Design and Testing of a Drill Stop for Orthopedic Surgery

Joseph Benert, Lucas Schimmelpfenning, Brandon Jonen, Kevin McConnell
Client: Dr. Tim O'Connor, Orthopedic Surgeon- UW Hospital
Advisor: Chris Brace, Department of Biomedical Engineering – University of Wisconsin Madison

Abstract

Dr. Timothy O'Connor is a surgery resident at the UW Hospital. He is concerned with nerve and tissue damage associated with over-penetration of a drill bit when drilling through 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 drill bit before tissue damage occurs. A device needs to be created that can advance the drill through the bone in one millimeter increments and withstand a force of 20 N without allowing the drill bit to plunge through the bone. In order to limit damage to the bone caused by heat transfer the device must allow the surgeon to complete the drilling in 15 seconds. The team has created a rack and worm gear device that advances the drill bit with one hand using a thumb wheel. The device was tested by novice and experienced subjects to determine improvements that need to be made.

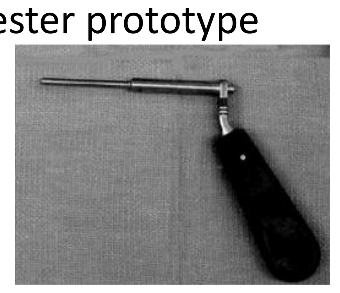
Problem Definition

Motivation

- Orthopedic drilling is required whenever a screw is inserted to stabilize a bone
- No current devices allow a surgeon to precisely drill through the bone without risk of plunging

Current Designs

- Drill guide
- Spinal drill sleeve
- ACRA- Cut smart drill
- Previous semester prototype



Spinal Drill Sleeve
www.medscape.com

ACRA- Cut smart bit
www.acracut.com

Problem Statement

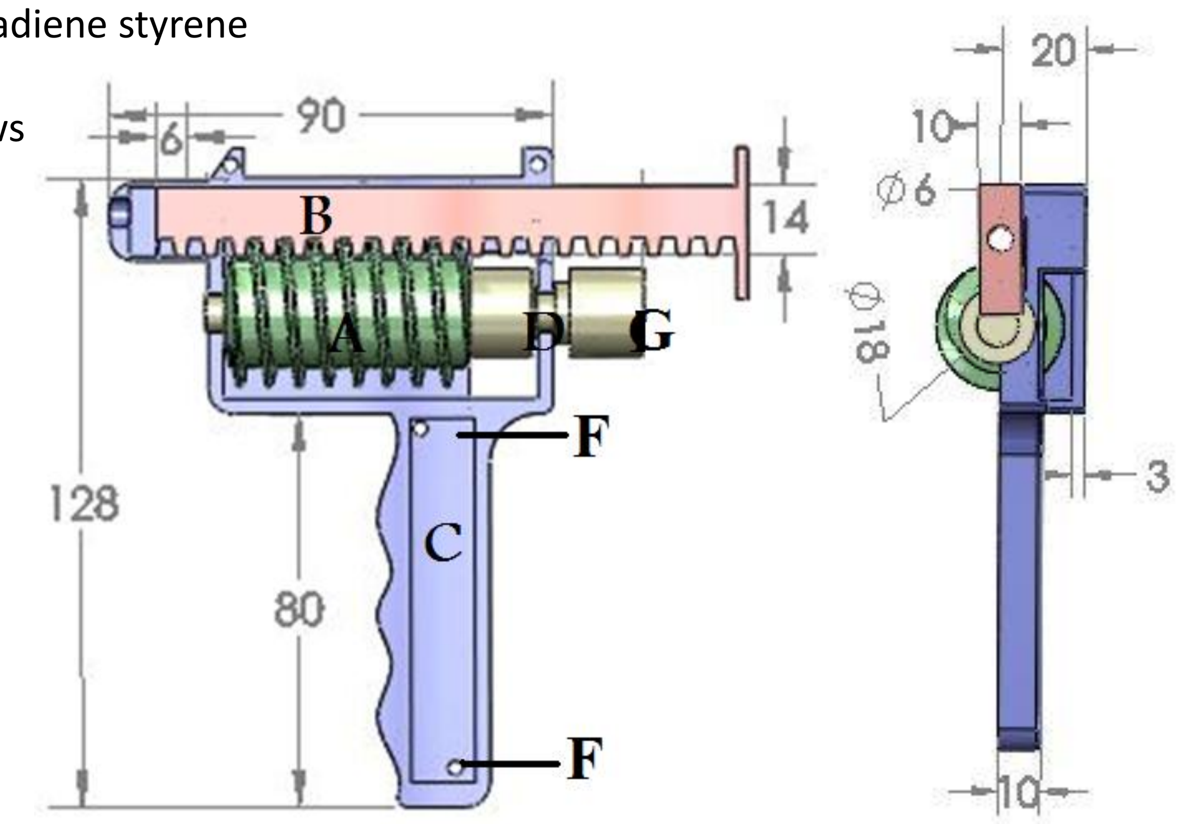
- Critical to limit over-penetration to 4 mm in order to prevent tissue and nerve damage
- Current devices do not allow precision of drilling if the bone diameter is unknown
- Device should be operable with one hand so one surgeon can complete the drilling and insert a screw

