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Usefulness of a drill stopper to prevent iatrogenic soft tissue injury in orthopedic surgery

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A B S T R A C T

Objective: This study introduces a novel technique utilizing a drill stopper to limit drill penetration depth and to prevent iatrogenic injuries, specifically neurovascular damage, in orthopedic surgeries. Orthopedic surgeries frequently involve the use of drills, which are essential tools for various procedures. However, improper handling of drills can lead to iatrogenic soft tissue injuries, causing severe consequences such as permanent disability or life-threatening complications. To address this issue, we propose the use of a drill stopper as a safeguard to prevent excessive drill penetration and reduce the risk of soft tissue damage during surgery.

Materials and Methods: The study involved 32 orthopedic surgeons, half of whom were experienced and the other half inexperienced. Synthetic femur bone models (Synbone) were used for drilling exercises, employing four configurations: a sharp drill bit without a stopper (SF, Sharp Free), a sharp drill bit with a stopper (SS, Sharp Stopper), a blunt drill bit without a stopper (BF, Blunt Free), and a blunt drill bit with a stopper (BS, Blunt Stopper). Each participant conducted three trials for each configuration, and the penetration depth was measured after each trial.

Results: For experienced surgeons, the average penetration depths were 3.83 (±1.826)mm for SF, 11.02 (±3.461)mm for BF, 2.88 (±0.334)mm for SS, and 2.75 (±0.601)mm for BS. In contrast, inexperienced surgeons had average depths of 8.52 (±4.608)mm for SF, 18.75 (±4.305)mm for BF, 2.96 (±0.683)mm for SS, and 2.83 (±0.724)mm for BS.

Conclusion: The use of a drill stopper was highly effective in controlling drill penetration depth and preventing iatrogenic injuries during orthopedic surgeries. We recommend its incorporation, particularly when using a blunt drill bit or when an inexperienced surgeon operates in an anatomically unfamiliar area. Using the drill stopper, the risk of severe injuries from excessive drill penetration can be minimized, leading to improved patient safety and better surgical outcomes.

1. Introduction

In the realm of orthopedic surgery, the drill is an indispensable tool used in a majority of procedures. The ability to handle the drill with precision is crucial in minimizing the risk of iatrogenic injuries that can occur during surgery. The risk of such injuries increases when drilling into bone with high mineral density or when using a blunt drill bit, as these factors can lead to an increase in drill penetration depth, potentially causing catastrophic damage to vital neurovascular structures [1].

While there are few papers examining prevalence of iatrogenic drill penetration injury, it seems to occur in approximately 0.1–0.49 % of cases [2]. However, many orthopedic studies have reported cases of iatrogenic drill penetration causing soft tissue injury. For instance, in distal radius fractures, penetration of the 3rd extensor compartment during volar plating is a well-known iatrogenic drilling injuries, and similar injuries have been reported during femur or clavicle surgeries [3–11]. Iatrogenic soft tissue injuries caused

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by drill penetration can be a common complication during orthopedic surgeries. These iatrogenic drilling injuries can result in permanent disability, and in severe cases, can even be life-threatening due to excessive bleeding. However, a definitive method to prevent such injuries has not yet been reported.

To prevent such injuries, several methods have been introduced, including the use of a dual motor drill and two-hand technique. These methods, while effective, have their limitations. For instance, they rely heavily on the surgeon's skill and concentration and do not provide a physical limit to the drilling depth. This leaves room for potential errors, especially in complex surgical situations or when the surgeon is inexperienced [12,13]. Furthermore, the costs associated with some of these state-of-the-art techniques can be prohibitive, and their applications may be restricted to specific surgeries. For instance, while ultrasound- and photoacoustic-guided fiber optic drilling might offer precision during spinal fusion surgeries [14,15], they might be impractical or too costly for broader clinical application.

To overcome these challenges, we propose a novel approach using a drill stopper that offers direct, physical control over the drilling depth. By setting a specific depth limit, the drill stopper acts as a safeguard, preventing the drill from penetrating too deep and reducing the risk of iatrogenic injuries, such as neurovascular damage.

