

## **Maxillomandibular Fixation**

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December 7, 2005

**Abstract:** The goal of this project is to create a new technique for fixating a fractured mandible that will be easier and faster to apply than the current method of 'maxillomandibular fixation' (MMF). The decision was made to use a design that incorporated aspects of orthodontic braces designed specifically to hold the lower jaw tight against the upper jaw. The device will accomplish this by the use of brackets attached to as many as 16 molars, and rubber bands strung from the upper jaw to the lower jaw. The patient will wear the device for 4 to 6 weeks or until completion of the healing process.

## **Problem Definition:**

Currently, the most common technique of fixating the jaw after a facial fracture is called maxillomandibular fixation (MMF), which requires wiring the mouth shut with the use of arch bars and wires. It has been proposed to us to design a device which will mimic the function of maxillomandibular fixation. Application time should take no more than 45 minutes and the device should cost less than \$100 for the raw materials. Our design needs to securely hold the lower jaw tight to the upper jaw, but also needs to have an emergency quick release system. The device should also be safe for the patient during application and for the 4 to 6 weeks of healing. (1)

## **Motivation:**

The first writings about mandible fractures were recorded in the Edwin Smith Papyrus which dates back to 1650 B.C. However, at that time there was no technique available for the treatment of mandible fractures. Individuals with such injuries thus went untreated and commonly faced subsequent complications, often leading to death. Hippocrates was the first to attempt treatment of mandible fractures by using bandages to immobilize the fractured jaw. Occasionally he used gold circumferential wires in the stabilization process as well. A textbook written in Salerno, Italy was the first to mention the importance of correct occlusion when treating mandible fractures. The first person to come up with the theory of maxillomandibular fixation was Guglielmo Salicetti, in 1492, introducing the method in which one would “tie the teeth of the uninjured jaw to the teeth of the injured jaw.” Since this time, many other people have slightly altered Salicetti’s technique, though the original principle remains. (2,3)

The current technique of MMF is not only outdated, but also tedious and time consuming. The application of the fixation device takes an average of 40 minutes, though the exact time varies depending on the difficulty the surgeon experiences in threading the circumferential wires around the teeth (1). A picture of this procedure can be seen in Figure 1. The small wires are often hard to manipulate when inserted in the correct position above or below the arch bar. Thus, our client is interested in developing a new device for the treatment of mandible fractures, which will use the same principle of fixation, but will be quicker and simpler to apply.

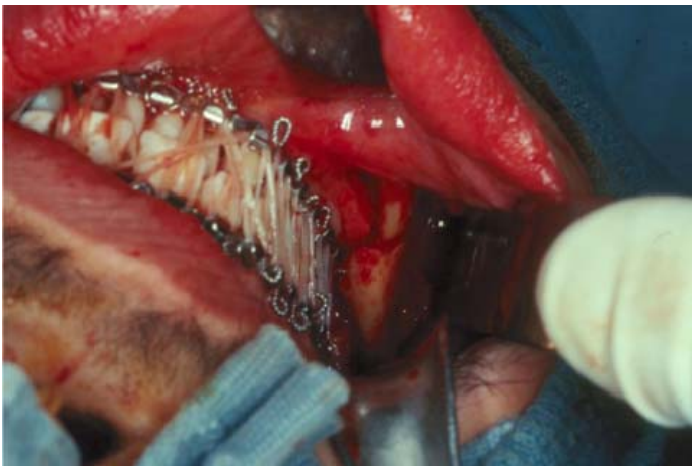


Figure 1. Picture of the current MMF technique (4)

### **Client Requirements:**

While the client has provided our group with the freedom to be creative in designing a new MMF technique, he has also provided multiple design constraints in order to ensure safety of the patient. Our device must be of an appropriate size, protruding no more than 3 mm, as to provide minimal discomfort to the patient. Forces must not be exerted on front teeth as they are easily moved out of alignment. The device must also be cost and time effective when compared to the current technique that costs

\$175 and takes an average of forty minutes to apply. Due to the nature of jaw fixation, the patient must be able to obtain nutrients from liquid foods with the help of a syringe. Most importantly, the mechanism must incorporate a way to quickly release the lower jaw from the upper jaw in case of an emergency. (1)