Design Criteria

- Stop drill bit from plunging more than 4 mm
- Advance drill bit in 1-2 mm increments
- Operable with one hand
- Determine screw gauge from device
- Withstand 20 N force without slipping
- Ergonomic and easy to use
- Surgical grade materials

Final Design

- Material
  - Fused deposition of the thermoplastic acrylonitrile butadiene styrene
- Housing Unit (Blue):
  - Composed of 2 symmetric pieces assembled with screws
  - Hollowed out to minimize weight
  - Houses the worm, rack, and thumbwheel shaft
  - Ergonomic handle
- Worm and Rack(Green and Red, respectively):
  - 6 mm pitch of worm to enable slow drill advancement
- Thumbwheel Shaft (Gold):
  - Bumpy texture to maximize grip
  - Ergonomic placement for smooth use with thumb
  - Allows ambidextrous use
  - 1.8 cm diameter

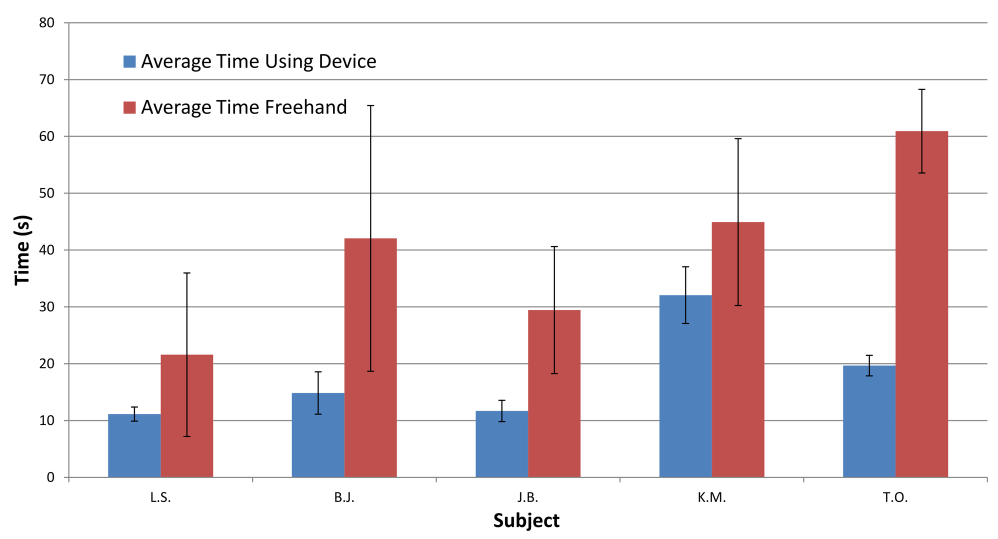


Cross-sectional side and rear views of assembled prototype with dimensions in millimeters. Letters correspond to parts listed to the right.