Our method provides an alternative that complements the surgeon's skill and judgment with a tangible means of preventing drilling-related complications. With this approach, we aim to enhance the safety and precision of orthopedic surgeries, particularly in critical situations where precise drilling is crucial to avoid potential harm to vital structures.

2. Materials and Methods

This study involved voluntary recruitment of orthopedic surgeons who were informed about the study's purpose upon enrollment. The participants were categorized into two groups based on their experience: the experienced group comprised surgeons with over seven years of orthopedic service, including residency training, while the inexperienced group included those with less than four years of residency training. Surgeons with experience between four and seven years were excluded to ensure clear differentiation between the two groups.

The study utilized a drill stopper, a device that can be attached to the drill bit using a screw, providing direct control over the drilling depth [Fig. 1(A-C)]. The materials used in the study included a synthetic femoral bone (Synbone, Switzerland), a drill tool, 3.2 mm sharp and blunt drill bits, a rubber cover for measuring plunging depth, a depth gauge, and the drill stopper (DAYFULI, China) [Fig. 2(A-B)].

Each participant conducted three drilling trials using a freehand technique with both sharp and blunt drill bits. To minimize bias, the drill bit type was not disclosed before the trials, and a rubber cover was fixed to the near cortex to aid in measuring the plunging depth. Post-drilling adjustments were not allowed to maintain consistency [Fig. 2C-F].

Subsequently, participants repeated the experiment using the drill stopper. In this study, to demonstrate the flexibility of the drill stopper, the stopper was initially fixed to the proximal part of the drill bit (Fig. 2B). After penetrating the near cortex and reaching the nearest portion of the far cortex, the stopper was adjusted and fixed 13 mm proximal from the near cortex, and drilling continued. The thickness of the medial cortex of the femur Synbone used in our study was approximately 10 mm. To ensure safe drilling and prevent iatrogenic injuries, we aimed for an acceptable plunging depth of 3 mm. Consequently, we adjusted the gap in the drill stopper trial to be 13 mm.This mid-drilling adjustment of the stopper can be particularly valuable when working around anatomically sensitive structures, depending on the surgeon's preference and the surgical situation.

Each participant conducted a total of 12 trials, including three freehand trials with sharp drill bits, three freehand trials with blunt drill bits, three trials using the drill stopper with sharp drill bits, and three trials using the drill stopper with blunt drill bits.

Plunging depth was calculated by subtracting the bone depth from the total drilling depth. In the freehand technique group, the

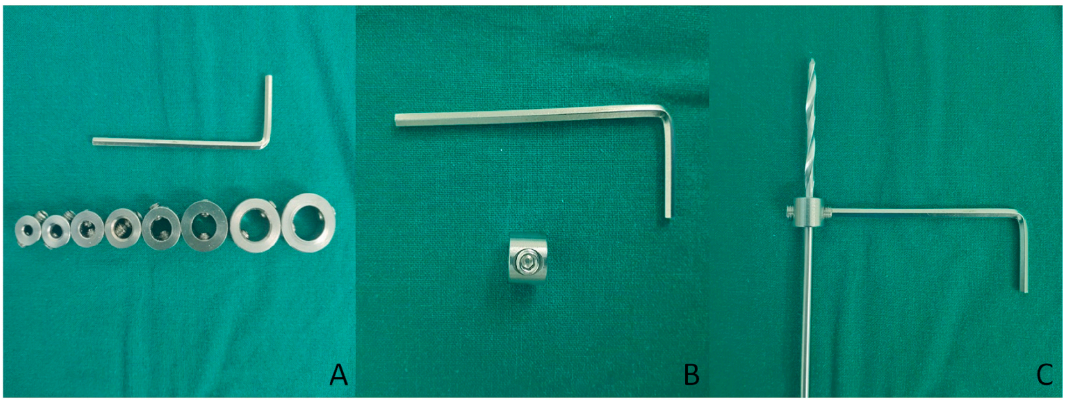

Fig. 1. Shows the assembly of the drill stopper to the drill bit, which is an essential step in our procedure. The stoppers come in various sizes to fit different drill bit sizes (Fig. 1A). A screwdriver is used to tighten the stopper screw part to the drill bit (Fig. 1B), and the completed assembly is shown in Fig. 1C.

