Right Angle Screwdriver

December 9, 2009

Team:

Scott Carpenter - Team Leader

Chuck Donaldson - Communicator

Nate Retzlaff - BWIG

John McGuire - BSAC

Client:

Ashish Mahajan, MD Resident

Plastic and Reconstructive Surgery

Advisor:

Thomas Yen, Ph.D.

Abstract

In the case of mandible fractures, titanium plates are fastened to the mandible with titanium screws to aid in the healing process. Current procedure requires an external incision on the cheek to gain access to these screws resulting in a scar following operation. A right angle screwdriver could eliminate this need by allowing access to the screws from inside the mouth. However, such a device would need to meet many specifications including size and safety restrictions. Three ideas involving a variety of gears and sprockets were taken into consideration: a worm and wheel gear, right angle gears, and a sprocket and chain design. Through research and an evaluation of the design ideas, a sprocket and chain concept was chosen as a promising solution to this problem. Following the decision of a final design, a final prototype was built to specifications.

.

Table of Contents

Problem Statement

The goal of this project is to design a right angle screwdriver for the reconstruction of the mandible. The right angle screwdriver must be able to fit through a 5 cm incision inside the mouth while providing enough torque to tighten the screws down on to the plate in accordance with standard surgical protocol for safety and sanitation.

Background

Motivation

Facial reconstructive surgeries sometimes include the fastening of plates, normally made from titanium, onto the skull to keep bones correctly placed during the healing process. An incision must be made somewhere on the face, as in all facial reconstructive surgeries, to gain access to the bone in order to attach these plates. Consideration for post-operative scar tissue is taken into consideration and incisions are usually made in places that won't be aesthetically marring. Unfortunately, not all surgeries can be performed without leaving a visible scar due to the limitations of the instrument used. The implementation of a right angle screwdriver that could fit though an incision of standard size (5 cm) and still effectively seat the screws into the bone would simplify the procedure for the surgeon by allowing better access to the screws. It would also improve the procedure by eliminating the need for another incision and thus not leave any external scarring on the patient's face.

Current Procedure

Figure 1: Attaching plates with a straight screwdriver.

http://products.synthes.com/KYO_US/kyo_us_cmf/home/pdfframeset.asp?MEDBODYRGN=MANDIBLE&MEDPRODFAMILY=METALLIC%20PLATES%20AND%20SCREWS&MEDPRODNAME=2.0%20MM%20MANDIBLE%20LOCKING%20PLATE%20SYSTEM

Reconstructive surgery of the mandible is a case in which the limitations of the instrument used in attaching the plates leaves a visible scar. The surgeon makes an incision inside the mouth, approximately where the gum and cheek meet, to insert the plates to be attached. A straight screwdriver is used to seat the screws that will fasten the plate to the bone. The only way to gain access to the screws is to make an incision on the exterior cheek. In order to reduce the amount of scar tissue, the surgeon limits the size of the incision made, which in turn makes it difficult to reach the screws and is a constant source of frustration to the surgeons.

Design Constraints

The right angle screwdriver prototype must:

1. Be in line with surgical safety standards.
    a. This includes non toxic materials, sanitary parts, and safe mechanical components that will not cause harm to the patient
2. Be able to apply proper torque without compromising the structural integrity even after repeated uses.

3. Be durable enough to withstand multiple uses during the day for extended periods of time.
4. Withstand body temperature and also be able to function with bodily fluids such as saliva.
5. Be easily operable with 1:1 torque ratio so the surgeon can maintain feel of the screw while seating.
6. Fit through incision of 5 cm and screw head cannot be more than 1.5 cm wide.
7. Be composed of non-toxic, non-corrosive material. This material must also be able to withstand steam autoclaving for sterilization purposes.

Current Apparatus

Figure 2: Example of existing right angle screwdriver

http://www.matcotools.com/ProductImages/RSD5A.jpg

Right-angle screwdrivers are commonly found in any typical hardware store in many different designs. These drivers are designed to tighten screws or bolts in hard to reach, space-confining areas. However, these current right angle screwdrivers are not appropriate devices for surgical applications.

