So You Think You Don't Plunge? An Assessment of Far Cortex Drill Tip Plunging Based on Level of Training

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ABSTRACT

Introduction: **Drill bit tip plunging past the far cortex places critical anatomical structures at risk. This study measured plunging past the far cortex based on level of training. The time required for screw placement when a depth gauge was used to measure bone tunnel depth was compared to the time required for screw placement when bone tunnel depth was measured in real time.**

Materials and Methods: **Thirty orthopedic surgery staff with 1–37 years of experience applied 10-hole plates to cadaveric limbs. Procedures were performed using two different drilling systems. Time and plunge depth**

were recorded.

Results: Penetration past the far cortex ranged from an average of 11.9 mm in the novice group to an average of 6.1 mm in the experienced group (P <0.001). The time required to drill and place a screw decreased by an average of 14 seconds per screw when depth gauge use was eliminated.

Conclusions: Penetration past the far cortex occurred at all levels of training, but decreased with increased levels of experience. Real time measurement of bone tunnel length decreased total drilling time. The time saved with real time measurement decreased with increased level of experience.

INTRODUCTION

Surgical drilling of bone is a fundamental skill in orthopedic surgery. This skill requires complex processing of both proprioceptive and auditory feedback. Mastery is acquired largely through experience. Drill bit tip plunging past the far cortex occurs frequently. Although past drilling is often benign, there is the potential to cause substantial harm to adjacent structures. Prominent hardware (screw penetration past the far cortex) may also cause injury in the short, intermediate, and long-term. The orthopedic literature is replete with case reports detailing injuries to nerves, blood vessels, tendons, and even bladder injury due to drill tip over-penetration or overly long screws. Complications related to these injuries include sepsis, limb loss, blood loss requiring massive transfusion, functional impairment requiring additional reconstructive procedures, and death.[1-13]

Drilling past the far cortex occurs at all levels of training and experience, as separately demonstrated in bone model studies by Clement et al. and Alajmo et al.[14,15] The concern for patient safety dictates that orthopedic training emphasize these risks during the residency process and help residents develop the skills required to minimize these risks.

Novel drill technology has been developed that measures and reports the drill track through bi-cortical bone. In a "free hand mode", the software will report the length of the bi-cortical bone tunnel and the depth of drill tip penetration past the far cortex (plunging) in real time. By measuring the drill track from the near to far cortex, the need for depth-gauging to determine screw length is eliminated, potentially saving intraoperative time. In the present study, we used this technology to determine drill bit tip plunging past the far cortex for all levels of trainees and to evaluate whether perceived depth of plunging correlated with actual plunging. Additionally, we explored whether eliminating the need to use a depth gauge affected the time necessary to drill and place screws.

MATERIALS AND METHODS

Institutional Review Board approval was obtained for the study. Orthopedic surgery residents at various levels of training, hand surgery fellows, and attending orthopedic surgeons were

Table I
Cadaver data, plates, and trials

	All	Group 1 (PGY 1-2)	Group 2 (PGY 3-5)	Group 3 (PGY 6-7)	Group 4 (PGY > 7)
Age: traditional (Years +/- SD)	74.6 +/-11.2	76.1 +/- 12.3	76.5 +/- 7.4	67.0 +/- 12.6	68.7 +/- 13.4
Age: intelligent drill	71.1	69.1	71.0	82.7	68.3
(Years +/- SD)	+/- 9.7	+/- 9.0	+/- 9.0	+/- 3.4	+/- 10.4
Plate used ◆		Plate (Trials)◆	Plate (Trials)◆	Plate (Trials)◆	Plate (Trials)◆
Distal humerus		1 (10)	1 (9)	1 (10)	2 (16)
Radial shaft		2 (18)	3 (24)	1 (7)	2 (12)
Ulnar shaft		3 (22)	3 (29)	1 (8)	
Distal radius		1 (5)	3 (24)		
Metacarpal		4 (31)	2 (19)		

◆ number of specific type of plate used. Trials represents the cumulative number of recorded drill holes placed.

Table II
Plunge depth in mm as a function of bone type and cadaver age

	PD◆ (mean) mm	PD (SD†) mm	PD (Median) mm	PD (range) mm
PLATE				
Distal humerus (n = 35)	11.2	8.6	7.9	0.7–33.6
Radial shaft (n = 61)	6.3	3.3	5.4	1.4–16.0
Ulnar shaft (n = 59)	10.6	5.2	9.0	1.6–28.4
Distal radius (n = 29)	8.6	4.4	8.1	2.2–18.9
Metacarpal (n = 50)	10.3	5.5	8.9	2.3–23.1
Cadaver Age				
58–64 years (n = 10)	9.0	3.3	8.8	4.9–14.8
65–85 years (n = 20)	8.9	4.7	7.8	3.5–21.7

