Right Angle Screwdriver

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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 were taken into consideration. Through research and an evaluation of the design ideas, a sprocket and chain concept was chosen as a promising solution to this problem.

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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 standard incision inside the mouth and provide 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. As in all surgeries, an incision must be made somewhere on the face 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.

Current Procedure

Reconstructive surgery of the mandible is such 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 Philips head 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 effectively and is a constant source of frustration to the surgeons.

Figure 1: Attaching plates with a straight screwdriver

The implementation of a right angle screwdriver that could fit though an incision of standard size 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.

Design Constraints

The following requirements must be included in the design process:

1. Prototype must 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. It should be able to apply proper torque without compromising the structural integrity even after repeated uses.
3. It should be durable enough to withstand multiple uses during the day for extended periods of time.
4. The prototype needs to withstand body temperature and also be able to function with bodily fluids such as saliva.
5. One surgeon should be able to easily operate the prototype with 1:1 torque ratio so the surgeon can feel the screw.
6. Device and its casing should fit through incision of 5 cm and screw head cannot be more than 1.5 cm wide.
7. Device must be composed of non-toxic, non-corrosive material. This material must also be able to withstand steam autoclaving for sterilization purposes.

Current Apparatus

The basic structure of the current screwdriver looks similar to an average 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 makes it easier on the surgeon because it only takes 2 fingers to turn and there is less rotation of the hand to turn the metal shaft. 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 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. This allows for screws to stay on the screw head until seated without losing grip or torque.

Design Ideas

Worm and wheel design

The first design idea is the worm and wheel design. The worm gear has a thread that is angled so that it turns the wheel gear that is perpendicular to its own axis of rotation. Because the teeth of the gear are angled, one full rotation of the worm causes reduced rotation of the wheel. This increases the amount of torque that can be applied with the gear, but it also increases the number on times the gear has to be turned to achieve a full rotation. 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.

Figure 2: Worm and wheel

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 large amount of 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. 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 to the mouth and device.

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.

Figure 3: Bevel gears

Fatigue would be similar to the current device, as the number of rotations for the handle would be the same as the number of turns for the screw. The design also allows for easy enclosure, which makes it safe for operation and simplifies cleaning.

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 one 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.

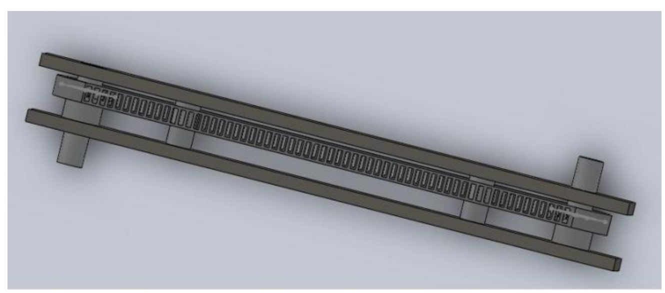

Figure 4: Sprocket and chain

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

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 (Figure 5).

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. The bevel gears are too bulky to allow for a clear path of sight for the surgeon. However, the ergonomics of the bevel gear are strong because of 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 (Figure 5), when the point values were totaled, the wheel and sprocket idea strongly beat out the other two alternative designs.

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

Figure 5: Design Matrix

Future Work

Although the prototype design ideas have been isolated and evaluated, there is much work ahead to finalize the device.

There is a need for some testing to be done to find the requirements of the device. The torque required to seat the 2.0 mm cross-head screw into the human mandible must be measured so that the device can be designed to apply this torque. Once the device has been fabricated, it will need to be tested for its torque load capacity. The torque load capacity of the device should easily exceed the required torque to seat the screw during operation.

The layout of the final device also needs to be considered. The prototype has been built given structural integrity by basing the design off of two 1/8" nickel-coated steel bars. It was found that this offered plenty of rigidity for the device, ensuring that thinner steel can be used for the final design. The casing of the moving parts must also be considered. It would be mandatory that the moving parts of the sprocket and wheel can be accessed, which requires a removable casing. By disassembling the product, all moving components could be separately sterilized. This also brings up aspects of the device's durability. Research must be conducted on materials that can be used for the device. The material must hold up to frequent exposure to potentially harmful chemical compounds used in sterilization of the surgical equipment. The final device must not lose any structural integrity when exposed to cleaning agents, blood, saliva, or other common factors in the operation.

Other future work involves the ability to replace screw heads on the device. When working with screw heads, often driver heads become worn or stripped after extended use. Replacing the entire device would be quite costly; so an interchangeable head or bit would eliminate this need. This would allow for the device to be used on different screw head types used in surgeries as well (spider drive, cross-head, or flat head).

References

Pictures

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Product Design Specifications for BME 300 Group 24: Right Angled Screwdriver
September 23, 2009

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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.