The basic structure of the current screwdriver used in surgery looks similar to a typical straight screwdriver in a family home. There is a handle that fits into the palm of your hand and metal shaft with a screw head at the end that attaches to the screw. The main difference in the existing screwdriver is the feature of a ball bearing handle that rotates the metal shaft. This ball bearing idea makes it easier on the surgeon because it only takes 2 fingers to turn instead of rotating the whole hand and wrist like a regular screwdriver. Another unique part of the current apparatus is the interchangeable screw heads. If the surgeon changes screw size, the metal shaft containing the screw head simply pops off the handle and a new shaft with a different screw head is simply clicked in; this makes it fast and easy to change sizes in the surgery room. The screw head itself is also unique because it is specifically designed for the titanium screws used to hold down the plates. Because the screws are so small, the screw head is designed to keep the screw on no matter which way the screwdriver is turned or held. The slipping is reduced because of a flattened version of a Phillips head that allows the entire screw head to turn the screw. Regular Phillips heads only used the tip of the screw head to seat screws. The current apparatus also includes a sleeve that slides down over the screw that helps initialize the seating of the screw.

<u>Design Ideas</u>

Worm and wheel design

The first design idea is a worm and wheel concept. The worm gear has a thread that is angled so that it turns the wheel gear which is perpendicular to its own axis of rotation. Because the teeth of the gear are angled, one full rotation of the worm results in reduced rotation of the wheel. This creates in a huge torque output to input ratio but also requires

Figure 3: Worm and wheel

http://static.howstuffworks.com/gif/gear-worm.jpg excessive turning of the handle to create this output. For example, the ratio of turns could be about 20 turns of the handle for every one turn of the screwdriver head. A casing would be placed around the outside of the gears in order to protect the device and the patient's mouth.

The worm and wheel design is advantageous because it allows the user to apply torque to a handle directed straight out of the mouth. Because of the nature of the gear, the rotating motion is translated perpendicular to the handle. This creates the necessary angle for inserting a screw into the mandible within the cheek, while having dimensions small enough to fit inside the mouth. Also, the extreme torque provided would make it easier to seat the screws into the bone.

The main problem with this design is the number of turns it would require to fully rotate the screw. The average surgery requires between 4 to 48 screws, each of which requires about 8 turns using the current screwdriver. A typical surgery using the worm gear would drastically increase the required turns to properly seat the screw and would fatigue the surgeon. It is also important for the surgeon to be able to feel the screw during the surgery in order to be safe and accurate. A good feel range is approximately a one to one ratio (Mahajan, 2009). The high torque output of the worm gear decreases the amount of "feel" the surgeon has while inserting a screw.

Bevel Gear design

The bevel gear design uses conical gears which allow for a 90-degree angle between the axes. The gears allow for a 1:1 torque ratio and can be modified based on the size of each gear. This design also requires a casing for protection of the mouth and device.

Figure 4: Bevel gears

http://www.elizabethtown.kctcs.edu/members/jnail/BRX-Gears_files/image004.jpg

The main advantage of the bevel gear design is that it can provide a 1:1 torque ratio. This is very important in surgery because it allows the surgeon to better feel the screw going in. Fatigue would be similar to the current device, as the number of rotations on the handle would be the same as the number of turns for the screw. The design also allows for easy enclosure because all the moving parts are in a small space. This aspect allows for a simple casing to fit around the two right angle gears, making it fit surgical safety standards.

The most critical flaw with the bevel gear design is that it will not fit the size specifications. In order to fit design requirements of sanitation and torque application, stainless steel must be used for the bevel gears. However, stainless steel bevel gears that are small enough could not be found.

Sprocket and Chain design

The sprocket and chain design involves two sprockets, connected with a chain that translates torque over a distance. There would be a sprocket on each end of the screwdriver shaft: one sprocket attached to the head of the screwdriver and the other attached to the handle. The surgeon would turn the handle, causing the sprocket to turn the chain, which would result in equitable rotation of the sprocket and screw head. The torque ratio could vary depending on the size of each sprocket and could allow for a 1:1 torque ratio. This would provide an appropriate feel for the surgeon and maintain a reasonable amount of turns per screw. The apparatus would be encased in metal to ensure safety and sanitation.

