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# Orthopedic Drill Stop Device

*When drilling through bone, a surgeon must be able to quickly cease the advancement of the drill after passing through the far cortex to avoid penetrating and causing potential damage to the underlying soft-tissue structures. Currently, surgeons rely solely on their experience, the feel of the force applied from the bone, and auditory feedback. This can lead to higher than acceptable plunge depths seen from less experienced residents. This paper describes a device that removes the high plunge depth variability from the sensory control of the operator. This device contains a stopping mechanism for the drill bit and a trigger which allows a 1.5mm dynamic advancement of the bit per trigger pull. This device decreases the plunge depth of the bit and the corresponding injury to soft tissue surrounding the bone.*

## 1 Introduction

Surgical technique requires sophisticated motor skills. Many fields such as psychology, neuroscience, ergonomics, and biomechanics study the learning and performance of these motor skills, from the error detection mechanisms of the brain, the biomechanical constraints of the movements, and the sources of sensory information that are integrated to guide a surgeon. When drilling through a bone, an orthopedic surgeon must have precise motor skills to be able to quickly cease the advancement of the drill when the far cortex has been penetrated to avoid injuring soft tissue structures. The amount that a drill-bit protrudes past the bone is known as the "plunge depth". Minimizing the plunge depth is a significant issue and the focus of this paper.

Studies done by Adam Dubrowski and David Backstein found that orthopedic surgeons demonstrated significantly less plunge depth than junior residents did. The results showed that junior residents relied mainly on reactive control during surgery, whereas the surgeons used anticipatory control for the application of the drilling force. This reactive control translates to larger temporal delays between penetration of the bone and the termination of the drilling action. [5]

Aside from personal experience, other factors such as distracting noise can adversely affect a surgeon's performance during drilling. In a study done by Praamasma, it was found that in general residents plunged deeper than intermediate trainees and surgeons. With the addition of distracting noise, the plunges of both residents and surgeons were adversely affected [8].

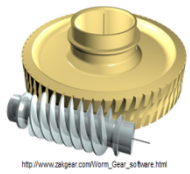
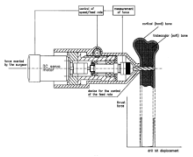
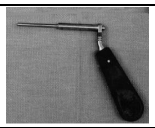
| Design | Method | Benefits | Drawbacks |
|---|---|---|---|
| Thumbwheel-driven  | Thumbwheel mechanism is used to control drill bit plunge depth | - Simple mechanism<br>- Extremely precise ability to control drill depth | - Potentially not that comfortable or intuitive for the user |
| Trigger-driven  | Trigger mechanism is used to advance a tube that controls drill bit plunge depth | - Simple mechanism<br>-Ability to control drill depth while drilling<br>- Intuitive design | - May be difficult to sterilize |
| Electronic feedback [2]  | Electronic mechanism measures the force applied at the tip of the drill bit, which is relayed to another component to control the speed and feed rate of the drill. | - Extremely precise mechanism as it can control speed and force applied at the bone | - Too complex |
| Spinal drill guide  | Guides drill bit during spinal surgery, can be pre-set to a specific drill depth | - Ability to pre-set drill depth | - No ability to change drill depth while drilling |
| Drill sleeve  | Guides drill bit during general orthopedic surgery | - Easy to sterilize | - No ability to control drill depth |
| ACRA-cut Smart Drill [1]  | Specific to brain surgeries, uses a pressure-clutch mechanism to sense when to stop the drill bit from spinning after skull has been penetrated | - Precise mechanism | - Too specific |

**Fig. 1 Preliminary Design Ideas**

There are a variety of unavoidable factors that cause plunging during surgery. The current method of surgery involves using a drill sleeve to ensure that the drill bit enters the bone straight; however there is no stopping mechanism to prevent over-penetration of the bone. Other devices have adjustable depth settings but are cumbersome because the depth cannot be changed while drilling. This leads to extended drilling time and may compromise the patient's stability and healing. Plunging depends on the motor skills, auditory feedback, and the experience of the surgeon. Our device aims to eliminate plunging during orthopedic surgery by minimizing an individual's dependence on experience and reaction ability.

