

UNIVERSITY OF WISCONSIN MADISON

Orthopedic Drill Stop

Biomedical Design

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Client

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Abstract

Our client Dr. Timothy O'Connor is a resident at the UW Hospital. He is concerned with the nerve and tissue damage associated with the over penetration of a drill bit when drilling through a bone. Tissue damage can occur when the drill bit penetrates as little as four millimeters through the back side of the bone. The current practice for surgeons is to rely on experience, pressure, and auditory feedback in order to stop the bit before over penetration occurs. The device must be able to withstand up to 20 Newtons of pressure without slipping and accomplish the task within 15 seconds to minimize heat transfer to the bone. In this report three different designs are evaluated using a design matrix. A design using a worm gear and thumb wheel has been chosen to proceed to the prototyping stage, and will be tested using a device Dr. O'Connor designed.

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Background

Client Description

The client Dr. Tim O'Connor is a Resident in Orthopedic surgery at the UW Hospital. He is conducting research involving eliminating nerve and tissue damage that occurs during orthopedic drilling, primarily on the extremities of the body. He has proposed a project to create a device that stops the drill bit within two millimeters of the posterior of the bone. This device would limit tissue damage as well as simplify the process for determining the length of the screw to be inserted.

Orthopedic Drilling

The focus of this device is to increase the precision with which a bone can be drilled without damaging tissue behind the bone. Damage can be caused by over penetrating as little as 4 mm past the bone. During the process of drilling, an orthopedic surgeon typically relies on experience and the feel of the drill as it penetrates. With practice surgeons can expect accuracy of approximately 4 mm, but this varies depending on orientation of the bone and type of drill and bit being used. In a study performed by Praamasma, it was found that general residents plunged deeper into the tissue beneath the bone than surgeons. With the addition of distracting noise the residents and surgeons were both negatively affected [1]. After the bit penetrates the bone the surgeon must determine the proper length of the screw to be inserted. A separate device is used to gauge the length of the screw to be inserted (Figure 1). This process takes time and requires the use of an additional device. Bone can be damaged by overheating due to the drill bit which requires surgeons to not only be precise with the procedure but work as quickly as possible [4].

Figure 1: Device used to gauge length of screw, which is operated by inserting into screw hole hooking the tip of the gauge on the posterior side of the bone. It can be difficult to determine if tip is hooked on bone.



Existing Devices

Drill Guide

The device shown in Figure 2 is an example of an orthopedic drill guide. It is made to have two size options for each separate device, but a surgeon would have access to multiple sized devices. The sizes of the device depend on the size of the drill bit being used. The device holds the drill bit securely to ensure it is driven straight through the bone allowing easier penetration for a screw. This device has no method of stopping the bit once it has penetrated the bone.



Figure 2: One gauge of drill guide

<http://www.alibaba.com/product-free/108852771>

Spinal Drill Guide

A spinal drill guide (Figure 3) is a precise way to stop the drill bit once it has drilled through the bone. In order to use the device the surgeon must first know the diameter of the bone, and set the device in advance to stop the bit at this pre determined depth. Spinal guides are adjustable for any length of screw that would be required and are easily adjusted by loosening a set screw, repositioning a slide, and retightening the screw. This device has been tested and has been found to be simple, ergonomic and accurate. The problem with this device is the need to know the diameter of the bone prior to drilling. In most orthopedic surgery procedures the diameter is unknown prior to drilling [2].



Figure 3: Spinal Drill Guide

ACRA-Cut Smart Drill

The ACRA-Cut Smart bit is shown in Figure 4. It has two offset bits, an inner and an outer bit. The drill bit is only allowed to operate when the bits are engaged; this occurs when pressure is applied to the inner bit. Once pressure is released from the inner bit and the bits become disengaged, the drill bit immediately stops operating. This is a very important device for neurosurgery because it is imperative that when drilling through the skull there is absolutely no plunge depth into the brain. Although it is perfect for this function, this device is not able to be used for general orthopedic surgeries. The bit is too thick and in



Figure 4: ACRA-Cut Smart bit

order to scale a similar bit down to a usable size the diameter of the inner bit would be too small to handle the torque caused while drilling [4].

www.acracut.com/perforators.html

Prior semester prototype

The previous team that worked on this project designed and prototyped a trigger controlled mechanism. This device works in a similar manner to a caulk gun. Through a system of metal plates and springs, pulling the trigger causes an incremental advance of a metal tube (bit sleeve) of approximately one to two millimeters. This metal tube passes through the main housing of the device, holding the drill bit and preventing over penetration during surgery.

