.9% decrease compared to tape support. A similar change was found between the average stresses. A fully supported mandible had a 91.0% and 91.1% decrease versus no support and tape support, respectively. The tape support increased the maximum and average stress 0.62% and 1.12%, respectively, compared to without any support.

The data was then exported to Matlab for additional analysis. The ten values collected for each condition were loaded and a box plot for the stress around the fracture site was created. The box plot can be seen in Figure 14.

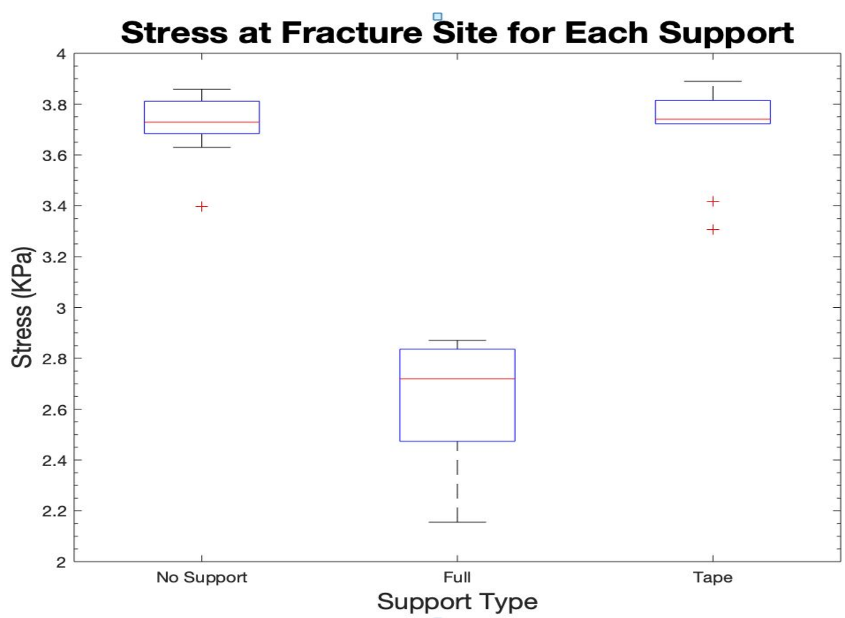


Figure 14: Box plot of stress under various support types

As seen in the box plot, the no support and tape support each had low extreme values. This is the result of that randomly selected point being further away from the fracture site compared to the rest of the data. However, even these extrema values are approximately 0.5 KPa above the largest value for the full support.

Next, a one-way ANOVA test was conducted. This test confirmed that at least one support method was significantly different from the others, with a resulting $p<<0.001$. By inspection, the different group is a full support method.

Testing for a difference in means was then completed by directly comparing each of the methods. The initial significance level was set to $\alpha=0.05$. The results found a significant difference in the mean between both the tape and no support, each with a p-value$<<0.001$. This p-value was also significant under a bonferroni corrected α. The difference in means between no support and the tape support was not significantly different. SolidWorks random probing and analysis, along with full Matlab code can be found in Appendix D.

8. Discussion

The testing and data analysis implies that our product, as well as other nylon muzzles on the market, offer superior support than that found in tape muzzles. If our findings are to be corroborated, the implications are that a nylon muzzle could alter the current common medical practice. There exists a potential to better the current treatment of a tape muzzle enough that a significant reduction in the need for surgery could be observed. This would then lead to not only a better state of living for the patient, but a substantial decrease of financial strain on the patient owner. The team has taken into consideration the ethical implications of the project throughout the fabrication of our design. Focus was placed on implementing features that we believe to have aided in the ability of the muzzle to offer better support for the mandible while limiting the common side effect. The entire design of our product was based around materials, designs, and features that would result in the most humane and ethical final prototype and design. Ultimately, the use of the device could in theory be tested in its current prototypical stage on a live patient. However, the team recommends either postponing live testing or using exceptional caution until a new prototype can be made. This new prototype would feature smaller buckles for superior and less obstructive adaptability as well as a less stretchy, thicker nylon material that would offer even better support of the mandible. Potential sources of error also arose in our product design and testing in our finite element analysis. As a result of idealizing the fracture, we lack variation in other elements such as fracture angle, spread, and microfracturing within the bone. Extensive testing would need to be done with development of an algorithm or use of a database of mandible fractures to obtain a much larger sample size of fracture location, severity, and variance.