## **Background:**

### **Facial Fractures: A Brief Overview**

The mandible is the second most commonly fractured bone of the face, after the nasal bones. In a paper by Ellis, a study of 4711 patients with facial fractures found that 45 percent were mandible fractures. The most common cause of mandible fractures was assault, followed by motor vehicle accidents, falls, and sporting accidents. The exact fracture sites were influenced by the cause of injury, the prominence of the mandible, and the individual's areas of weakness. The most commonly fractured sites were the angle, the body, and the condyle which are shown in Figure 2 (2). There are three steps in the healing of most mandible fractures. First, reduction of the fracture must be accomplished by realigning the bones into their original positions. Second, the fracture must be fixed into place by means of MMF, internal fixation, or external fixation. Lastly, sufficient time is needed for the important healing and rehabilitation process (5).

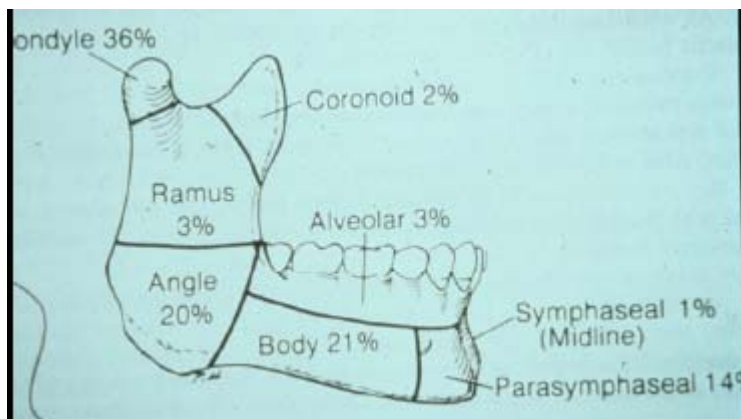


Figure 2. Diagram showing the locations and frequency of mandible fractures (4)

## Methods of Fixation:

While MMF is the most commonly used treatment for mandible fractures, internal and external fixation are occasionally used as well. Internal fixation involves the use of plates and wires or screws attached directly to the bones to hold them securely in their correct positions. This procedure involves the use of anesthesia. Internal fixation is shown in Figure 3. External fixation, though less commonly used, involves the use of surgical pins to attach a rigid external fixation device, which holds the jaw in place. This type of fixation is shown in Figure 4. Depending on the severity of the case, a combination of the treatment methods may be used. (5)

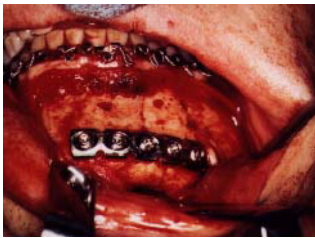


Figure 3. Photograph displaying internal fixation: metal plates attached to mandible fracture site. (5)



Figure 4. External fixation. (5)

## Maxillomandibular Fixation: A Brief Overview

MMF, which is used to treat non-displaced fractures of the mandible, is commonly known as “wiring the jaw shut.” This process involves anchoring arch bars to the gums of the maxilla and the mandible. The arch bars are held in place by 24 gauge wires, which are wrapped around the molars. Rubber bands or 26 gauge wires are then wrapped around hooks extending from the arch bars. These elastics or wires connect the upper and lower jaws. This process allows the upper jaw to act as a splint for the lower jaw during the healing process. MMF is the process that our client wishes us to improve upon. (3)

## Jaw forces:

In order to create a design that will properly fixate the jaw, we must understand the forces that act in the opening and closing of the jaw. There are three main muscles in charge of mastication. They are the masseter, the temporalis, and the medial pterygoid. The masseter's function is to provide slow, forceful closure of the jaw. The masseter is shown in Figure 5. The temporalis (Figure 6) allows fast closure of the jaw while the pterygoid (Figure 7, a,b) allows sideways movement of the jaw. These three muscles work together to raise the lower jaw to the upper, and they position the jaw (either forwards or backwards) so that the teeth come down on top of one another. (1, 6)