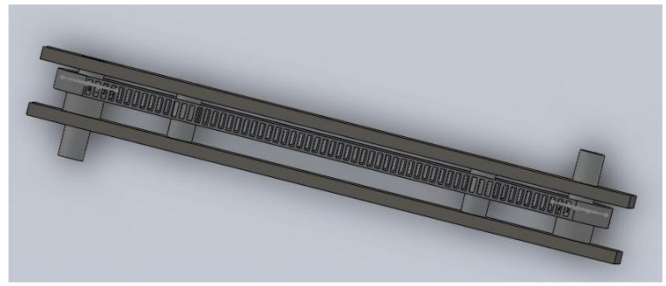

Figure 5: Sprocket and chain

The sprocket and chain idea has many advantages. It provides a 1:1 torque ratio, and allows for a small width, making it easy for it to fit into small incisions. This design allows for the integration of the current screwdrivers parts, eliminating the need to design a custom handle and head. This would also make it easy for the surgeons to use, as they have already had experience with the existing model.

The main disadvantage to the sprocket and chain design is that the parts would be hard to sterilize. It could be difficult to case the chain and sprockets in a manner that would also allow easy access for cleaning. The moving parts could also cause wear on the sprocket and chain over time.

Design Matrix

Criteria		Possible Designs		
Considerations	Weight	Sprocket and chain	Worm and wheel	Right angle gear
Safety	10	10	10	10
Ease of Use/Ergonomics	20	18	12	13
Size	35	32	32	15
1:1 Torque provided	25	23	12	23
Durability	10	8	10	10
Total	100	91	76	71

Table 1: Design Matrix

In order to evaluate our three alternative design ideas, a design matrix was created with various weighted criteria. Each design was given a rating for each of these categories (Table 1).

The heaviest weighted criterion of this product is size. Due to the restrictions of the surgical operation, the final size of the device is critical to its effective use. The device driver head needs to fit into an incision size of 5 cm, with a width of no more than 1.5 cm. Size also directly relates to the surgeon's ability to see what they are doing. If the driver head is large, the surgeon loses sight of the procedure. Therefore size was weighted with 35 of the 100 points. Both the sprocket with chain idea and the worm with wheel idea scored high in size because of the ability to acquire very small parts that allow minimum thickness of the device. However, the bevel gear concept scored poorly because of the gear assembly size. The necessary alignment of each gear more than doubles the width required to create the mechanical assembly.

The next most important criterion of the device is a 1:1 torque ratio (25 of the 100 points). The 1:1 torque ratio provides the surgeon with the most "feel" when operating.

Having more feel allows the surgeon to get a good idea of when the screw is seated even if he can't see very well (which is the case with this operation due to the incision location in the mouth). The sprocket and chain idea scored well because of the ability to adjust sprocket sizes in order to optimize the torque ratio. The bevel gear concept also scored well because, once again, the size of the gears are the same and simply translate the rotational force into a perpendicular plane, thereby turning the end piece just as much as the handle (a 1:1 ratio). The worm and wheel idea scored poorly in regards to a 1:1 torque ratio. This is because worm and wheel concepts are based on the idea of changing the input to output ratio of both torque and motion. Worm gears, for example can change an input of 20 turns into an output of one turn, while drastically increasing the torque. This would result in an enormous loss of feel to the surgeon.

Ergonomics and ease of use was also deemed an important consideration to the project. The sprocket with chain idea scored highest in this category because of its ease of operation. The design allows for good visual of the operating area for the surgeon. It can also be encased with a multitude of different options allowing for a very comfortable device for the surgeon to use. The bevel gear idea didn't score as well with ease of use because of its bulky head; this bulkiness inhibits the ability for the surgeon to clearly see during the operation. However, one positive aspect of the bevel gear is the previously mentioned 1:1 torque ratio. The worm and wheel design would improve upon the ability to see while operating. However, the mechanics of worm and wheel gears would create an inefficient device for fastening screws. The number of turns on the handle required to seat a screw would immensely increase, increasing fatigue on the surgeon as well as difficulty of use.