9. Conclusions and Future Work

Canine mandibular fractures are a frequent occurrence, and many veterinary professionals, like Dr. Thatcher, recognize there is a lack of treatment options. Apart from the expensive surgeries, tape muzzles are currently being utilized to stabilize the jaw; however, this method can displace the jaw further. Our client tasked us to design an alternative, affordable nylon muzzle that uses cantilever and suspension bridge construction to improve the treatment process. With SolidWorks and finite element analysis, the team has quantitatively proved the effectiveness of the nylon muzzle over the tape muzzle. To create this device, the team researched the anatomy behind the fracture, the types of muzzles already available, and the mechanics associated with cantilevers and suspension bridges. Based on these mechanics, the team proposed three preliminary designs which were evaluated using the weighted criteria in our design matrix. The Mesh and Nylon design is our final proposed idea. It contains elastic material, specifically, mesh and nylon fabrics along with reinforcing battens. The main purpose of this design is to improve breathability and support surrounding the fracture site. Previously, Dr. Thatcher provided us with a cadaver of a mandible from a medium sized dog with the location of an M1 favorable and unfavorable fracture [13]. Our goal was to accurately replicate the jaw in SolidWorks and conduct finite element analysis on the mandible to locate the concentration of the typical bite force. Upon completion of our muzzle design, we used CAD drawing to build a prototype with the correct dimensions to fit the cadaver mandible; furthermore, we proceeded with fabrication of this muzzle with the appropriate materials. This should be a testable model of our muzzle design and must evenly distribute the forces produced by a canine bite. We also created a simplified canine mandible in SolidWorks with appropriate constraints resulting from the muzzle support. Finite element analysis was carried out in order to determine the difference in stress concentrations between no support, tape muzzle support, and our nylon muzzle support. With this analysis, we saw that our muzzle design reduces the pressure near the fracture site in order to aid in healing without displacing the jaw further.

Although we were successful with our simplified muzzle simulation and designing a prototype, there are a few improvements and testing procedures that would need to be implemented going forward with this project. Right now, the materials in our prototype are not exactly what we envisioned. Alternative materials need to be ordered, specifically less stretchy, more durable nylon and smaller buckles, to improve the muzzle support capabilities. In SolidWorks, the simplified mandible needs to be enhanced to more accurately represent the canine jaw. With this more detailed model, we would carry out more finite element analysis to refine the simulation and advance our computer modeling results. Furthermore, we need to conduct stress analysis with the physical model through experimentation. This will validate the nylon prototype in real-life situations where we could use the results to make necessary changes to our design. Lastly, other testing procedures need to be executed to analyze specific material components focusing on the durability and flexibility of the muzzle and the comfort for the canine. These additional, more detailed, calculations and experiments will allow us to continue to prove beyond anecdotal evidence provided by Dr. Thatcher, and other professionals, that a reinforced nylon muzzle would assist in healing the fractured mandible more effectively than the tape muzzle.

10. References

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11. Appendix

A. Product Design Specifications

VetMed: Affordable Muzzle to Assist in Mandibular Fracture Repair in Dogs- BME 300/200

Product Design Specifications

September 18, 2020

Client: Graham Thatcher

Team:

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Function: Our client is seeking an improvement in current muzzle techniques during pre- and post-surgery stages for mandibular fracture repair in dogs. The muzzle could also be used as a cheaper alternative to the surgery. Canine mandibular fractures most commonly occur at the M1 tooth, as a result of the large volume of the tooth compared to mandible [1]. Existing methods of repair require surgeons and several anesthetic events, resulting in a high-cost to the patient owner. A suggested way to relieve pain before and after surgery, and a possible cheaper solution, is using a muzzle to support the mandible. The bite force of this tooth ranges from 620.33-1,091.1 N [2], and displaces that force into the jaw. The team is tasked with designing and validating a muzzle that evenly distributes the bite force applied to the mandible away from the fracture site, without completely restricting movement.

Client requirements: The client is expecting the following:

- The muzzle to evenly distribute force throughout the mandible that is applied by the masseter and biting.
- Must properly support the fractured mandible.
- Prevent stress concentrations or displacement near the existing fracture site at the M1 tooth.
- Create a small, medium, and large size, and be adjustable to fit dogs between sizes.
- A model to validate a decrease in stress compared to existing taped muzzle options.

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements:*

- The muzzle is designed to be used in the treatment and recovery of the mandibular fracture repair of dogs. It will support the mandible by distributing the force throughout the mandible, allowing it to properly heal, and it will limit the motion of the jaw. Compressive forces of the jaw can reach up to 5000 N depending on size, breed, and location within the mouth [3]. A nylon or canvas muzzle provides support and distributes force through most of the mandible's length, whereas a tape muzzle has a fulcrum point where the tape is wrapped around the dog's jaw.
- We will be testing and comparing the nylon muzzle vs. the tape muzzle in its ability to support the mandible and how the stress is distributed on the mandible.