♦PD = plunge depth
†SD = Standard deviation

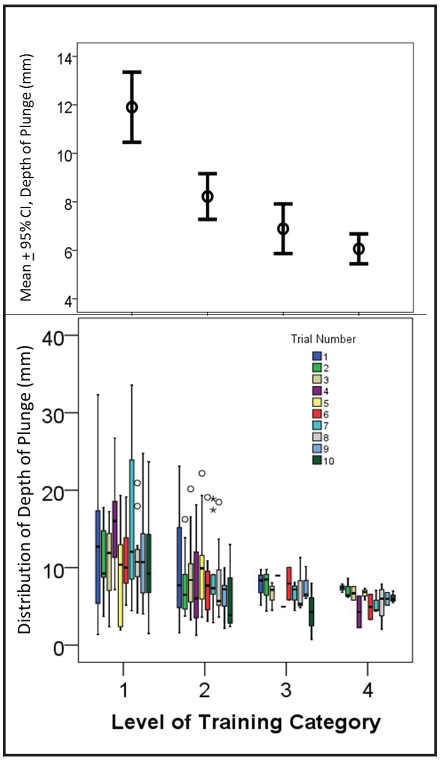

Figure 1. a) The mean and 95% confidence intervals of the plunge depth for each category of level of training is shown: Group 1 = PGY 1,2; Group 2 = PGY 3-5; Group 3 = PGY 6,7; Group 4 = PGY > 7. b) Boxplots representing the distribution of plunge depths for each of the 10 trials, in each of the training level categories. Each box plot represents 25th, 50th, and 75th percentiles. The whiskers represent the minimum and maximum, with outliers represented by individual markers.

recruited to participate in the study. Study participants were informed as to the nature of the study and the research aims. All participation was voluntary. Demographic information regarding postgraduate training year (PGY) was collected. No other identifying information was collected.

Non-matched fresh-frozen upper extremities with intact soft tissues from cadavers aged 50–95 years were prepared through standard surgical approaches for plate application to the lateral distal humerus, radial shaft, ulnar shaft, distal radius, and metacarpal. Participants were asked to apply a 10-hole plate and place screws of the appropriate length to either a distal radius, radial shaft, ulna shaft, distal humerus, or metacarpal according to their preference. They were asked to replicate their normal intraoperative conduct with regard to drilling, depth gauge use, and screw placement. Ten holes were drilled and 10 screws were placed for each exercise.

Identical procedures were performed with two different drill types. The first was a traditional battery powered drill, identical to that which is used at the training hospital (Stryker Cordless Driver 2^{O}, Kalamazoo, Michigan). The other procedure was performed using an "intelligent drill" (Intellisense™ Drill Technology^{O}, Casper Wyoming) which has two functional modes: the bicortical mode, where the drill motor stops on breeching the far cortex, and the freehand mode. In the freehand mode, used in the present study, the drill functions similarly to a standard drill, except that a digital measurement of the bone tunnel is automatically provided to the surgeon. In the freehand mode, it is possible to plunge beyond the far cortex, but the integrated software will provide both the depth of the bone tunnel and the depth of drill bit plunge beyond the far cortex. The product manufacturer's specifications indicate that the measurement is accurate to 0.6 mm.

Participants performed 10-hole plate applications on two separate cadaver bones. Procedures were matched to the same location initially selected by the participant. One procedure was performed using a traditional drill. The other procedure was performed using the "intelligent drill" in the freehand mode. Participants were randomized such that half completed the exercise using the "intelligent drill" first, and half completed the exercise using the traditional drill first.

The time required to complete each procedure was recorded using a stopwatch. In the traditional group, depth gauge measurements were not recorded. The depth of the drill-pathway and the depth of plunge beyond the far cortex were measured only with the intelligent drill procedure through its integrated measurement system. Plunge data was not obtained in every trial. In some attempts, the hole was uni-cortical, the surgeon slipped, or there was tissue accumulation in the drill bushing that disrupted accurate data collection. The total time for placement of all 10 screws was recorded. No plunge data was collected from the traditional drill system, as the specimens were prepared to closely replicate a surgical setting and

Table III
Actual average plunge in mm versus perceived average plunge in mm

	Plunge average (actual)	Plunge average (perceived)	Range (perceived)	Average difference from actual (min, max) mm
Group 1 (n = 7)	11.8	4.1	1–8	1.4, 16.7 *
Group 2 (n = 9)	7.3	5.4	2–10	1.1 , 5.4 †
Group 3 (n = 3)	6.9	3.7	3–5	2.3, 4.1
Group 4 (n = 3)	5.8	6.0	5-juil.	0.7, 1.3 ◆

* one participant in group 1 overestimated his perceived plunge by 1.2 mm.
† one participant in group 2 overestimated his perceived plunge by 6.5 mm.
◆ one participant in group 4 overestimated his perceived plunge by 1.1 mm

far cortex penetration could not be visualized.