The function of this design is made possible by the location of the three metal plates, all of which the bit sleeve passes through. These plates act as clutches that control the advancement and locking of the tube. The first clutch is located inside the housing and acts as the advancing mechanism. When the trigger is pulled, this plate pushes the tube forward approximately one to two millimeters. The other two clutches act as locking mechanisms.

The first of two locking clutches is located in the interior housing directly behind the trigger and is designed to prevent forward motion of the tube while the trigger is at equilibrium. Pulling the trigger rotates the plate to a vertical position, allowing the tube to advance without the resistive force of friction. When the trigger is released this clutch returns to its original position, creating friction between the tube and preventing motion. The third clutch is located on the exterior of the device and acts as a second locking mechanism. By the use of friction, this plate prevents the tube from returning to its original position when the trigger is released.

This design is not, however, without its flaws. One of the biggest concerns the client still has is slippage of the bit sleeve. Because the design relies solely on friction to prevent unwanted motion of the drill bit, it is possible to exert enough force to cause the tube to “slip” through the clutches and advance in a large increment to an unwanted depth. This level of force can be reached by the pressure the user applies to the drill while drilling.

Problem Motivation

The client’s request for the construction of an orthopedic drill stop device arises from the need to be more precise and more efficient in drilling through and installing a screw in a bone. Over penetration of the drill bit and screw can lead to severe nerve and tissue damage depending on the location of the screw being implanted. In addition, temperature elevation during drilling can cause irreversible damage and bone necrosis. There are several factors that affect the onset of osteonecrosis, including drill speed and diameter [4]. The longer it takes to drill the bone, the higher the risk for bone necrosis [5]. As a result, the client would like use to develop a prototype which accounts for these issues.

Design Requirements

It is important that the device can be used efficiently and not slow the process of drilling, while advancing the drill bit in 1-2 mm increments. By increasing the speed of drilling, reduction of heat and damage to the bone will occur. By moving in 1-2 mm increments, it will be possible to prevent over penetrations and limit damage to nearby tissues.

In addition, the device needs to be able to resist peak forces of 20 Newtons exerted on the drill bit without allowing the bit to slip. This is the maximum force exerted by an average person driving a drill forward. If the drill bit sleeve is not stopped, over penetration can still occur, resulting in tissue damage. To improve on the current device, some sort of opposing force mechanism must be introduced, as opposed to relying only on friction to resist the drill force.

After penetrating the posterior of the bone the surgeon should be able to easily determine the length of the screw needed and reset the device without difficulty. To do this,

the bit sleeve tube of the prototype will have calibration markings on it, eliminating the need for an additional length-determining tool. If the device is to be used multiple times, it should have an easy reset mechanism.

Alternative Designs

Current Device Modifications

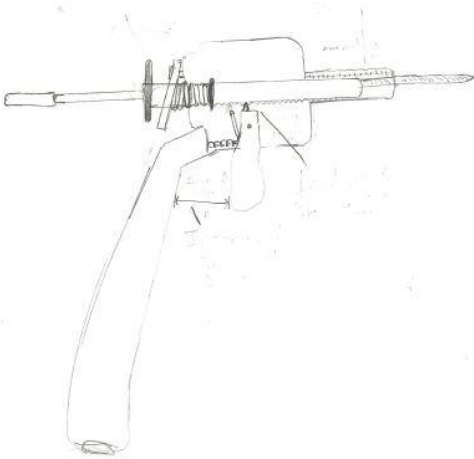


Figure 5 shows the first alternative design: current design modifications. The pins are located on the trigger and move along notches on the drill bit sleeve.

