Maxillomandibular Fixation

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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 brackets and a power chain attached to a total of 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, but be easier and faster to apply while maintaining an adequate cost of application. 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 4-6 weeks of healing.

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 circumdental 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.

The current technique of MMF is not only outdated, but also tedious and time consuming.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 circumdental wires about the teeth. 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 be quicker and simpler to apply.

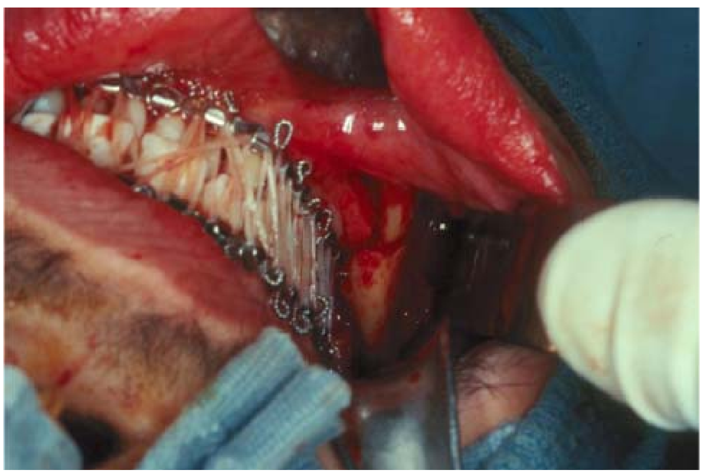

Figure 1. Picture of the current MMF technique

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 to the patient. Our device must be of an appropriate size and weight 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 complete the procedure. 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.

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. 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.

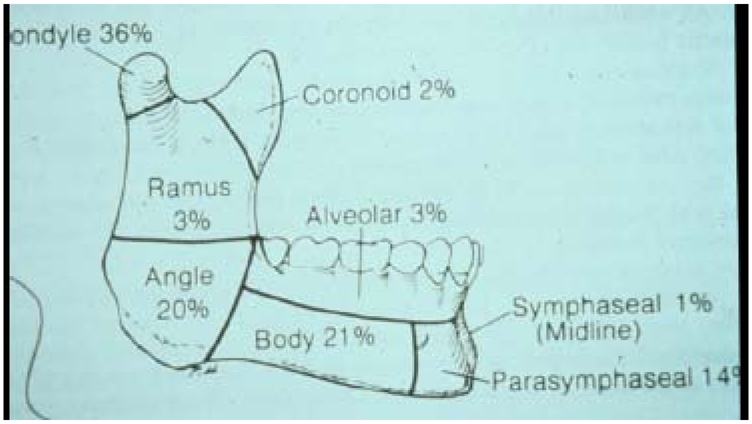

Figure 2. Diagram showing the locations and frequency of mandible fractures

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.

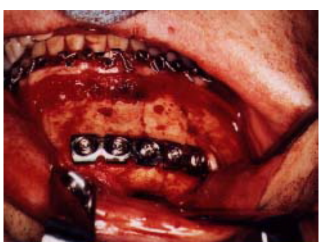

Figure 3. Internal fixation

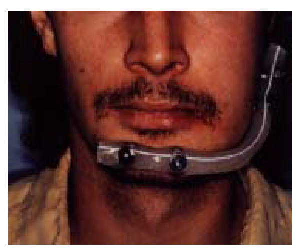

Figure 4. External fixation

Maxillomandibular Fixation: A Brief Overview

MMF is the technique most commonly used to treat non-displaced fractures of the mandible. It 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 loops extending from the arch bars, which 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.

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 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 and 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 to position the jaw (either forwards or backwards) so that the teeth come down on top of one another.