Safety accounted for a portion of project design criteria as well. All three concepts received full points in the safety category. Each design requires moving parts to translate rotation from the handle to the screw head. Therefore, these moving parts would need to be enclosed to protect the safety of the patient. Since the casing material and shape could be chosen to fit the safety requirements, all three designs received full point values.

The final criterion that the team considered was durability. The final device should hold up to stress during operation as well as frequent cleaning. The worm/wheel and right-angle gear designs both received maximum points for this category because these mechanical concepts have withstood the test of time in similar applications. The materials for these designs are metals, meaning that chemical interactions or weakening of the gears due to sanitation wouldn't pose a problem. However, the wheel and sprocket idea could create a problem because of the potential breakdown primarily due to the chain. The chain involves many jointed segments that could weaken through repeated sterilizations. This received a small point deduction for durability. However, the wheel and sprocket design could also allow for metal components where durability is still very competitive with the other alternative designs.

As you see in the table of our design matrix (Table 1), when the point values were totaled, the wheel and sprocket idea strongly beat out the other two alternative designs.

Final Prototype

Actuation

The final prototype changed from the initial plans for the design. Casing was changed from a solid stainless steel frame to a top and bottom stainless steel plate with a stainless steel meshing around the sides. This was because if the prototype would've been entirely enclosed by stainless steel plates, the inner components wouldn't be able to be sterilized and the device couldn't be taken apart because the prototype would be permanently assembled. The meshing allows for ordinary sterilization techniques to be carried out upon the final device because the whole device can be disassembled. Another aspect of the final prototype that changed from the initial design was the handle and screw head. The initial design called for the prototype handle and screw head to be made from the current apparatus components. However, acquisition of the desired screwdriver handle and head posed a problem. The cost of the current apparatus far exceeded our budget and medical accreditation is required to order these parts. Therefore, the team decided to acquire nylon handle with a stainless steel shaft and the smallest stainless steel Phillips bit that could be found. Although this kept within budget constraints, it affects the efficiency of the device since the screw head isn't designed to specifically fit the screws used during operation. However, all components that were decided upon are still completely autoclavable holding to the design specifications.

Fabrication

After we received the correct parts to build the prototype, fabrication began. First, the bore size of each sprocket was adjusted using a lathe in order to fit the handle shaft and the screw head. The stainless steel plate was then cut into two 17.8 cm pieces to serve as the top and bottom plates of the device, meaning the overall length of the device is 17.8 cm. Holes were then drilled into each plate using a drill press in order to fit the diameter of the shaft and screw head. After all holes fit specifications, the thickness of the apparatus was taken into consideration. A file was used to reduce the width of each sprocket until they both matched in width and could still hold the shaft without slipping. The team was unable to file down the sprockets to the desired width because of adhesive concerns. Since a cold-weld epoxy was to be used for fastening the driver shaft and bit to the sprockets, maximum surface area for adhesion was required. Therefore, the sprockets weren't filed down significantly. Additionally, due to excessive cost, the existing specialized driver bit wasn't attainable, so a similar Phillips head was used.

Figure 6: Final prototype

The structural integrity was maintained with the use of two support spaces. Drilling two holes in the middle of the both plates, bolts could be placed through the holes and the width could be adjusted using threaded spacers. Also, washers were placed on the outside of the sprocket containing the screw head in order to insure that the chain would not touch the stainless steel plates. When the spacing was finalized, the sprockets were attached to each shaft using a cold-weld epoxy. This ensures that both shafts will not slip during use. Finally, after all the inner parts were put together and working, a casing had to be fabricated. Although the easiest concept was to have completely enclosed the entire device with the stainless steel plates, this wouldn't allow for any sort of maintenance or cleaning. Instead, the team opted to enclose only the operating portion (lower 14.5 cm) of the device leaving 3 cm of the device nearest the handle open. Since the handle end will not be used within the mouth, this shouldn't create a problem. Stainless wire mesh was used for the casing; the mesh was bent to cover any moving parts and any openings that would be harmful to the patients. The mesh attaches to the bolt spacers that help keep a rigid structure.