b. *Safety:*

- The dog must be able to eat soft food and drink water. A gap of 0.5 cm to 1.0 cm (1.5 cm max) usually accomplishes this.
- It must not disrupt the blood supply to the oral tissues.
- The muzzle's material should be comfortable and minimize irritation to the dog's skin.
- The muzzle should not limit the dog's ability to breathe or lightly pant as this is how dogs circulate the necessary air throughout their bodies to cool down.
- The muzzle should be washable, so it is easy to clear away any build-up of dirt or bacteria that could lead to infection.
- The device needs to account for common complications of muzzles including moist dermatitis, aspiration of food and hyperthermia due to possible impairment of panting[4].

c. *Accuracy and Reliability:*

- In order to validate the model, the team will perform mechanical strain testing on a canine cadaver mandible. The strain readings of the jaw must be within 5% of the results of the model.

d. *Life in Service:*

- The muzzle must support the jaw without loss of strength for at least 6 weeks when the jaw is stable. Canine dental fractures are reported to have functionally healed within as little as 2-3 weeks, with average healing time of 5.5 weeks [5]. Fractures often return to 90% of their original stiffness within 6-weeks [1]. The dog is then able to resume normal activities without risking further damage to the mandible.

e. *Shelf Life:*

- The muzzle has no specific shelf-life components as it will be stored in the dry, clean environment of a veterinary clinic before use.

f. *Operating Environment:*

- The muzzle will be exposed to the forces typically experienced by a canine mandible. These include but are not limited to biting, resting, and chewing.
- The material will be exposed to the typical fluids secreting from the canine mouth area for extended periods of time (duration of recovery of about 5-6 weeks).
- The muzzle may be exposed to dirt or dust a canine may encounter during everyday activities.

g. *Ergonomics:*

- The adjustable strap should be breathable and lightweight in order for the canine to perform daily needs such as eating, drinking, and panting. The muzzle should be tight yet comfortable, providing support and range of motion.

h. *Size:*

- 3 sizes will be produced, small, medium, and large, with standard snouts analogous to a [labrador]
- The product shall not exceed 12 inches in circumference for the largest muzzle size, 8 for medium, and 4 for small
- The product will be easily portable as a result of its small size and ability to be compacted flat
- The space available is the immediate area surrounding the head of the dog, with as little being taken up as possible with most pieces flat and flush to the dog
- Access for maintenance is not a primary concern, as the muzzle can be taken off easily for repair or adjustment, with possibility for adjustment while product is still on

i. *Weight:*

- The weight of the muzzle shall not exceed 1 pound (454g), and not weigh less than 2 oz (57g)
- An optimum weight for the product relies on the most efficient sustainability with the least weight possible.

j. *Materials:*

- Non-toxic and non-abrasive materials should be used in the product for the safety of the patient
- Metals should also be avoided when possible due to their tendency to have increased weight and rigidity in comparison to other materials

k. *Aesthetics, Appearance, and Finish:*

- The final product should be neutral in color, with a cylindrical shape that can be compacted flat for packaging/storage
- The texture will be as non-abrasive as possible with key areas specified as high sensitivity locations necessitating special attention.

2. Production Characteristics

a. *Quantity:*

- The project requires 1 prototype muzzle and 1small, 1 medium, and 1 large final design.

b. *Target Product Cost:*

- The team will have a budget of $500 to create an adjustable and reinforced muzzle. Though this number is subject to change. The team will also have remote access to the Makerspace, to which we will pay a $50 materials fee. Commercially available muzzles for everyday use range from $10-20, though many lack adjustability and support to cradle a mandibular fracture. The muzzle will also act as a potential alternative treatment to high-cost mandibular surgeries, such as plating, which can range from $6,000-8,000.

3. Miscellaneous

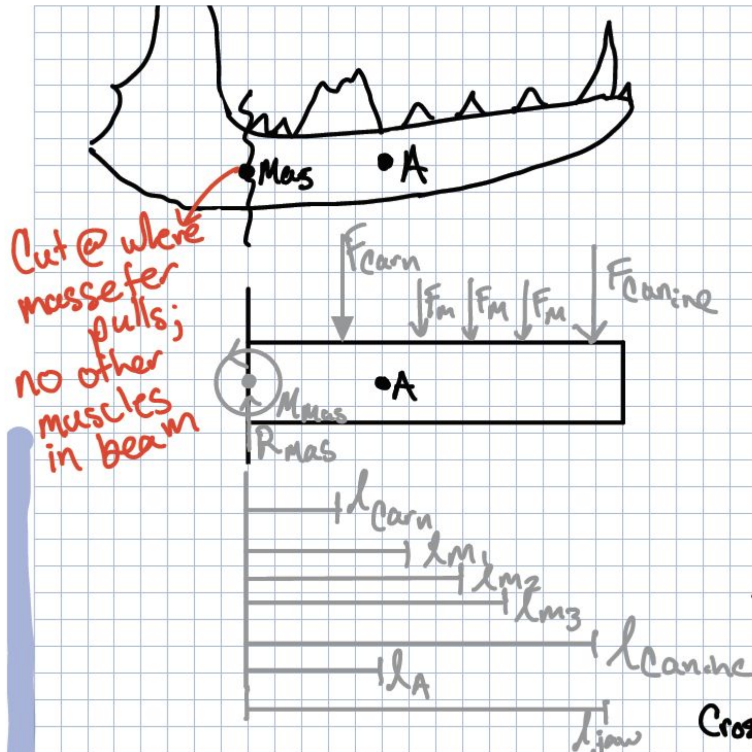
a. Standards and Specifications: For veterinary medical devices, FDA approval is not required. However, veterinary devices are required to follow the guidelines stated in the Federal Food Drug and Cosmetic Act regarding misbranding, mislabeling and adulteration [6].