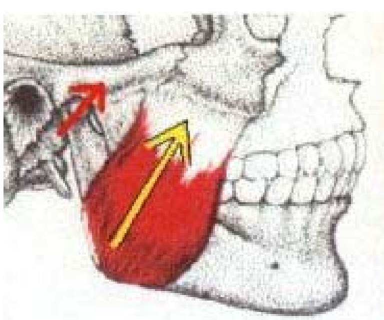

Figure 5. Diagram showing the masseter

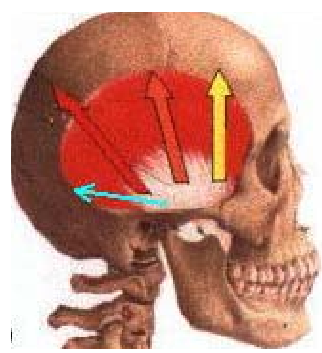

Figure 6. Diagram showing the temporalis

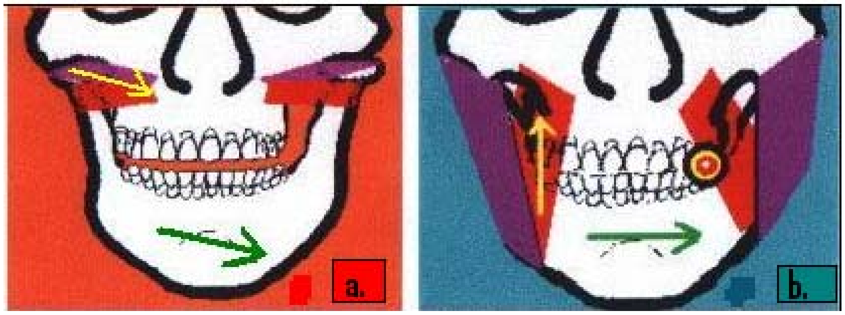

Figure 7. Illustration of the movement allowed by the pterygoid

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 holes are drilled in between the canine and the first pre-molar using a centre drive hexagonal screwdriver. The cortical bone screws that we will be 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. The following picture, Figure 8, shows the use of cortical bone screws; however, our design will use magnets rather than rubber bands to hold the upper and lower jaw together.

Figure 8. Photograph showing placement of screws

This design will feature aluminum nickel cobalt (AlNiCo) magnets, because this type of magnet is most easily manufactured to the specific size and dimension that we need. For this design, we will use rectangular magnets with a pre-drilled hole. The screw will pass through the hole in the magnet and be screwed into the jaw (See Figure

9). The head of the screw will be large enough to prevent the magnet from sliding off of the screw.

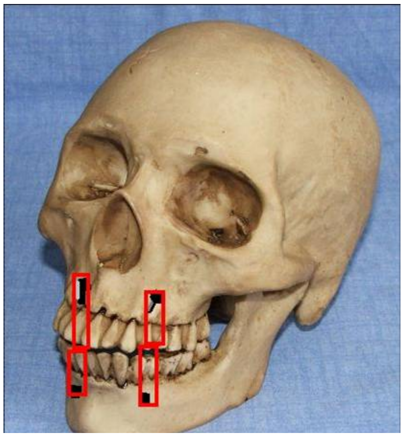

Figure 9. Diagram showing placement of magnets

The cost of this design will include 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 will cost between $252 and $270, depending on which length is used. The AlNiCo magnets cost about $0.64 a piece. 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/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. The doctor would 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

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 side 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.

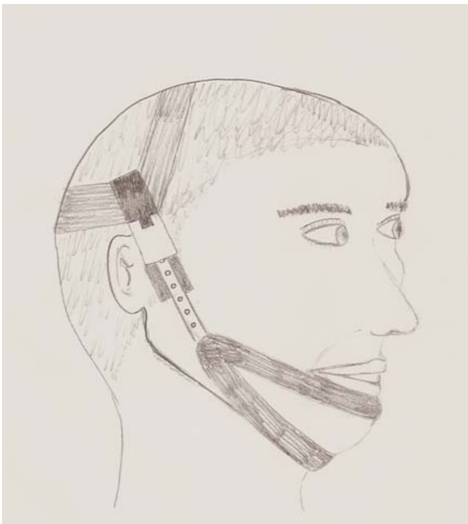

Figure 10. Sketch of external stabilization design

This design is cost-effective, as it costs only $70, but it may not be the most pleasing option for the patient. 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, only 16 brackets will need to be applied. These brackets will be applied to the first and second premolars (also known as bicuspids) 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.

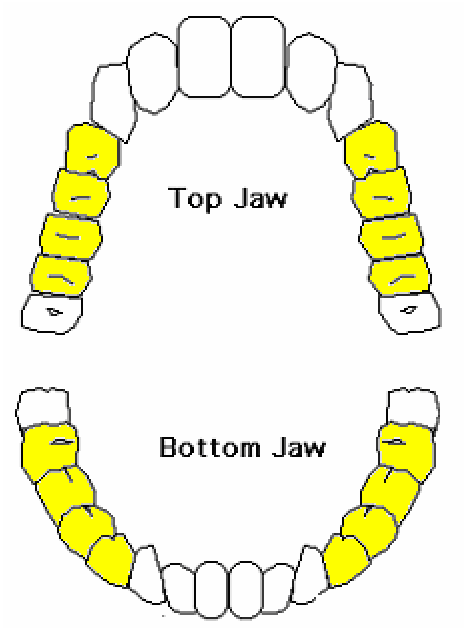

Figure 11. Diagram highlighting teeth used for bracket placement in Design 3

These brackets will then be linked together using elastics in the form of a power chain. This power chain can be seen in Figure 12. After the 4 sets of 4 brackets have been connected with the power chain, rubber band connectors are then looped from top to bottom bracket on each side of the mouth.