## 2 Preliminary Design

There are several design requirements of the orthopedic drill stop device, which are as follows: (1) decrease normal plunge depth from 1.5 – 3 cm to 1 – 3 mm past the far cortex of the bone, (2) advancement of the drill bit in increments of 1 – 2 mm in depth, (3) change drill depth while drilling, (4) sterilizable, (5) operate by mechanical properties for more intuitive application.

Figure 1 shows several choices to regulate plunge depth. Included are existing devices that are in use right now, as well as benefits and disadvantages of each option. Each option has

**Fig. 2 From left to right: 1st prototype, 2nd prototype, and final prototype**

certain limitations compared to our chosen design, the trigger driven mechanism. Other design ideas were found in patents [3], [4], [6], [7], [9], but these were not suitable for this application.

## 3 Orthopedic Drill Stop Prototypes

The initial prototype was constructed as a proof of concept for our design, and is shown in Figure 2. The second prototype had the following improvements: the device was scaled down to the appropriate dimensions for a smaller drill bit, the housing is more compact, the handle is connected to the housing and made out of the same material, a view window is present in the tube of the housing to measure how far the drill bit has advanced, and the trigger is smaller and more ergonomic.

The second prototype is also shown in Figure 2. It is composed of acrylonitrile butadiene styrene (ABS), an inner tube of stainless steel seamless tubing, three metal clutch pieces, three precision compression springs, and a trigger composed of polycarbonate. The set of up the clutches and trigger restricts the advancement of the inner tube to advance only when the trigger is pulled. Two of the clutches are set up inside the housing. There are slots in the upper wall of the housing to hold these clutches in place along with an opposing spring between the clutch and the wall. In the second prototype, the geometry of the first clutch allows it to be a locking mechanism such that when the trigger pulls the inner tubing forward, the tubing is not able to return to its original position with the return of the trigger to equilibrium. The second clutch is a locking mechanism that is designed such that at equilibrium, the inner tubing is not allowed to advance forward. This prevents the tubing from sliding forward from force of the drill. When the trigger is pulled towards the handle, the trigger rotates counterclockwise and the backside of the trigger straightens this clutch allowing forward motion only when the trigger is pulled. The third clutch is what determines the forward advancement of the inner tubing. When pulled, the rotation of the trigger causes forward translational motion of this clutch and increments the tubing by 1 mm.

The third and final prototype improved upon the mechanism of the second as well as eliminating some ergonomic problems. A lip was added to the inner tube to allow the user to more easily reset the device without concern for pulling the tube out completely. The trigger was modified to make sure that no pressure from the drill would advance the tube while the trigger was pulled; the only way the

tube can advance is by the pull of the trigger. The outer cylinder that protrudes from the main housing was made detachable and was modified with more vents to allow for less bone dust accumulation and make it easier to clean. Finally, the handle was modified to make the device more ergonomic, with an added thumb rest and more careful modification of the handle.