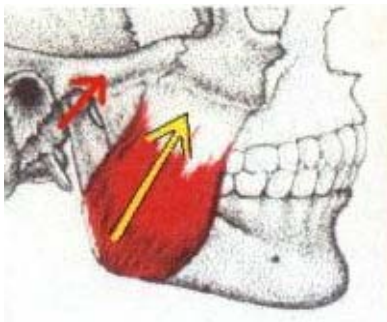


Figure 5. Diagram showing the masseter (7)

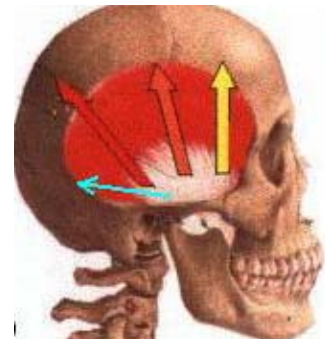


Figure 6. Diagram showing the temporalis (7)

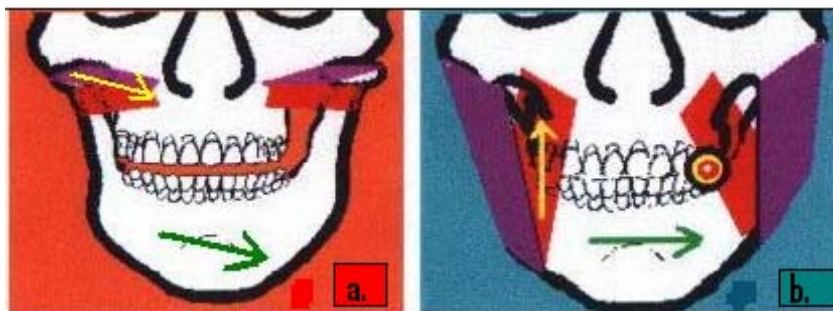


Figure 7. Illustration of the movement allowed by the pterygoid (7)

The maximum pressure exerted by the muscles during mastication is 2.07 MPa. This pressure is generated through the closing of the jaw. Similarly, the maximal biting

force is approximately 440 N (8). One muscle, the lateral pterygoid, is responsible for the lowering of the mandible, or opening of the jaw (9). Multiple experiments have been carried out in order to determine the maximum opening force, but results vary. Forces have been reported over a range of 99.6-237.4 N (10, 11). No experiments were found that reported the maximal pressures exerted through the opening of the jaw.

Due to the wide range of values reported for forces involved in the opening of the jaw, we have decided to use the closing forces for our design parameter. As can be seen from the values indicated above, the closing forces largely exceed those of opening. By using a larger parameter than necessary, this will ensure that our design is of appropriate strength.

## **Design Possibilities:**

### **Design 1: Magnets and Screws**

This design involves the use of four cortical bone screws. These are inserted into four pre-drilled holes in the jawbone, with two in the upper jaw and two in the lower. The



Figure 8. Photograph showing placement of screws in upper and lower jaw connected with a rubber band. (12)

holes are drilled in between the canine and the first premolar using a centre drive hexagonal screwdriver. The cortical bone screws that we are using are constructed of titanium, with a 2 mm diameter and a self-tapping thread. A 10 to 16 mm thread length may be used (12). The following picture, Figure 8, shows the use of cortical bone screws; however, our design uses magnets rather than rubber bands to hold the upper and lower jaw together.

This design features aluminum nickel cobalt (AlNiCo) magnets, because this type of magnet is most easily manufactured to the specific size and dimension that we need (13). For this design, we are using rectangular magnets with a pre-drilled hole. The screw passes through the hole in the magnet and screws into the jaw (See Figure 9). The head of the screw is large enough to prevent the magnet from sliding off of the screw.