After completing the two drill exercises, participants were asked to complete a short survey regarding their perception of how much they plunged during the procedure.

Data analysis

Postgraduate year (PGY) levels were categorized into four groups: group 1: PGY 1–2; group 2: PGY 3–5; group 3: PGY 6–7; and group 4: PGY > 7. Plunge depth was evaluated as a function of level of training.

The independent variables included PGY level and type and age of cadaver bone as well as drill type. The dependent variables included the average time for each screw placement and the plunge depth measured with the novel drill. A general linear model (GLM) was established to evaluate differences in each of the dependent variables as function of PGY level, bone type, and age. Additionally, t-tests were used to compare the perceived plunge depths to the average plunge depth for each individual measured using the novel drill.

RESULTS

Study cohort

Thirty orthopedic surgery residents and attending orthopedic surgeons participated in the study. There were 11 participants in group 1 (PGY 1–2), 12 participants in group 2, three participants in group 3, and four participants in group 4. Twelve cadavers were used and randomly divided between the traditional drill group and the intelligent drill group (Table I).

Plunging

Penetration past the far cortex occurred at all levels of training. The mean plunge depth (PD) was 11.9 +/- 6.7 mm in group one, decreasing to 6.1 +/- 1.6 mm in group 4. Specifically, group 1 had 11 participants with 86 trials. The mean plunge depth was 11.9 mm (SD 6.7 mm). Group 2 had 12 participants with 105 trials. The median plunge depth was 7.2 mm (SD 4.9 mm). Group 3 had three participants with 25 trials. The mean plunge depth was 6.9 mm (SD 2.5 mm), and group 4 had four participants with 28 trials. The mean plunge depth was 6.1 mm (SD 1.6 mm) (Table II and Fig. 1).

Survey

Twenty-two of 30 participants answered the survey regarding how much they believed they plunged past the far cortex on average for 20 drill holes. By paired t-test analysis, the average perceived depth of plunge was 4.9 +/- 2.2 mm. The average plunge was 8.4 +/- 0.9 mm. When each participant's perceived depth of plunge was compared to the same participant's average actual plunges, the differences were on average 3.5 +/- 5.2 mm (p=0.005) more than the perceived plunge. When each participant's depth of plunge was compared to that participant's maximal plunge, the average difference was 7.6 +/- 7.6 mm (p = <0.0001) more than perceived plunge (Table III).

Table IV
Drilling time using different drilling methods by level of experience

	Group 1 (n=11) (min:sec)	Group 2 (n=12) (min:sec)	Group 3 (n=3) (min:sec)	Group 4 (n=4) (min:sec)	Total
Intelligent Drill (range)	5:39–10:00	6:06–14:11	5:23–10:15	5:07–10:29	5:07–14:11
Traditional (range)	7:04–17:18	6:13–12:01	9:50–14:31	7:25–11:08	6:13–17:18
Intelligent Drill (mean +/- SD	8:10 +/- 1:38	8:52 +/- 2:06	7:56 +/- 2:27	8:08 +/- 2:23	8:22 +/- 1:56
Traditional (mean +/- SD	11:27 +/- 2:59	10:02 +/- 2:00	11:53 +/- 2:24	9:14 +/- 1:47	10:41 +/- 2:29
Difference	3:16	1:10	3:57	1:06	2:19
P-value	0.005	0.18	0.12	0.53	0.003

Time

In general, the total time participants spent to drill and insert a screw was longer with the traditional drill than the time required with the intelligent drill by an average of 135 seconds (2 minutes 15 seconds) for all 10 holes. The differences between the traditional and intelligent drills decreased with increasing levels of experience; however, these differences were not statistically significant, except in group 1 and in the entire sample (Table IV).

Multivariate analysis

Taking into account the participant training level category, bone type, and donor age, the multivariate analysis indicated that training level had the largest effect on plunge depth. Specifically, this analysis estimated that the level of training had a significant effect on plunge depth ($p < 0.001$), with the category 1 participants (PGY 1 and 2) plunging on average 2.6 mm deeper than the senior participants (category 4), and training category 2 (PGY 3–5) plunging on average 1.7 mm deeper than the senior participants. Plunging was indicated to be nearly the same for category 3 and 4 participants ($p = 0.49$), despite the wide variation in years of training. Plunge depth was also significantly correlated with the type of bone that was being plated ($p < 0.001$), but the effect of the bone type was estimated to be approximately half of the effect of training level (Table II). The age of the specimen donor was not estimated to have a significant effect on plunge depth ($p = 0.72$).