Testing Procedure

The key testing elements of our project involves the required torque to seat a screw in a mandible surgery as well as the torque capacity of our final prototype which should far exceed the required torque.

To test the required torque, a torque measuring screwdriver calibrated in inch-ounces was acquired from the student shop. The team used the torque measuring screwdriver to fasten one of the titanium screws into the provided skull, which is comprised of material with similar density as human bone (Mahajan, 2009). The torque measuring screwdriver applies torque on a screw until the torque being applied exceeds the user-defined torque setting (0 to 100 inch-ounces). The team found that to seat one of the screws used in the mandible surgery, 26.0 inch-ounces of torque was required. By converting this into a more universally understood torque rating, the team found that 0.135 foot-pounds of torque will seat a titanium surgical screw into the mandible. This torque requirement was significantly lower than initially expected. Initializing the seating of the self-tapping screw proved to be a challenge; although once the self-tapping screws are started, they are easily seated. The team found that screws easily slipped when initially tightening because a typical bit was used rather than the specially designed, flattened head found on the current apparatus.

The team needed to ensure that the final prototype provided enough torque. However, since the maximum torque would occur when the chain would snap, testing for the maximum applied torque wasn't an option. The mechanics of measuring the torque from the prototype required some additional ingenuity. Since the screw would need to be tightened by the prototype, the torque-measuring screwdriver would need to be connected to this system somehow to compute a torque measurement of the prototype. The team devised a plan to take a wooden dowel, and place a screw on each side. One screw would very closely represent the titanium screws used in the surgery. The first screw inserted into the dowel will be a small Phillips head screw. The other side of the dowel will have a regular #2 Phillips bit placed in it, which can easily be fit to the torque-measuring screwdriver. By placing the prototype driver head on its screw on one side of the dowel and the torque-measuring screwdriver on the

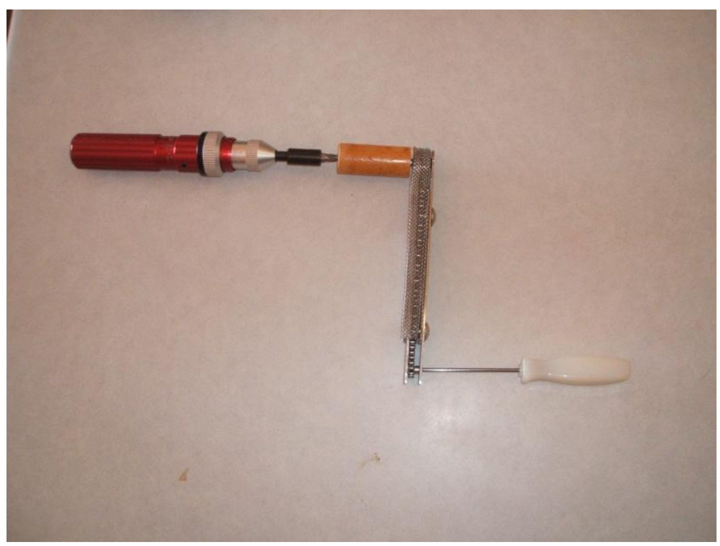

Figure 7: Testing layout with dowel intermediate and final prototype

other side and working incrementally upwards in torque applied, the team was able to find an easily applied torque for the prototype.

The prototype almost effortlessly applied the required 26 inch ounces (0.135 foot pounds). The torque measuring screwdriver used in testing maximized at 100 inch ounces (0.53083 foot pounds); seeing as though the prototype maxed out the torque-screwdriver, four times the required torque was easily applied by the prototype.

Conclusion

Future Work

Although the team has completed a functional prototype, specifications were not fully met. The largest problem posed in the final prototype, is that the overall width of the screwdriver head (from the bottom of the bit to the top frame plate) measures 1.75 cm, when the specifications stated a maximum width of 1.5 cm. This specification was unable to be met due to previously mentioned concerns of surface area for adhesion of sprockets to the handle and driver head.

Alternative casing options could be an area for improvement in regards to future work on the design. The current stainless steel wire meshing holds up to sterilization techniques, but with the attachment design, occasional catching of the chain can create resistance while operating. A more ergonomic handle could also be an area where the design could be altered more to the liking of the surgeon.