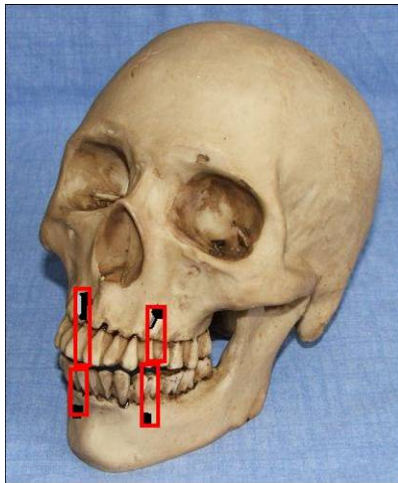


Figure 9. Diagram showing placement of magnets

The cost of this design includes the cost of the screws and the cost of the magnets. The screws are relatively easy to find, seeing as they are currently being used in hospitals. A pack of 10 screws costs between \$252 and \$270, depending on which length is used (12). The AlNiCo magnets cost about \$0.64 a piece (13). This puts the total cost between \$103.36 and \$110.56 per application of the device. This does not include the cost of any additional surgical supplies to be used

Since this method requires many of the same steps as the existing method of using screws and rubber bands, we can estimate that the process of applying the screw and magnet design will take roughly the same amount of time to apply. This puts the average application time at 15 minutes, depending on the doctor (14). The doctor will also be making the decision of whether to use general or local anesthesia when applying the design. Both are being used today for the application process, with little difference to the outcome. The screws can be removed quite easily with no anesthesia.

The potential problems concerning this design include the cost, the magnets' interactions with pre-existing medical devices such as pacemakers, corrosion of magnets

in the mouth, the need for a safety sealant, and the tendency of magnets to crack when machined or allowed to snap together. The main concern is the lack of a method for quickly releasing the magnets in case of an emergency. Also, the magnetic force holding the jaws together is strictly vertical, and any horizontal slipping may cause the magnets to come apart more easily.

## Design 2: External Stabilization

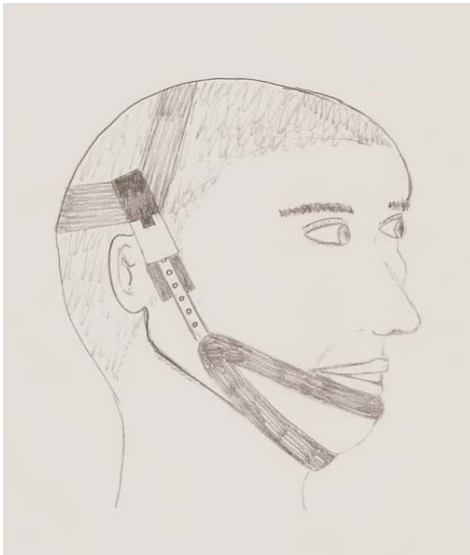


Figure 10. Sketch of external stabilization design

The second design is a completely unique approach to fixating the jaw. This design is external and encompasses the head. Figure 10 shows a sketch of this device. This design is similar to orthodontic headgear, but while headgear involves placement of a metal bar across the teeth, no part of our design is applied inside the mouth. Instead, there is a fabric chin strap to immobilize the jaw. The jaw is cradled by two separate parts of the chin strap, one beneath the

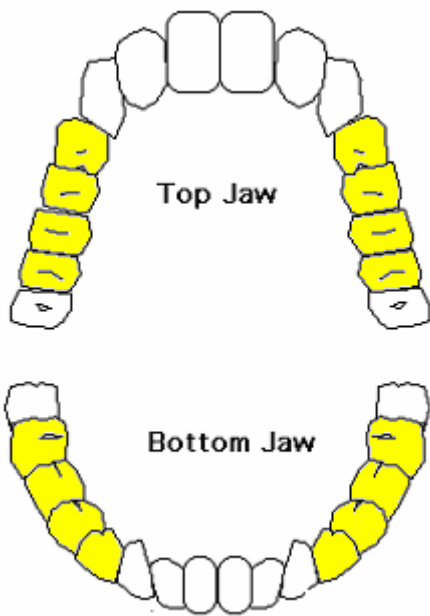
chin and the other just below the bottom lip. The straps along the sides of the head are adjustable in order to accommodate patients of all head sizes. In case of an emergency, these straps can be detached in order to release the lower jaw from the upper jaw.