The first proposed design is strictly an improvement on the previous team's final product (Figure 5). The current design uses the friction of metal to stop the hollow cylinder from slipping. It is proposed that this will be improved by cutting notches from the outside of the hollow cylinder and allowing pins to move in and out of the notches allowing the cylinder to advance incrementally. Our group progressed to a design that used a spring loaded trigger of the drill stop as a controller of the movement of two pins on the top and bottom of the hollow cylinder. Pulling the trigger engages the top pin and disengages the bottom pin, and releasing the trigger disengages the top pin and engages the bottom pin. The notches on the top and on the bottom of the hollow cylinder are offset by 1 mm so as to allow 1 mm increment advancements made for each pull or release of the trigger. A more ergonomic trigger and handle assembly is also implemented. There is a drill reset washer attached to the rear of the hollow cylinder which enables easy reset of the device.

Mechanical Pencil Mechanism Design

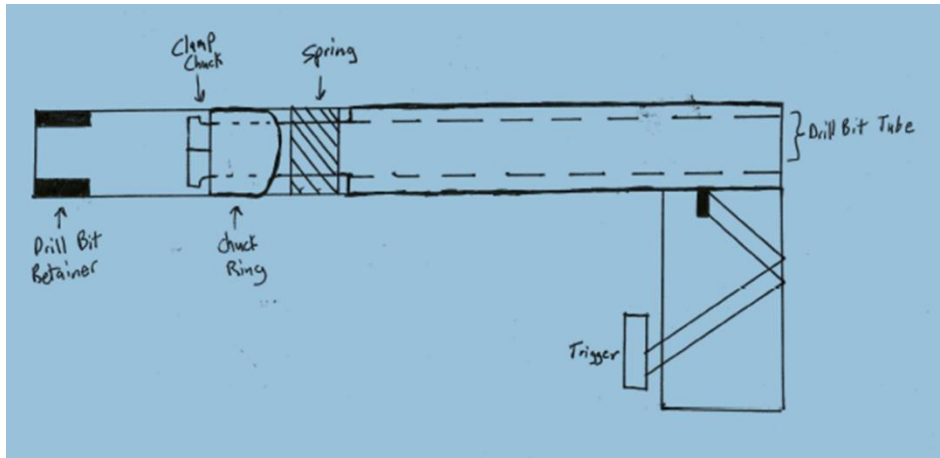


Figure 6: A preliminary sketch of the mechanical pencil design shows how the trigger activates the clamp chuck.

The design resembles a gun and makes use of a mechanism mimicking that used in a mechanical pencil (Figure 6). The drill bit will slide into a metal tube and protrude out the far end. This metal tube will be gripped by a clamp chuck and chuck ring. A trigger pull will push the entire apparatus forward until the chuck ring hits a resistance point and releases from the clamp chuck. The clamp chuck will separate, allowing the metal tube and drill bit to slide forward in the desired 1-2 mm increment. A spring mechanism will return the device to its original position, with the clamp chuck gripping the metal tube at a lower location. The tip of the “gun” will have a material with a high coefficient of friction so that the metal tube and drill bit cannot move freely unless moved by a trigger pull, so that slipping does not occur. The device can be reset after use by pulling and holding the trigger and pulling the metal tube back to its starting position.

Worm Gear Design

The third design involves the use of a worm gear system to advance the hollow cylinder (Figure 7). With a worm gear system, movement of the system is only possible by turning of the worm gear directly and not by turning the attached spur gear. This eliminates the possibility of slip. A crankshaft, which will be spun via a thumb wheel, protrudes out of the housing of the drill stop. When a thumb spins the crankshaft, the worm gear spins and turns a spur gear. This secondary gear pushes a track which is on the exterior of the bit sleeve, and therefore advances the drill bit.