DISCUSSION

This study evaluated the extent of drill bit tip plunging past the far cortex as a function of surgical experience in a cadaver model. We found that plunging occurs at all experience levels, ranging from an average of 11.9 mm in inexperienced trainees to 6.1 mm in experienced surgeons. Several anatomic studies have been performed to evaluate the proximity of structures at risk during orthopedic procedures, noting neurovascular structures as close as 1.7 mm from bone. Anatomic studies have been performed to identify “safe zones” for drilling where nerves, vessels, or tendons are close to the opposite cortex of the procedure.[16-21] Several factors, including trauma, reconstruction, and anatomic variability, may require physicians to work outside of these safe zones. These studies highlight the risk to critical structures that could be injured by drill plunging or prominent screw tips.

The extent of drill plunging has been investigated in a few studies. In evaluating how trainees develop motor skills, Dubrowski and Backstein compared applied force and plunge depth between PGY 1 surgical residents and attending surgeons while drilling in a Sawbones® (Pacific Research Laboratories, Inc., Vashon Island, Washington) model.[22] The authors found that the attending surgeons penetrated the far cortex to a lesser extent, though not quantified. Force trajectories demonstrated that attending surgeons applied progressively less force during drilling and perceived the breach of the second cortex in an anticipatory manner. In contrast, the junior residents applied progressively more force during drilling and, on breaching the second cortex, relied on reactive control to mitigate plunge depth. Clement et al. quantified plunge depths in a bone model. Far cortex penetration averaging 6.3 mm was reported for all levels of experience, with no clinically or statistically significant differences between levels of experience. Their study was based on three trials per participant and was performed during an AO course where surgical skills and technique were being emphasized. Our study demonstrated progressively lower plunge depths and a smaller standard deviation with increasing levels of experience. The greatest improvements were observed between group 1 (PGY 1–2) and group 2 (PGY 3–5). Consistency of motor skills as indicated by the standard deviation improved most between group 2 and group 3. Experienced surgeons also had improved insight regarding penetration past the far cortex, with inexperienced surgeons generally failing to recognize the extent of the cortical breach.

Overall, the intelligent drill reduced the total time for drilling and screw placement by an average of 2 minutes and 21 seconds for a 10-hole plate application. This would be approximately 14 seconds per screw. The time savings was more in the novice group at 19 seconds per screw compared with the experienced group who saved, on average, seven seconds per screw. These differences would reflect the time needed to use a depth gauge. The effect size noted in this study is not directly transferrable to the surgical setting where other factors may create greater difficulty in using a depth gauge.

Reducing the incidence of complications of drill tip plunging can be achieved through training and experience. Technological advances, such as a reciprocating drill that minimizes injury to structures past the far cortex and drills that have a motor arrest on breaching the far cortex, may also increase patient safety. The potential for decreasing surgical time associated with a drill that provides real time measurement of bone tunnel length without the need for depth gauging may offset the costs associated with the adoption of new technology, although the time savings diminished in this cadaveric model with increasing levels of training.

The limitations in this study include potential variations in bone density, inconsistency between groups of the types of bones that were drilled, and lack of independent verification of the manufacturer’s specifications regarding accuracy of tunnel length measurements as well as accuracy of the use of a manual depth gauge. We did not directly compare the digitally derived tunnel length with a depth gauge or caliper measurement, and we were not able to independently verify plunge depth. A cadaveric model was used to reproduce, as closely as possible, an operative setting. However, our results are not directly transferrable to a surgical setting, where intra-operative distractions, fracture comminution, variations in bone quality, and myriad other factors may affect intra-operative plunging. The intelligent drill used in this study requires an intact far cortex both to detect tunnel length and when used in “bi-cortical mode” to stop the drill motor to prevent penetration past the far cortex. This study did not address whether this would function the same in the setting of far cortex comminution or severe osteopenia.

Plunging beyond the far cortex occurred in all levels of training. Increased experience decreased the plunge depth and produced a greater awareness of estimated plunging past the far cortex. This model likely underestimates actual plunge depths in an operative setting. Advances in technology have the potential to reduce intraoperative risks and reduce surgical times, but are not a panacea to the clinical risks associated with surgery. Surgical training should continue to emphasize these risks for trainees, especially in their first years of training with the use of Sawbones® models and instructional feedback.[23]

CONCLUSION

During surgical drilling of bone, penetration past the far cortex occurred at all levels of training, but decreased with increased levels of experience. Real time measurement of bone tunnel length decreased total drilling time. The drilling time saved with real time measurement decreased with increased level of experience. Although not addressed in this study, technological advances that result in drill motor arrest on breaching of the far cortex may improve patient safety. STI

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