This design is relatively cost-effective, as it estimated to cost around \$100, but it may not be the most pleasing option for the patient (15). The cost approximation is based on the current price of orthodontic headgear. The external stabilization device may cause some discomfort to the skin and be a hindrance to the patient's daily activities, such as showering and sleeping. For example, a patient wearing this device will have a limited

ability to bathe the head due to the fact that the brace must be worn at all times. Also, this design is not aesthetically pleasing as compared to the far less visible internal fixation options.

### Design 3: Braces

Our third design is what we are calling ‘The Braces Design.’ This design is very similar to the braces used by orthodontists to correct the teeth. However, instead of



putting brackets on every tooth, between 8 and 16 brackets may be applied, depending on the severity of the fracture. At the surgeon’s discretion, the appropriate number of brackets can be placed on any number of the first and second premolars (also known as bicuspid) and the first and second molars on each side of the mouth and on the top and bottom jaw. These teeth are labeled in yellow in Figure 11.

This placement is due to the restraint that forces cannot be placed on any other teeth in the jaw.

Figure 11. Diagram highlighting teeth used for bracket placement in Design 3

This method will not only have the quick release that is needed, as the elastics can be cut quickly, but it is also very time efficient to apply. At an orthodontist office it takes approximately 45 minutes to apply brackets to every tooth. However, since at most 16 brackets are needed (instead of the full set of 32) the procedure should only take 15 to 20 minutes (15). The adhesive that is used, ‘GC Fuji Ortho’, can be applied on wet surfaces and only takes 10-20 seconds to set and 3 minutes to dry completely (20).

After searching various companies for brackets that would fit our needs, we came across a company called Fairfield Orthodontics, which is a manufacturer of orthodontic supplies. Fairfield Orthodontics, being a fairly new company, has very competitive prices for their orthodontic brackets. In selecting a bracket, we mainly focused on finding the bracket with the largest hook size. The type of bracket that we chose is called the Stratus-BT, shown in Figure 12. The Stratus-BT is a specialized bracket called a



Figure 12. Image of Stratus Bracket (16)

buccal tube which is normally used in conjunction with headgear. The Stratus-BT is their most popular buccal tube with a price of \$3.25 per bracket. It is composed of stainless steel and comes with large, curved hooks for our rubber bands. The bottom of each bracket contains an 80-gauge mesh direct bond pad for increased bond strength. (17)

As previously mentioned, the adhesive that is being used for this project is called GC Fuji Ortho. It is a glass ionomer cement that is light-cured. It is made by GC America, Inc. The major benefit to this product is that it is the only one available right now that can be applied in a wet environment. Studies have shown that if you first prime the tooth with 10% polyacrylic acid, GC Fuji Ortho is just as strong as current adhesives such as Phase II and Transbond XT, which need to be applied in dry environments. GC Fuji Ortho has a mean shear strength of 14.84 MPa after 24 hours and 17.88 MPa after 7 days. Phase II and Transbond XT have means around 15 MPa after 24 hours and 19 MPa after 24 hours. All of these adhesives exceed the amount of shear strength needed to hold a bracket system to the tooth, which is approximately 6 MPa. (18, 19)

In application, the GC Fuji Ortho system is applied to the tooth, a bracket is set in place, and the adhesive is light cured with a standard VLC curing light for 20-40 seconds. The adhesive is completely set after 3 minutes. During the time that the bracket and adhesive are in place, GC Fuji Ortho actually continually releases a small amount of fluoride. This fluoride release helps to prevent decalcification and decay. At the end of the procedure, the tooth can be desiccated easily to release the bracket with little to no damage to the enamel. (20)

The exact materials needed for this design are 8 to 16 brackets, 4 to 8 elastics, and approximately 1/30 of the bottle of adhesive. The total cost of this design is about \$60. The biggest contributor to the cost is the adhesive at \$216/bottle, but only about 1/30 of the bottle is used for each application (20). The cost of the brackets is \$3.25 per bracket. The elastics will only cost about \$0.11 for a pack of 24. (15)

This design incorporates all of our client's requirements. It has a fast application time of only 15-20 minutes, it has a quick release system and requires no anesthesia to apply or remove. Also, this design is very aesthetically pleasing in that many people already have braces and this design won't stand out. The only potential drawback to this design would be the possibility of a bracket detaching from the tooth. This complication occurs in the use of orthodontic braces, though brackets often detach during eating. However, patients using our brace design would be limited to a liquid diet. Thus, the risk of bracket detachment would be less likely to occur.