Fig. 2. We provide a step-by-step visual representation of the drilling process. Fig. 2A shows the preparation tools, including the drill with the installed stopper (Fig. 2B). The drilling process is depicted in Fig. 2C and D. After drilling, we measure the bone depth (Fig. 2E) and the total drilling depth (Fig. 2F). The plunging depth is then calculated by subtracting the bone depth from the total drilling depth.

total drilling depth was measured from the drill tip to the rubber cover, while in the drill stopper group, it was measured from the drill tip to the drill stopper. Bone depth was measured using a standard orthopedic depth gauge. If the drill stopper did not reach the near cortex after drilling, the plunging depth was recorded as less than the measured plunging depth.

Data on each participant's orthopedic training period, age, gender, etc. were collected for further analysis. Statistical analysis was performed using IBM SPSS Statistics version 20.0, with appropriate tests for group comparisons. Results were presented as mean ± standard deviation, and a p-value <0.05 was considered statistically significant. Graphs were generated using Microsoft Office Excel. This study was exempt from IRB approval.

3. Result

A total of 32 participants took part in the experiment, with 16 being experienced orthopedic surgeons and the remaining 16 being inexperienced. The experienced participants had an average orthopedic service year of 10.1 years, while the inexperienced participants had an average of 18 months (Table 1).

The average plunging depths for each technique and drill stopper usage were as follows: for the experienced group - SF: 3.83 (±1.826) mm, BF: 11.02 (±3.461) mm, SS: 2.88 (±0.334) mm, and BS: 2.75 (±0.601) mm; for the inexperienced group - SF: 8.52 (±4.608) mm, BF: 18.75 (±4.305) mm, SS: 2.96 (±0.683) mm, and BS: 2.83 (±0.724) mm (Table 2), (Fig. 3).

When comparing the plunging depths based on the use of drill stoppers, the average depth for the freehand technique group was 10.53 (±6.548) mm, while that for the drill stopper group was 2.85 (±0.605) mm, a statistically significant difference ($p < 0.01$).

There were also statistically significant differences when comparing subgroups based on the use of sharp and blunt drill bits. For SF and SS, the plunging depths were 6.18 (±4.208) mm and 2.92 (±0.536) mm, respectively ($p < 0.01$), while for BF and BS, they were 14.89 (±5.494) mm and 2.79 (±0.664) mm, respectively ($p < 0.01$) (Table 3).

In the experienced group, the average plunging depth for the freehand technique was 7.43 (±4.542) mm, and for the drill stopper technique, it was 2.81 (±0.488) mm, showing a significant difference ($p < 0.01$). In the inexperienced group, the average plunging depth for the freehand technique was 13.64 (±6.790) mm, while that for the drill stopper technique was 2.90 (±0.703) mm, also showing a significant difference ($p < 0.01$).

4. Discussion

Iatrogenic injuries from drill penetration, such as those occurring in distal radius fractures or femur and clavicle surgeries, are well-documented and can have severe consequences, including permanent disability or life-threatening bleeding [3–11]. Various preventive methods have been explored to mitigate these risks.

Alajmo et al. conducted a study including 20 experienced and 17 inexperienced surgeons, measuring the plunging depth after drilling using a sharp drill bit and a blunt drill bit on an osteoporotic bone model and a normal bone model. According to their data, the plunging depth of the osteoporotic bone model measured less than that of the normal bone model, and the experienced surgeons drilled a smaller plunging depth than the inexperienced surgeons. Also, the plunging depth measured less when using the sharp drill bit instead of the blunt drill bit. In conclusion, the study reported that the drill plunging depth was statistically less when the operator was highly skilled, using the sharp drill bit, and when drilling the osteoporotic bone [1]. Our study also showed statistically significant smaller plunging depth when drilling with a sharp drill bit and when drilling was performed by an experienced surgeon, and this corresponds with previous studies.

There are some methods previously introduced in other studies to prevent drilling injury during orthopedic surgery. To reduce plunging depth, the two handle technique and the dual-motor drill device (Smart Medical Devices SMARTdrill 6.0.2. Las Vegas NV) have been introduced. Ding et al. proposed that the drilling technique could reduce the plunging depth. They compared the plunging depths after drilling the saw bone model using the single hand smooth technique, the single hand bounce technique, and the double hand smooth technique, respectively. The authors proposed that the plunging depth could be minimized using the two-hand smooth technique [12].