Testing and Analysis

Drill Time

- Three tests freehand, three with device for novices
- Eight tests freehand, seven with device for expert
- Timed from start to penetration of posterior side

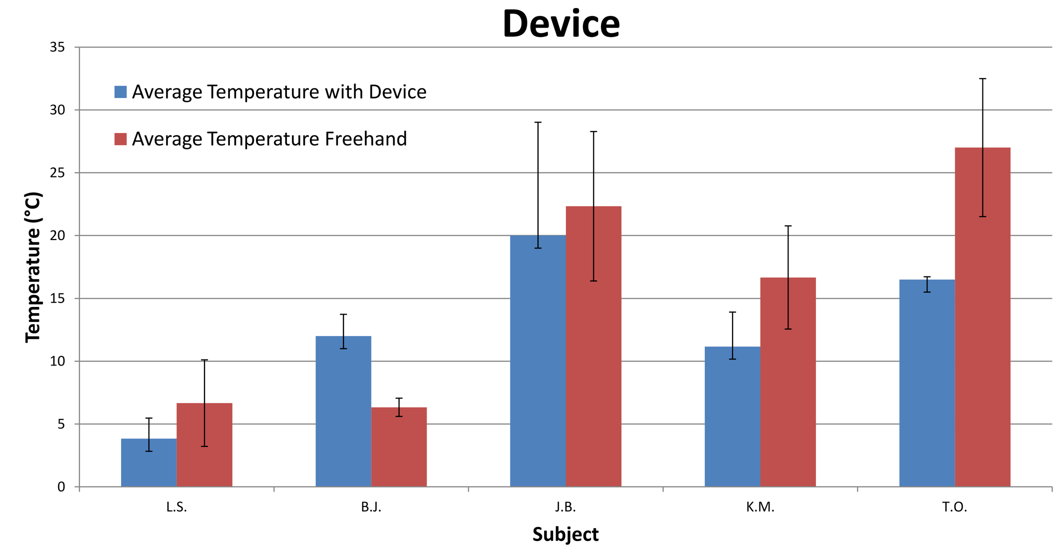


Plot of average drill times with and without device for each subject. Positive and negative standard error of the mean are shown.

Averages:
With device: 18.6±8.5 s *Without device: 44.2±44.2 s*
T value = 2.53

Temperature Change

- Thermocouple inserted 0.5 mm from drill site
- Temperature in one second intervals
- Comparison of change in temperature



Plot of average temperature changes with and without device for each subject. Positive and negative standard error of the mean are shown.

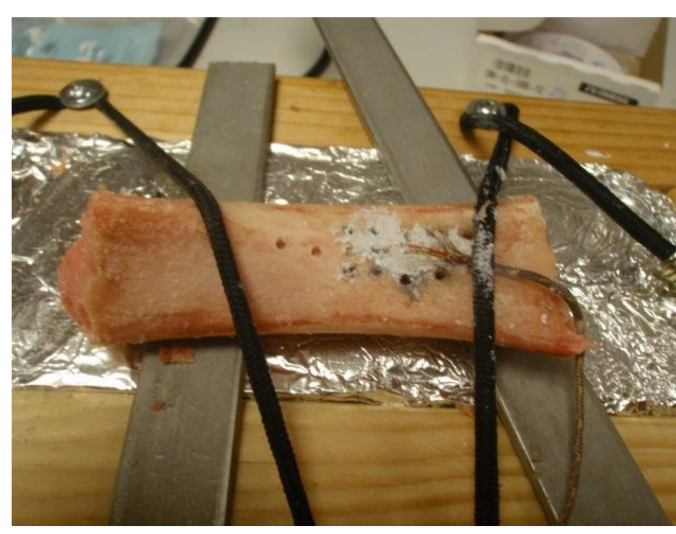
Averages:
With Device: 13.5±9.8 °C *Without Device*: 18.6±13.7 °C
T value = 1.34

Prevention of Over-Penetration

- Tin foil barrier 4 mm below bone
- Tested on break/no break of foil

Over-penetration testing results. Failure was defined as penetrating through a tin foil layer located 4 mm below the bone.