This method will not only have the quick release that is needed, as the elastic 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 only 16 brackets


Figure 12. Photograph of power chain

are needed (instead of the full set of 32) the procedure should only take 15 to 20 minutes. The adhesive that is used, ‘System I’, can be applied on wet surfaces and only takes 30-45 seconds to dry. It is also different from certain adhesives used in orthodontist offices in that a UV-light is not needed for the glue to fully dry.

The exact materials needed for this design are 16 brackets, approximately 24 rings of elastics (in a linked chain), and approximately 1/30 of the bottle of adhesive. The total cost of this design is about $375. The biggest contributors to the cost are the brackets at $23 a piece. The adhesive costs $216/bottle, but only about 1/30 of the bottle is used for each application. The elastics will only cost about $0.11 for all 24. We are looking into finding cheaper brackets, possibly making our own brackets or re-using the brackets in order to lower the overall cost of the design.

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 wouldn’t stand out. The only drawback to this design would be the high cost.

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 are 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	10	4
Local Anesthesia	5	1	5	5
Total	100	54	76	85

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, 85 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 have encountered in designing a method for fixation of the jaw is that we have been unable to find any information or figures regarding the maximum force exerted by the jaw. Though we have found values for the compression force of the jaw, we are concerned with the force exerted when a human opens the mouth. This is the exact force that our device must be able to withstand in order to stabilize the mandible during the fixation period. If we cannot find this value with further research we may need to conduct an experiment to determine the maximum force that the human jaw can exert when opening.

Another problem we have faced while designing a new, innovative method of fixation is that there are multiple techniques currently available. Our client has requested a device that can be applied more quickly than the arch bars and wires of MMF, and there are currently such devices available. For example, the use of cortical bone screws in conjunction with rubber bands is a procedure currently being used in treatment of mandible fractures. In order to improve upon the efficiency of such designs we have had to fabricate completely new and creative ways of stabilizing the jaw.

One concern regarding our design possibilities is that many of the necessary parts 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. One resolution to this problem is the utilization of parts that can be reused from one patient to the next. Such parts must be able to withstand the high temperatures used in the procedure of autoclaving. Thus, we will aim to use materials that are suitable for use in the human mouth and can be manufactured to fit our design requirements but can also undergo autoclaving.

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 will acquire a model skull and apply our device as a simulation of application to a patient.

References:

Brady, Tom. Interview with Emily Maslonkowski. Reed Switch Development Co., Inc. 5 Oct. 2005.

Chang, Edward W. "Mandible Fractures, General Principles and Occlusion." E-medicine. 3 Oct. 2005. Columbia University Medical Center. 5 Oct. 2005 <http://www.emedicine.com/ent/topic170.htm>.

Goldman, Kim E. "Mandible Fractures." Ask An Oral & Maxillofacial Surgeon. 2005. 8 Sept. 2005 <http://www.calweb.com/~goldman/mandible_fractures.html>.

Gray, Henry. Ed. T. Pickering Pick and Robert Howden. 15th ed. New York: Bounty Books, 1977. 305-316.

Ismail, S.f. H., and A. S. Johal. "The role of implants in orthodontics." Journal of Orthodontics 29 (2002): 239-245. 15 Sept. 2005 <http://http://jorthod.maneyjournals.org/cgi/content/full/29/3/239>.

"Muscles of Mastication: Form dictates function; Function follows form." Nociceptive Trigeminal Inhibition - Tension Suppression System. 15 Sept. 2005 <http://www.nti-tss.com/slide1.htm>.

"Orthocare Implants and Instruments." Orthopaedic Screws. 2005. 30 Sept. 2005 <http://www.careimplants.com/>.

Peltier, Jacques, comp. Mandible Fractures. 26 May 2004. UTMB Dept. of Otolaryngology. 11 Sept. 2005 <http://www.utmb.edu/otoref/Grnds/Mandible-fx-040526/Mandible-fx-040526.htm>.

Prater, Michael E., comp. Mandibular Fractures. 27 Nov. 1996. UTMB Dept. of Otolaryngology. 20 Sept. 2005 <http://www.utmb.edu/otoref/Grnds/Mandibular-fx-961127/Mandibular-fx-961127.htm>.

Scanlon, Carrie. Interview with Nina Lewis. Madison: Associated Orthodontics. 2 Oct. 2005.

Stierman, Karen, and Byron J. Bailey. "Mandible Fractures." 14 June 2000. 10 Sept. 2005 <http://www.utmb.edu/otoref/Grnds/Mandible-fx-0006/Mandible-fx-0006.pdf>.

Thota, L. G., and D. A. Mitchell. "Cortical Bone Screws for Maxillomandibular Fixation in Orthognathic Surgery." Journal of Orthodontics 26.4 (1999). 15 Sept. 2005 <http://jorthod.maneyjournals.org/cgi/content/full/26/4/325>.

Maxillomandibular Fixation
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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.