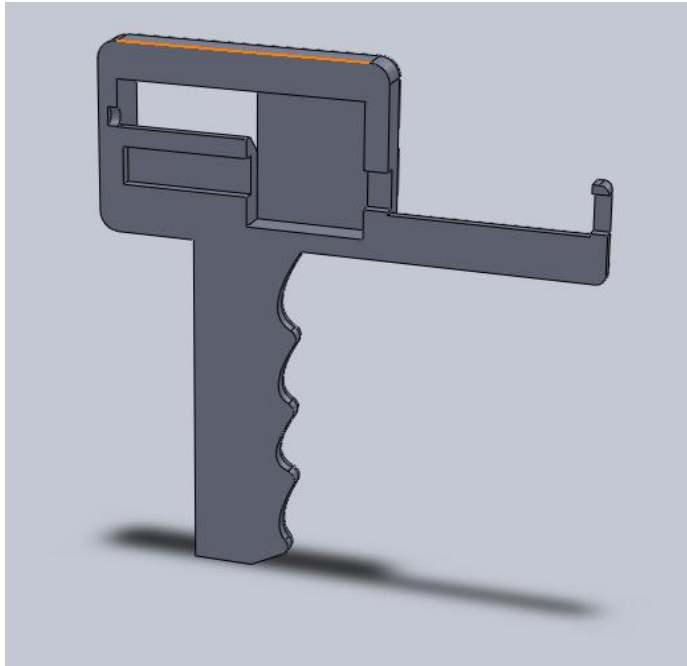


Figure 7: The housing for the worm gear design is shown. The worm and spur gear would rest on top of the drill bit sleeve. The opening shows where the thumbwheel would protrude from the housing.

Design Matrix

In order to assess the value of each of the three designs for an orthopedic drill stop device, a comparison of the proposals was conducted with a design matrix, shown in Table 1 below. The matrix provided a quantitative analysis of which design would prove most beneficial. The categories used for analysis were ability to advance in 1-2 mm increments, prevention of slipping, ease of reset after use, ability to calibrate, and cost. Each category was evaluated on a scale of 1-10, then weighted based on importance to final design. Based on the point breakdown seen in the design matrix, the worm gear design received the most points, so our team has chosen to proceed with this design.

Table 1: The design matrix used for comparative analysis of the design alternatives. Each category was evaluated on a scale of 1-10, and then multiplied by a weighted factor, indicated in the parentheses seen in row headings. The worm gear design will be used at the primary design going forward.

	Current Device	Mechanical Pencil	Worm Gear
Advance in 1-2 mm Increment (3)	5	7	9
Prevention of Slipping(3)	3	5	10
Ease of Reset (2)	3	6	8
Ability to Calibrate (1)	8	9	10
Cost (1)	9	9	5

Total (out of 100)	47	66	88
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Ability to advance in 1-2 mm Increments

The ability to advance in 1-2 mm increments was given the largest weight because of its importance to the application of this device. Since the goal of this device is to prevent over drilling, the ability to limit motion to such an increment is crucial, so that the drill does not penetrate too far beyond the posterior side of the bone and damage other structures, such as blood vessels. The modifications to the current device received the fewest points because it uses friction and a trigger pull to move the drill bit forward, which allows for variance based on the trigger pull force and friction on tube force. The mechanical pencil design was next because although it uses similar trigger and friction mechanisms, the design allows for more uniform motion from these same forces. The worm gear received the most points because it is moved by a wheel instead of a trigger. The movement mechanism involves gears, which are much more precise than moving by friction. The combination of these two changes made this design the best option.

Prevention of Slipping

The ability to prevent slipping was also given the largest weight. When the drill is being used, it pushes against the device with a 20 N. If this is not prevented, it will cause for movement in larger than the desired increments, resulting in the device being ineffective. The current device has demonstrated many problems with slipping, and as there is no absolute stop device in the design, this will still be an issue. The mechanical pencil design will use a material with a high coefficient of friction, which will solve the slipping issue but still leave potential for it under a high enough force. The worm gear design received a perfect score because one quality of a worm gear is that it does not allow for movement except for from the external force, which in this case is from the wheel.