b. *Customer:* Customers prefer that the muzzle be user-friendly, meaning that it can easily be taken on and off without displacing the fracture further. An inevitable consequence of long term wear of the muzzle is a build up and dirt and bacteria. Providing multiple muzzles or an easy way to clean the muzzle needs to be considered. Another customer preference would be the ability to easily provide food and water while not compromising the integrity of the muzzle.

c. *Patient-related concerns:* A main concern for this product would be patient non compliance. Comfort, sizing and placement of the device are all areas of interest that would help reduce the patient's ability to fight the device. The muzzle must also be able to provide proper stability and alignment while allowing the patient to easily drink, eat and breathe [4].

d. *Competition:* Currently the primary form of non-invasive treatment for mandibular fracture in canines is a tape muzzle. This treatment has been standardized and is taught all over the world, however there are numerous fallbacks to this method. Secondary to tape muzzles are commercial nylon muzzles. Most nylon muzzles on the market are for everyday use.

B. Hand Calculations



$F_{carn} = 1091.1\,N$

$F_{molar} = 571\,N$

$F_{canine} = 511.8\,N$

$l_{carn} = 3.0\text{ cm}$

$l_{M_1} = 4.25\text{ cm}$

$l_{M_2} = 5.50\text{ cm}$

$l_{M_3} = 6.75\text{ cm}$

$l_{canine} = 8.75\text{ cm}$

$l_{jaw} = 9.0\text{ cm}$

$l_A = 3.25\text{ cm}$

Cross-section area @ A: ~1.0x1.75 cm, $A = 1.75\text{ cm}^2$

Without Support

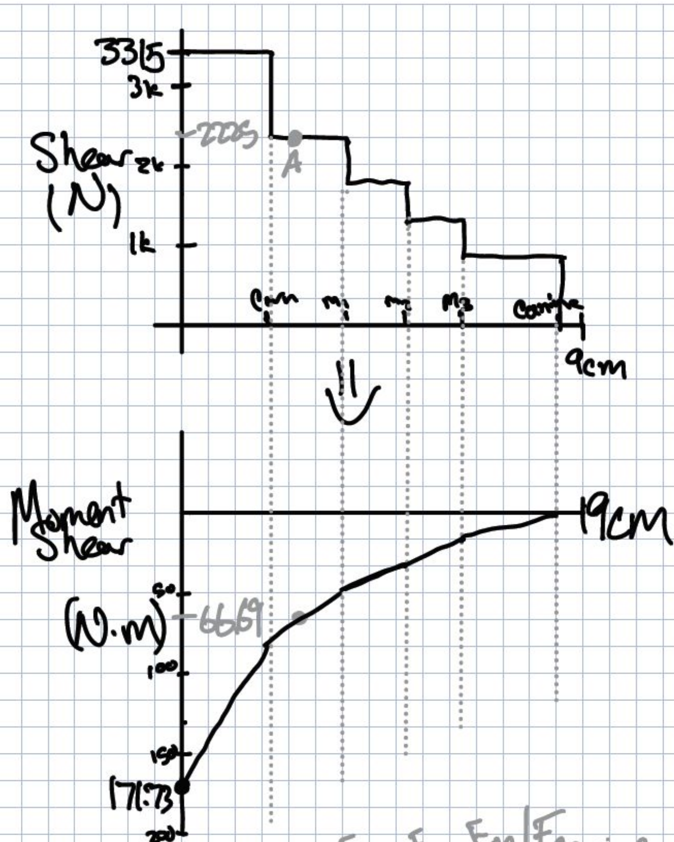
$$\Sigma F_y = 0: \quad R_{Mas} = F_{carn} + 3 \cdot F_m + F_{canine}$$