Wallace et al. introduced the dual-motor drill as a technique to reduce the plunging depth. In the dual-motor drill, the first motor operates in the same way as the conventional drill, and the second motor retracts the attached sleeve according to the set rate. The device transmits the measured drill power to the monitor via Bluetooth to enable the operator to check whether the near cortex and the far cortex have been drilled in real time. The authors claimed that using this device can reduce the plunging depth [13].

Shubert et al. and Gonzalez et al. devised a method using ultrasound- and photoacoustic-guided fiber optic drilling to avoid critical structures and impending cortical breaches during pedicle screw insertion for spinal fusion surgery [14,15]. In a similar attempt, Losch et al. introduced diffuse reflectance spectroscopy-guided pedicle screw insertion during spinal surgery [16].

However, the techniques introduced above depend on the skill of the operator and the equipment used is quite costly. Some of the techniques are limited to spinal surgery and may be impractical in actual clinical settings.

In our study, we devised a commercial industrial drill stopper to control the drill plunging depth and decrease the risk of drill penetration injury when the operator is a novice and in situations where the operator has no choice but to use a blunt drill bit. The comparison of methods to prevent such drilling injuries during orthopedic surgeries mentioned above are organized in Table 4.

In this experiment, when the sharp drill bit was used, the experienced surgeons showed a plunging depth of 3.83 mm on average, and the inexperienced showed a plunging depth of 8.52 mm. When the blunt drill bit was used, the experienced showed 11.02 mm, and the inexperienced showed 18.75 mm. However, when the drill stopper was used, the average plunging depth was less than 3 mm

Table 1
Demographic and professional characteristics of participants.

	Experienced	Inexperienced
No. of participants	16	16
Years in orthopedics	10.1	1.5
Dominant hand		
Rt.	16	15
Lt.	0	1
Sex		
Male	16	15
Female	0	1

Table 2
Comparison of drilling depths between experienced and inexperienced groups for different techniques.

	Experienced (mm)	Inexperienced (mm)	p value
SF (sharp free)	3.83 (±1.826)	8.52 (±4.608)	**<0.01**
BF (blunt free)	11.02 (±3.461)	18.75 (±4.305)	**<0.01**
SS (sharp stopper)	2.88 (±0.334)	2.96 (±0.683)	0.450
BS (blunt stopper)	2.75 (±0.601)	2.8 (±0.724)3	0.869

Bold values indicate significant results.
Values presented as mean (±SD).
Significance was defined as P < 0.05.

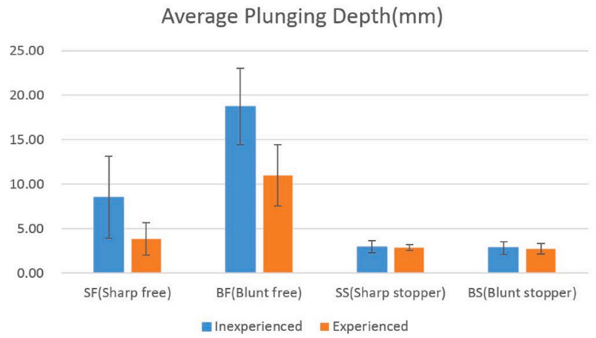

Fig. 3. Presents the average plunging depths for both experienced and inexperienced participants across four conditions: SF, BF, SS, and BS. These data demonstrate the variation in plunging depth based on the experience level of the participant and the specific condition. The average SF, BF, SS, and BS plunging depth of the experienced participants were 3.83 mm, 11.02 mm, 2.88 mm, and 2.75 mm, respectively. The average SF, BF, SS, and BS plunging depth of the inexperienced were 8.52 mm, 18.75 mm, 2.96 mm, and 2.83 mm, respectively.

Table 3
Comparison of drilling depths for sharp and blunt techniques using free and stopper methods.

	Free (mm)	Stopper (mm)	p value
sharp	6.18 (±4.208)	2.92 (±0.536)	**<0.01**
blunt	14.89 (±5.494)	2.79 (±0.664)	**<0.01**

Bold values indicate significant results.
Values are presented as mean (±SD).
Significance was defined as P < 0.05.