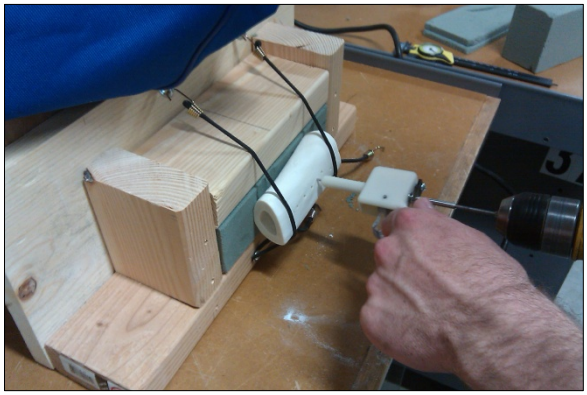


**Fig. 3 Testing Setup**

## 4 Device Experimental Testing, Results and Discussion

**4.1 Methods.** Experiments were conducted to determine if the device minimized plunge depth for both novice users and resident surgeons. Four novice users were tested as well as one resident. The testing setup, shown in Figure 3, was designed such that a pig's femur could be attached to a 5 mm piece of foam in front of a piece of tin foil, which was considered a "threshold point" at which tissue and nerve damage would occur. Behind the threshold system was a foam block for added structure. A Stryker medical drill was used in conjunction with first a drill sleeve and then the third prototype. For the resident surgeon, time was kept from the start of drilling to the end of depth measurement. To measure the depth, as if one were measuring for the screw size, the depth gauge shown in Figure 4 was used.

**Fig. 4 Depth gauge, which is used by catching the tip shown at the top of the figure to the far cortex of the bone, and then reading the measurement. The process is difficult, as it is tough to catch the fragile tip on the other side of the bone.**

**4.2 Results.** Three novice users drilled three times with both the drill sleeve and the drill stop device. Another novice user drilled twice with both the drill sleeve and the drill stop device. One expert user, a resident surgeon, drilled three times with each device, and his times were recorded. Figure 5 shows the results of each novice trial.

| Novice User Data | | |
|---|---|---|
| Trial | Drill sleeve, past threshold (Y/N)? | Drill stop device, past threshold (Y/N)? |
| 1 | Y | N |
| 2 | Y | Y |
| 3 | Y | N |
| 4 | Y | Y |
| 5 | Y | N |
| 6 | Y | N |
| 7 | Y | N |
| 8 | Y | N |
| 9 | Y | N |
| 10 | Y | N |
| 11 | Y | N |

**Fig. 5 Novice User Data**

Looking at the novice user results found in Figure 5, it is seen that the testers plunged past the threshold in every trial using the drill sleeve. When the novice users then used the drill stop

device there was a dramatic improvement. Using the drill stop device, the novice users improved their performance in decreasing plunge depth 82% of the time. The plunge depth that occurred using the drill stop device can be attributed to the fact that a prototype was used in testing. This prototype was not made of materials that would be used in the final device. It was also not intended to be used under the stress of multiple testing trials.

However, promising results were still seen from this initial testing. This device has market potential for residents in medical school as this device could significantly decrease the learning curve for preventing plunge depth in bicortical drilling procedures for novice users.

Looking at the expert user results found in Figure 6, it can be seen that the tester did not plunge past the threshold using either device. However, one of the limitations of the expert user testing results is that there was only one expert test subject. Thus, it is difficult to make conclusions from this initial testing. Future testing will be done with more expert users. The limited data does suggest that the drill stop device has the potential to decrease the time of the drilling procedure. It also increases the efficiency of the procedure by moving from a procedure that requires two devices to only requiring one device, as well as providing the additional benefit of error reduction. Thus, this device has the potential to also be marketable to expert users; however, more testing will be required to validate this claim.

## 5 Conclusions

Although results from experimental testing are promising, they reveal a few issues with the final prototype. The prototype must be made of different materials so that the longevity will be improved and the device will be easier to sterilize. Also, further testing must be done to assess the grip and ergonomic aspects of the device for multiple surgeons with different hand sizes. These surgeons must also be timed to more accurately assess the time improvement for expert users.

| Expert User Data | | | | |
|---|---|---|---|---|
| | Drill Sleeve | | Drill Stop Device | |
| Trial | Past threshold (Y/N)? | Time (s) | Past Threshold (Y/N)? | Time (s) |
| 1 | N | 33 | N | 16 |
| 2 | N | 24 | N | 31 |
| 3 | N | 33 | N | 27 |

**Fig. 6 Expert User Data**

**Acknowledgement**

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**References**

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