In regards to future testing, the device would need to be tested to ensure that constant torque is applied over time, and that the structural integrity of the device holds up with repeated use.

Delivery to Client

Upon completion of aforementioned tasks, the device can be delivered to the client, Dr. Ashish Mahajan. After a brief explanation of device operation and limitations, the right-angle screwdriver could potentially be put into use for fastening titanium plates in reconstructive surgeries of the human mandible although it is slightly out of size specifications. The preferred sterilization techniques for the device's longevity will also be explained to the client upon delivery.

Ethical Considerations

During the design process, ethical considerations must be taken into account. As far as the fabrication of the right angle screwdriver prototype, subjects such as patent rights, safety of the device, and testing results were all considered. The fabrication of this device could easy conflict patent law with screwdriver heads, and other parts. The screwdriver head specific to the screws used in the surgery is a patented tool and therefore could not be used without that company's permission; to do so would violate the law and could result in a possible lawsuit. The safety of the device was also taken into consideration during the designing of it. Although the intent of the project was to make a tool that accomplished the surgery, patient safety was always paramount. If a screwdriver were made that is extremely effective during the surgery, but puts the patient at risk, it would be irresponsible to make it. During testing of the prototype, were the desired results not attained, presenting false data to agree with expectations would be unethical. It is important that those involved in any part of scientific testing report results truthfully. The team examined all of these factors and their relevance to the project during the design process and then applied them to create a safe product.

Bibliography

- Mahajan, A-Resident UW Hospital Dept. of Plastic Surgery. (Personal communication, September 14, 2009)
- Synthes CMF. *2.0 mm Mandible Locking Plate System: Advanced plating system for trauma, microvascular reconstruction, and orthognathic surgery. 2000.*

Product Design Specifications for BME 300 Group 24: Right Angled Screwdriver

September 23, 2009

Group Members: Charles Donaldson, Scott Carpenter, Nate Retzlaff, John McGuire

Problem Statement:

The aim of this project is to design a right angle screwdriver for use in surgery for facial fractures. The current procedure attaches titanium plates to the mandible by making a small incision on the exterior of the face, which makes it difficult to position the screwdriver effectively and leaves a scar. The right angle screwdriver must be able to fit through a standard incision inside the mouth and provide enough torque to tighten the screws down on to the plate.

1. Design Requirements:

The device must meet all of the client requirements

a. Safety: Mechanical components should not be exposed to tissue during standard procedure. Device should be in line with surgical safety standards including non toxic materials and sanitary parts.
b. Accuracy and Reliability: Device should give constant torque in repeated uses. Structural integrity should not lessen over time. It should be able to apply enough torque to set a screw into human bone without compromising structure.
c. Life in Service: Device should withstand multiple uses during the day for extended periods of time depending on the surgery. Device must be able to screw in 48 screws maximum per surgery.
d. Operating Environment: Device must withstand room temperature while in storage, in use, and idle. Device needs to withstand body temperature and work while surrounded by bodily fluids such as saliva.
e. Ergonomics: Device should be easily operable by a surgeon keeping comfortable handling and approximate 1:1 torque ratio in mind. Device should not cause excessive fatigue to surgeon.
f. Size: Screw head and casing should fit through incision size of 5 cm. Device must be no more than 1.5 cm wide.
g. Materials: Device must be composed of non toxic and corrosion resistant material. Material must also be able to withstand thorough and repeated cleaning.

2. Production Characteristics:

a. Quantity: One reproducible working prototype is necessary.
b. Target Product Cost: Under $300

3. Miscellaneous:

a. Standards and Specifications: Device must pass surgical tool standards
b. Customer: Client emphasizes the benefit of seeing operation and would ideally like to feel the operation but not necessary. Client also stressed the need for an ergonomic handle which could be taken from existing device. Screw head could also be taken from existing device.
c. Patient-related Concerns: Device must not cause any harm while device is being used. Device must be sterilized between surgeries.
d. Competition: Products that already exist include straight angle screwdrivers and ones with mild angles but none that are right angles.