### **Final Design Decision:**

In order to evaluate our three designs and select the one that best fit our client's requirements we rated all three designs according to their performance in several

important categories. These categories incorporated each of the client requirements in addition to a few others, which include durability and safety of the procedure. For instance, this takes into account whether the patient will need a local anesthetic or general anesthesia. A table with the categories and rankings is found in Table 1. We ranked the designs on a scale from 1 to 100, with 1 being poor and 100 being good. We then multiplied the assigned ranking by the weighted importance of each category. For example, application time and quick release are of the most importance, so they received a weight of 25% each, while local anesthesia is of least importance and received a weight of 5%.

	Weight (%)	Design 1: Magnets and Screws	Design 2: External Stabilization	Design 3: Braces
Application Time	25	20	25	20
Quick Release	25	5	25	25
Durability	20	16	8	16
Comfort & Aesthetics	15	6	3	15
Cost	10	6	7	9
Local Anesthesia	5	1	5	5
<b>Total</b>	<b>100</b>	<b>54</b>	<b>73</b>	<b>90</b>

Table 1. Design Matrix

As you can see from Table 1, design three is the design that best satisfies our client's requirements. This design acquired the most points in the rankings, 90 out of a possible 100 points, as shown above. This procedure will satisfy our client's

requirements, be most pleasing to patients, and improve the current technique for jaw fixation.

### **Problems and Possible Resolutions:**

The main problem that we encountered in designing a method for fixation of the jaw was that we were unable to calculate the maximum force exerted by the jaw. We were primarily concerned with the force exerted when a human opens the mouth, because this is the exact force that our device must be able to withstand in order to stabilize the mandible during the fixation period. Few experiments are designed to test this force, so they tend to produce varying results. We were only able to find values for the opening and closing force in two medical journals, and were unable to confirm these values with any other experimental results. Also, due to the complexity of the problem, we were unable to test this force on our own.

One concern regarding our design is that many of the parts we considered using are more expensive than the arch bars and wires required in MMF. In designing a device to replace MMF, it is important that the new device be nearly as inexpensive. Price was the main concern with regard to the different types of orthodontic brackets that we considered using in our design. In our current design, we use a type of orthodontic bracket that has a hook extending from it.

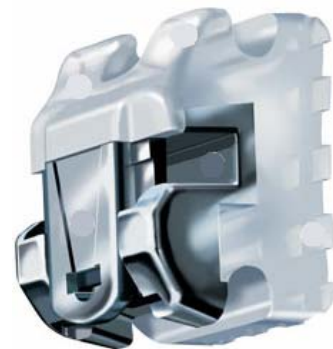


Figure 13. Damon 3 bracket with quick release clasp. (21)

This is the most common type of bracket on the market and is fairly inexpensive. We also researched more technologically advanced brackets which would be advantageous for use in our design.

The most promising bracket is called the Damon 3 (Figure 13), which is manufactured by a company called Ormco Orthodontics. This stainless steel bracket includes an easy release button. With the push of a button on this bracket, the clasp opens up and the rubber band is released with ease (21). This type of bracket would eliminate the need to cut the rubber bands in case of an emergency, thus making the design even safer. Also, the bracket would add to the comfort level of the patient, as there are no hooks protruding from the bracket. The only problem with this bracket is the price. Seeing that it is a fairly new concept, the price is still very high compared to the current brackets on the market, and thus it is not cost-efficient for our current design. We hope that in the future the price of this kind of bracket will drop and it may ultimately become the type of bracket used in our design.

Additionally, for future work, we would like to test this bracket to see if it is possible to reuse the bracket from patient to patient. Being made of stainless steel, it is likely autoclavable, and thus if the bracket is structurally unchanged after use and removal from each patient, it may be acceptable to reuse the bracket once sterilized.