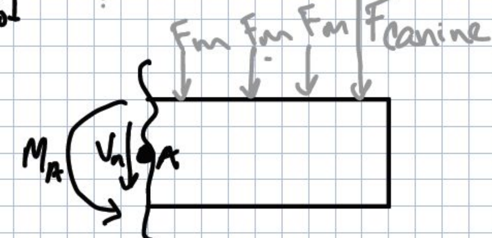
$$R_{mas} = 3315.9\,N$$

$$M_{mas} = F_{carn} \cdot l_{carn} + F_{m_1} \cdot l_{m_1} + F_{m_2} l_{m_2} + F_{m_3} l_{m_3} + F_{canine} l_{canine}$$

$$M_{mas} = 171.73\,N \cdot m$$

$$M_{end\ of\ jaw} = 0$$





$$\Sigma F_y: \quad V_A = F_m \cdot 3 + F_{canine}$$

$$V_A = 3 \cdot 571 + 511.8$$

$$V_A = 2224.8 \text{ N}$$

$\sum M_A$: $M_A = l_{A_{M}} F_{M_1} + l_{A_{M2}} F_{M_2} + l_{A_{M3}} F_{M_3} + l_{A_{Canine}} F_{Canine}$

$$M_A = (4.25-3.25)(571) + (5.5-3.25)(571) + (6.75-3.25)(571) + (8.75-3.25)(511.8)$$

$$M_A = 6669.15 \text{ N·cm}$$

⇓

$$M_A = 66.69 \text{ N·m}$$

Approx. Stress due to bending

$$\sigma_x = \frac{-My}{I}$$ → appoximating as a beam w/ b=1 cm, h=1.75 cm

$$\sigma_{x_A} = \frac{-(66.69 \text{ N·m})(-0.5E\text{-}2 \text{ m})}{\frac{1}{12} \cdot (1E\text{-}2 \text{ m})(1.75E\text{-}2 \text{ m})^3}$$

$$\frac{\text{N·m·m}}{\text{m·m}^3} \quad \frac{\text{N m}^2}{\text{m}^4} \quad \text{N/m}^2$$

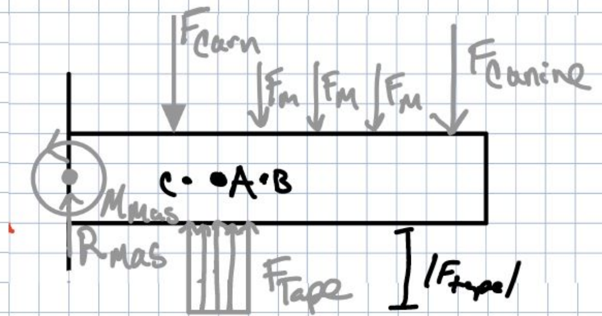
is this reasonable? → $\sigma_x = 746.6$ MPa

would be value if each tooth took Max force

$\sigma_x = 74.66$ MPa ↳ much more reasonable

https://www.doitpoms.ac.uk/tlplib/bones/bone_mechanical.php

Says Compressive strength of 70-280 MPa for bone...



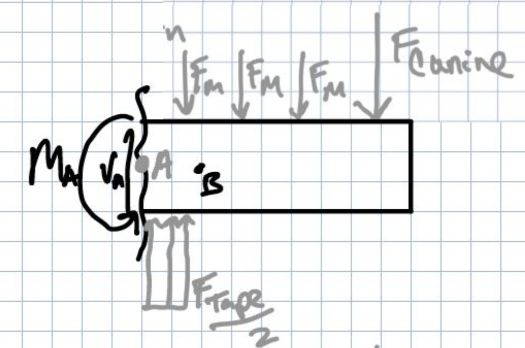
$l_{tape} = 2.5\,cm$

(1.25 on each side of A)

$|F_{tape}| = F_{Carn} + 3F_m + F_{Canine}$

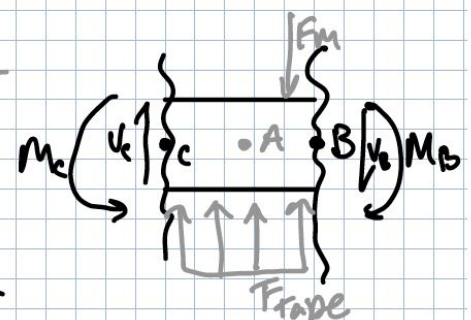
$= \frac{331.59}{2.5}$

A)



$l_{tape}/2 = \frac{2.5\,cm}{2}$

X B)