Ease of Reset

The ability to reset the device after use is also important to our client, so it was weighed by a factor of two. The current device has problems with this, as the release mechanism is not easy to use and pulling on the tube is inconvenient, so it received the fewest points. The mechanical pencil design received the second highest point value because it will be an easier release mechanism by using the trigger and will have a part to hold onto while pulling back. The worm gear design was given the highest value because it can be reset by turning the wheel in the opposite direction.

Ability to Calibrate

With orthopedic drilling comes the need to read the depth of the hole so that a properly sized screw can be used. To make this easier, the client desires this device to have calibration markings from which the depth of the hole can be measured. All three devices scored high in this category, because calibration should not be difficult. The drill bit will fit into a metal tube, and as the tube will slide, calibration markings can be easily placed on the outside. The current device and mechanical pencil designs did not receive full points only because of their issue with slipping, which can result in a lack of accurate calibration if slipping occurs once the bone has been drilled through. The degree of point loss deals with the relative potential to slip.

Cost

The cost of both manufacturing the prototype and potential mass production of this device was also considered as criteria, with the client setting a budget of \$200 for production of a prototype and any mass production cost needing to be comparable to current devices on the market. Difference in costs between the three designs arises from the movement mechanism. Since the mechanical pencil and current device designs make use of commercially available materials such as springs and metal tubing, cost of production will remain relatively low with them. The cost of manufacturing of the worm gear will be considerably higher in the final design, due to its need for precision in pitch and number of threads, which will drive up costs. As a result, the worm gear received the lowest score in this category.

Future Work

With a design now chosen, it is time to consider what must be done to create this prototype. The next step is to meet with an expert on worm gears. Information must be gathered so that final dimensions can be chosen for the pitch, length, number of threads, number of teeth, and radius of the worm gear and tooth gear. This information needs to be chosen in such a manner that the forward movement per turn stays within the 1-2 mm range and no forward movement occurs from the drill force. Once this information is obtained, the remaining device specifications will be determined to accommodate the gears.

After finalizing the dimensions of this device, part preparation and fabrication of parts must occur. This occurs in three steps. The first will be ordering of the gears from an outside vendor. Because of the importance of the gears to the design, it is important that they are fabricated by someone with experience making such parts. The metal tube will also be ordered so that the grooves for teeth match with the tooth gear. Second, a solidworks design of the outer housing must be created. It will be used to create the housing using 3D printing. Finally, all of the parts must be assembled into a working prototype.

With a prototype in place, testing will occur. The client desires to demonstrate that

such a device will result in a marked improvement to the depth of over drilling in orthopedic surgery. Using the setup in Figure 8, skilled surgeons and novices will perform a simulated surgery on chicken bones with and without the prototype. Parameters such as drill depth and time to drill through will be measured and compared to identify statistical differences. A survey on ease of use, ergonomic convenience, and any other parameters deemed necessary will be distributed to complete the evaluation of whether the prototype provides the desired advantages.

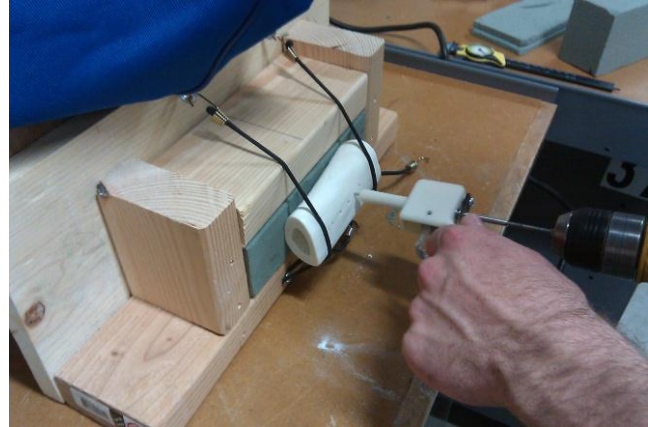


Figure 8: The testing set up for use with the prototype. A bone is secured 5 mm above a piece of tin foil. The bone is to be drilled through, with drilling stopped before breaking the foil.

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