Our research on adhesives has also shown that in the future, technological advances will likely produce an even better adhesive for wet application. Though it is still in the research phase, several groups are aiming to develop an adhesive that mimics the protein-based adhesives used by mussels and other aquatic organisms to adhere to surfaces under water. Mussels produce a protein adhesive as a liquid which reacts to form a hard, cross-linked surface plaque for the organism to attach to. The Messersmith Research Group at Northwestern University has found a single amino acid, L-3,4-

dihydroxyphenylalanine, that is believed to be responsible for the adhesive properties of the glue (22). Also, Jonathan Wilker and his team at Purdue University have found that the ingredient iron plays an important role in the strength of the adhesive. It is hoped that further research will lead to a versatile adhesive that can be applied to wet surfaces, and will thus have many medical applications (23). Ideally, such an adhesive will be incorporated into our design when it becomes available.

A final problem we have experienced in designing a successful fixation device is the inability to test the potential designs. Testing on a human subject would be ideal, as the external forces it must withstand and the conditions of the mouth are not easily replicated. However, such testing is not feasible, so instead we have acquired a model skull and applied our device as a simulation of application to a patient.

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Maxillomandibular Fixation  
October 17, 2005

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**Function:**

Currently, patients with specific and common types of facial fractures are treated with "maxillomandibular fixation," known as MMF, which entails holding the upper and lower jaw together using metal arch bars wired around the teeth in conjunction with a series of rubber bands. This technique achieves its goal of holding the two parts of the jaw together until the fracture heals, but involves the time consuming process of wiring the metal bars around the teeth as well as the time-consuming process of placing multiple rubber bands to hold the upper and lower jaws together. In addition, the rubber bands can often come loose and need to be replaced. We propose a project to develop a new and innovative device that will achieve the same goals as the standard type of MMF, yet make the process less time consuming and more reliable.

**Client Requirements:**

- Procedure must be completed in a timely fashion
- Forces cannot be exerted on the front teeth
- Must be cost-effective
- Must contain a quick release of upper from lower jaw in case of emergency
- Materials must be lightweight for comfort
- Person must be able to obtain nutrients

**Design requirements:**

**1. Physical and Operational Characteristics**

- a. *Performance requirements:* The device must be able to rigidly hold the jaw in place for a minimum of two weeks. The jaw should

be allowed minimal movement after two weeks to avoid muscle hypotrophy.

b. *Safety*: The device must incorporate a quick release of upper from lower jaw in case of an emergency. A design which is simple and takes less time to apply would evade the need for general anesthesia.

d. *Life in Service*: The device must be completely functional for up to eight weeks.

f. *Operating Environment*: The device must be able to resist deterioration from exposure water, heat or bodily fluids. It also needs to withstand forces exerted by the jaw.

g. *Ergonomics*: The device must be conscious of the forces placed on the fractured jaw without placing force on the front teeth. It must allow for food to be injected into the mouth.

h. *Size*: The device should be allowed to fit on the outside of the teeth. It should be able to fit inside the mouth with relative comfort for the patient.

i. *Weight*: The device must be light-weight as to not cause discomfort to the patient or apply large forces to the teeth.

j. *Materials*: The device should not be made with any material suitable for a human mouth. It must not contain radioactive materials or materials susceptible to rust and deformation.

k. *Aesthetics, Appearance, and Finish*: In order to draw as little attention to the patient's injury the device should be aesthetically pleasing.

## **2. Production Characteristics**

a. *Quantity*: 1

b. *Target Product Cost*: Device should not cost more than that of MMF unless the materials can be reused from patient to patient.

### **3. Miscellaneous**

a. *Customer*: The device should be quick and easy to apply. It should be adjustable if necessary and removable in case of an emergency.

b. *Patient-related concerns*: The device will be sterilized before each use as to safeguard against any types of infections. It must be suitable for a liquid diet in addition. The device must be compatible for patients with dentures or orthodontic devices.

c. *Competition*: Maxillomandibular fixation with screws and rubberbands.