	Freehand		Using Prototype	
	Successes	Failures	Successes	Failures
Experienced	0	8	7	0
Inexperienced	0	12	11	1
Total	0	20	18	1

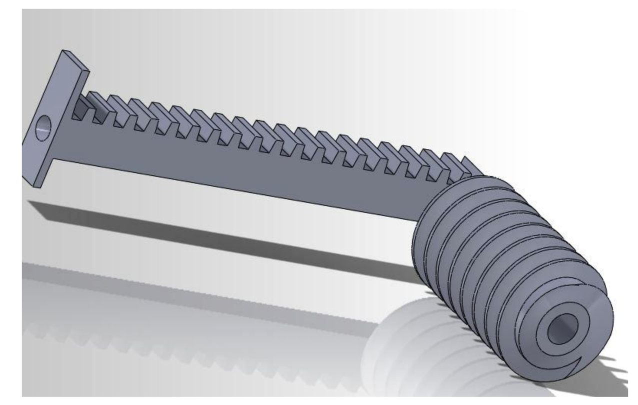


Testing Setup. Pig tibia secured 4 mm above foil barrier. Thermocouples placed 0.5 mm from drill site using conductive putty.

Subjects asked to drill through bone freehand and using device. Trial considered successful if foil was not broken, failure if foil was penetrated.

Parts List

A. Worm
B. Rack
C. Housing
D. Thumbwheel/shaft
E. Metal tubing
F. Screws & nuts
G. Vinyl Tape



Three dimensional solid works of Rack and Worm

Future Work

- Design Modifications
  - Eliminate internal thumbwheel
  - Add textured surface to thumbwheel
  - Lengthen handle by 3-5 cm
  - Combine worm, thumbwheel, and shaft into one piece
  - Add teeth to nose to better grip bone
  - Implement measuring gauge
  - Standardize dimensions
- Manufacturing
  - Consult industry expert
  - Custom order parts (stainless steel)
- Testing
  - Additional tests with more experienced subjects
  - Post drilling temperature data

References

ACRA-CUT smart drill. Retrieved 12/06, 2011. <http://acracut.com/perforators.html>.

Augustin, G. e. a. (2008). Thermal osteonecrosis and bone drilling parameters revisited. *Arch Orthop Trauma Surg, 128*(1),71,72-77.

Galley, I., Watts, A., & Bain, G. (2009). The anatomic relationship of the axillary artery and vein to the clavicle: A cadaveric study. *Journal of Shoulder and Elbow Surgery, 18*(5), e21, e22-e25.

Khokhotva, M., Backstein, D., & Dubrowski, A. (209). Outcome errors are not necessary for learning orthopedic bone drilling. *J can Chir, 52*(April), 98, 99-102.

O'Connor, T. Interview. 12 September 2011.

Praamsma, M. e. a. (2008). Drilling sounds are used by surgeons and intermediate residents, but not novice orthopedic trainees, to guide drilling motions. *Can J Surg, 51*(6), 442,443-446.

Wu, S., Liang, P., Pai, W., Au, M., & Lin, L. (1991). Spinal transpedicular drill guide: Design and application. *J Spinal Disord, 4*(1), 96,97-103.

Yang, K., Yoon, C., Park, H., Won, J., & Park, S. (2004). Position of the superficial femoral artery in closed hip nailing. *Arch Orthop Trauma Surg, 124*(3), 169,170-172.

Acknowledgements

- Dr. Tim O'Connor
- Professor Chris Brace
- Professor Frank Fronczak
- Andy Lacroix
- Eamon Bernardoni