X B) $\Sigma F_y: \; V_B = 2 \cdot F_m + F_{canine}$

$\Sigma M_B: \; M_B = F_m \cdot l_{BM_2} + F_m l_{BM_3} + F_m l_{Bcanine}$

A)

$$\sum F_y: \quad V_A + \frac{F_{tape}}{2} = F_M \cdot 3 + F_{camiña}$$

$$V_A = F_M \cdot 3 + F_{camiña} - F_{tape}/2$$

$$\boxed{V_A = 566.85 \text{ N}}$$

$$\sum M_A: \quad M_A = l_{AM} F_{M_1} + l_{AM_2} F_{M_2} + l_{AM_3} F_{M_3} + l_{A_{camiña}} F_{camiña} - l_{tape/2} F_{tape/2}$$

$$M_A = (4.25-3.25)(571) + (5.5-3.25)(571) + (6.75-3.25)(571) + (8.75-3.25)(511.8) - (1.25)\left(\frac{3315.9}{2}\right)$$

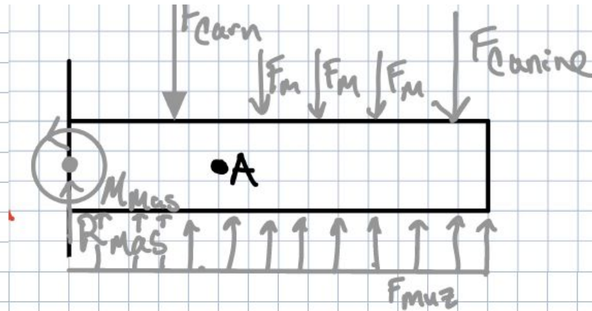
$$M_A = 4596.71 \text{ N}\cdot\text{cm}$$

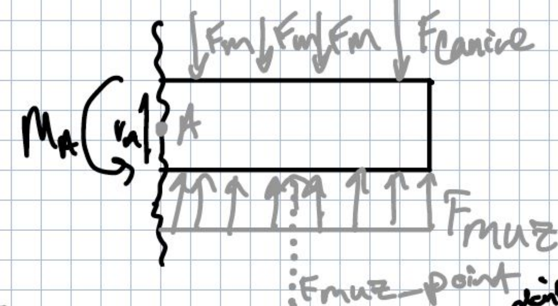
$$\Downarrow$$

$$\boxed{M_A = 45.98 \text{ N}\cdot\text{m}}$$

$$\sigma_A = \frac{-M_A y}{I}$$

$$\boxed{\sigma_A = 51.46 \text{ mPa}}$$





$F_{muz} = 3315.9\ N$ ↳ equal & opp to total bite

ΣF_y: $V_A + F_{muz}$ (→ don't need l here) $= F_m \cdot 3 + F_{canine}$

$V_A = 3F_m + F_{canine} - F_{muz}$ ↳ from A to end

$= F_{muz} \cdot \frac{total - A}{total}$

$= 3315.9 \cdot \frac{9-3.25}{9}$

$V_A = 106.3\ N$

ΣM_A: $M_A = l_{AM} F_{m_1} + l_{AM} F_{m_2} + l_{Am_3} F_{m_3} + l_{A_{canine}} F_{canine}$

$- l_{A\text{-}muz} \cdot F_{muz\_point}$

$l_{A\text{-}muz} = l_{muz}/2 = (9-3.25)/2$

$F_{muz\,point} = 3315.9 \cdot \frac{9-3.25}{9}$

$$M_A = (4.25-3.25)(571)+(5.5-3.25)(571)+(6.75-3.25)(571)$$
$$+(8.75-3.25)(5118)$$
$$\left(\frac{9-3.25}{2}\right)\left(3315\cdot\frac{9-3.25}{4}\right)$$

$$M_A = 578.49\ N\cdot cm$$

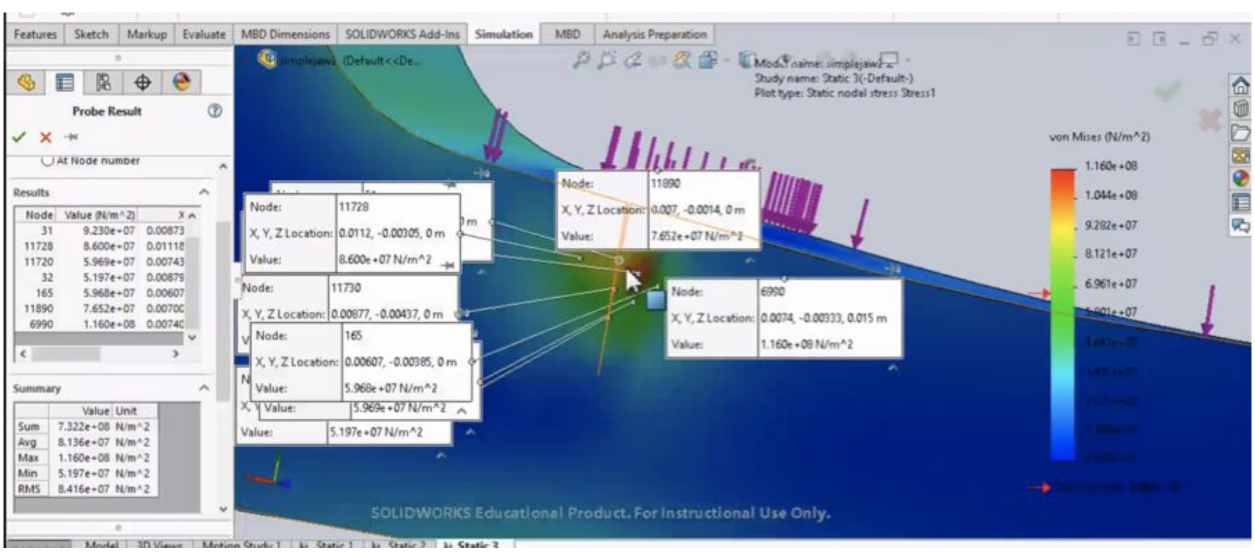
$$\Downarrow$$

$$\boxed{M_A = 5.786\ N\cdot m}$$

$$\sigma_A = \frac{-My}{I}$$

$$\boxed{\sigma_A = 6.48\ MPa}$$

C. SolidWorks Probing



- Random probing for the no support condition can be seen above. On the left hand side, is the resulting summary table, and results columns that were exported to Matlab.

D. Matlab Analysis

SolidWorks FEA analysis

Arrington Polman
BME Design 300/200
Began: 12/1/2020
Last edited: 12/2/2020

```
close all
clear all
```

Loading Data

```
data = readmatrix("FEAdata.xlsx");
```

Data at Fracture

```
none = data(1:10,4);
full = data(1:10,3);
tape = data(1:10,2);
% each is in Pa

none = none./1e3;
full = full./1e3;
tape = tape./1e3;
% putting into KPa

avg_none = mean(none)
avg_full = mean(full)
avg_tape = mean(tape)

max_none = max(none)
max_full = max(full)
max_tape = max(tape)

n_none = length(none);
n_full = length(full);
n_tape = length(tape);
```

avg_none = 5.3498e+03

avg_full = 482.5800

avg_tape = 5.4124e+03

max_none = 7226

max_full = 742.5000

max_tape = 7756

Stats

- Percent change; denotes drop first gives from the second

```
full_none_perchange_avg = (avg_full-avg_none)/(avg_none)
tape_none_perchange_avg = (avg_tape-avg_none)/(avg_none)
full_tape_perchange_avg = (avg_full-avg_tape)/(avg_tape)
```

full_none_perchange_avg = -0.9098

tape_none_perchange_avg = 0.0117

full_tape_perchange_avg = -0.9108

```
full_none_perchange_max = (max_full-max_none)/(max_none)
tape_none_perchange_max = (max_tape-max_none)/(max_none)
full_tape_perchange_max = (max_full-max_tape)/(max_tape)
```

full_none_perchange_max = -0.8972

tape_none_perchange_max = 0.0733

full_tape_perchange_max = -0.9043

- Box Plots

```
y = [log10(none), log10(full), log10(tape)];
x = ["No Support","Full","Tape"];
boxplot(y,x)
title('Stress at Fracture Site for Each Support',"FontSize",20)
xlabel('Support Type',"FontSize",15)
ylabel('Stress (KPa)',"FontSize",15)
ylim([2.0,4.0])
```

- ANOVA

```
[p,tbl] = anova1(y)
```

p = 1.6309e-13

tbl = 4×6 cell

	1	2	3	4	5	6
1	'Source'	'SS'	'df'	'MS'	'F'	'Prob>F'
2	'Columns'	7.6692	2	3.8346	106.0533	1.6309e-13
3	'Error'	0.9763	27	0.0362	[ ]	[ ]
4	'Total'	8.6455	29	[ ]	[ ]	[ ]

- 2 sample T-test for different means

```
[h_fullnone, p_fullnone, ci_fullnone, stats_fullnone] =
ttest2(full,none)
[h_fulltape, p_fulltape, ci_fulltape, stats_fulltape] =
ttest2(full,tape)

[h_tapenone, p_tapenone, ci_tapenone, stats_tapenone] =
ttest2(tape,none)
```

h_fullnone = 1

p_fullnone = 2.3644e-09

ci_fullnone = 2×1

$10^3 \times$
-5.8061
-3.9283

stats_fullnone = struct with fields:
tstat: -10.8910
df: 18
sd: 999.3074

h_fulltape = 1
p_fulltape = 1.0852e-07
ci_fulltape = 2×1
$10^3 \times$
-6.1533
-3.7064

stats_fulltape = struct with fields:
tstat: -8.4655
df: 18
sd: 1.3022e+03

h_tapenone = 0
p_tapenone = 0.9324
ci_tapenone = 2×1
$10^3 \times$
-1.4666
1.5918

stats_tapenone = struct with fields:
tstat: 0.0860
df: 18
sd: 1.6276e+03

- T testing with bonferfoni corrected α

```
alpha = 0.05; % default alpha
k = 3; % # of conditions
alphastar = alpha/(k*(k-1)/2); %bonferroni corrected alpha
```

```
[h_fullnone2, p_fullnone2, ci_fullnone2, stats_fullnone2] =
ttest2(full,none,"Alpha",alphastar)
[h_fulltape2, p_fulltape2, ci_fulltape2, stats_fulltape2] =
ttest2(full,tape,"Alpha",alphastar)

[h_tapenone2, p_tapenone2, ci_tapenone2, stats_tapenone2] =
ttest2(tape,none,"Alpha",alphastar)
```

h_fullnone2 = 1

p_fullnone2 = 2.3644e-09
ci_fullnone2 = 2×1
10^3 ×
  -6.0467
  -3.6878

stats_fullnone2 = struct with fields:
    tstat: -10.8910
       df: 18
       sd: 999.3074

h_fulltape2 = 1
p_fulltape2 = 1.0852e-07
ci_fulltape2 = 2×1
10^3 ×
  -6.4667
  -3.3929

stats_fulltape2 = struct with fields:
    tstat: -8.4655
       df: 18
       sd: 1.3022e+03

h_tapenone2 = 0
p_tapenone2 = 0.9324
ci_tapenone2 = 2×1
10^3 ×
  -1.8584
   1.9836

stats_tapenone2 = struct with fields:
    tstat: 0.0860
       df: 18
       sd: 1.6276e+03

E. Materials

Item Description	Supplier	Cost	Quantity	Total Cost
Nylon-spandex fabric	Rex Fabrics	$14.99	1	$14.99

Nylon mesh	Ben Textiles Inc.	$7.68	2	$15.63
Nylon thread	Anminy	$5.99	1	$5.99
1” parachute buckle	Dritz	$5.99	2	$11.98
1” nylon straps	Dritz	$5.99	1	$5.99
Foam padding	Grainger Item #5GCR9	$9.73	1	$21.85 (shipping included)
Acrylic supports	UXCell	$7.99	3	$23.97
Dog skulls	Client	0	2	0
Total Cost				$94.41
Budget				$200.00

F. SolidWorks Testing Protocol

1. Use the spline tool in solidworks to create a rough sketch of the mandible

   - To do this you will select Extruded boss/base
   - Select the front plane
   - Select the spline tool
   - Create a rough sketch of the model by going section by section connecting numerous splines until the sketch is complete
   - Once you are done click exit sketch and it will prompt you to select a thickness for the base. Input 1.5 inches.

2. Make an extruded cut approximately where the M1 tooth would lie.

   - Select extruded cut
   - Click on the front plane of the mandible model
   - Use the line tool to draw on the mandible where you would like the cut to be made
   - Click exit sketch and select the thickness of the cut
   - Select a thickness that is equal to that of the model (1.5 inches)

3. Click on SolidWorks Simulation

4. Select static test

5. Right click on fixture and select fixed geometry.

6. Place fixtures along the back of the mandible at the joint location. The placement of the fixtures can be seem in the images of the tests attached below.

7. Repeat this two more times so you now have 3 static tests that you can edit.

8. For each test right click external loads and select force

9. Select across the top of the mandible and set the force to 855N

10. Check total force before saving

12. Leave static 1 as is

13. For the static 2 right click applied load and select forces

14. Select the bottom of the mandible thats directly below the fracture site.

15. Set the force to 855 N and save

16. For static three complete steps 13 - 15 but add the forces across the entire bottom of the mandible and select total force before saving.

17. Right click the name of the model and select the apply/edit material

18. Right click custom materials and select new material

19. Input the mechanical properties of bone. When finished select save and apply. This will apply the new material to each of the studies.

Shear Modulus	3300 N/mm^2
Elastic Modulus	5650 N/mm^2
Poisson's Ratio	0.62
Mass Density	2000 kg/m^3
Tensile Strength	53 N/mm^2
Compressive Strength	65.2 N/mm^2
Yield Strength	44.1 N/mm^2

20. Right click mesh and select mesh and run for each of the studies,

21. A scale will automatically generate with the stress values seen throughout the mandible.

22. Select plot tools ---> probe tool and randomly select 10 points around the fracture for each test and record those values.