Table 4
Comparison of methods to prevent drilling injury during orthopedic surgeries.

	Method	Advantage	Disadvantage
Shubert et al. Gonzalez et al.	Ultrasound & photoacoustic-guided fiber optic drilling	- Decreases radiation exposure during surgery - Useful to determine optimal entry points into the pedicle - Useful to avoid critical structures - Useful to avoid impending bone breaches during pedicle screw insertion	- Needs specially designed drill - Can be expensive - Using ultrasound during surgery can be time consuming and depends on surgeon's skill - Application limited to spinal fusion surgery
Losch et al.	Diffuse reflectance spectroscopy	- Allows detection of impending cortical breaches during pedicle screw insertion	- Requires additional device (spectrometer with optical fibers) - Alternatives are needed to implement light beam steering - May be less practical in actual surgical settings - Application limited to spinal fusion surgery
Ding et al.	Two-handed technique	- Decreases plunging depth with low variance	- Determined solely by the surgeon's skill
Wallace et al.	Dual motor drill	- Decreases plunging depth regardless of the user's level of experience	- Relatively expensive - Requires the surgeon's eyes to be off the surgical field while drilling
Choi et al.	Drill stopper	- Able to perform accurate plunging depth regardless of the user's level of experience - Intended plunging depth is reproducible - Relatively inexpensive	- Additional attachment to the drill may be bothersome during procedures

regardless of the operator's experience. Hence, the drill stopper can be utilized at a very low cost to perform more accurate depth control than any other depth control technique that has been introduced. This should be considered during manufacture and commercialization of a drill stopper for orthopedic surgeries to reduce drill penetration soft tissue injuries.

When using the drill stopper, our intended plunging depth was set at 3 mm. However, the average result showed that the plunging depth was less than 3 mm. This discrepancy in the measured depth can be attributed to a few factors. First, the synthetic femoral bone used in the experiment had a cylindrical shape, and drilling at an oblique angle may have contributed to the error in the plunging depth measurement. Additionally, the thickness of the far cortex of the synthetic bone was not precisely 10 mm, which could also have influenced the results.

Despite these potential sources of error, the average plunging depth approached the intended 3 mm. Furthermore, the standard deviation of the measurements was very small. This indicates that the variations in plunging depth among the participants were minimal, making the results more reliable.

As a method of using the drill stopper, operators can set the location of the drill stopper before drilling or after drilling the near cortex and touching the near portion of far cortex. This can be adjusted according to the operator's preference. Though it is possible to stop drilling during surgery and attach a drill stopper temporarily, it may be more convenient to fix the stopper in advance and control the total drilling depth. However, due to the nature of the cylindrical experimental bone, if the total drilling depth is determined in advance and drilled at an oblique angle during the experiment, the error of the plunging depth may be significant. To reduce the error, we applied the stopper when the drill pierced the near cortex and made with to the nearest portion of the far cortex. This method has the advantage of being able to control the plunging depth more precisely when using a stopper. Therefore, we recommend fixing a stopper after drilling the near cortex if an anatomically crucial structure lies very close to the drilling site.

Regarding the acceptable plunge depth of 3 mm, this was set as a conservative estimate for the purposes of this study. In a real-world clinical setting, the acceptable plunge depth can be adjusted based on various factors, including the specific surgical situation and the surgeon's judgment. For instance, bone depth can be measured beforehand using X-ray or CT scans, and drilling can be performed by setting an acceptable depth in advance or by gradually adjusting the position of the stopper toward the shallow part of the drill.

This study has several limitations. First, the study was conducted with a relatively small number of participants (32 surgeons), which may limit the generalizability of the results. Second, the femoral Synbone used in this study is less dense than normal bone, which could result in a lower measured plunging depth compared to drilling actual bone. Third, there may be bias in the free handle trial because the drilling method was not standardized, and the participants were aware of the experiment's purpose in advance.

In terms of operational aspects, while the drill stopper used in this study demonstrated potential benefits in controlling plunging depth, its practical application in a surgical setting may present some challenges. For instance, adjusting the drill stopper during surgery could potentially interrupt the surgical workflow. Additionally, factors such as surgeon experience and specific surgical situation may influence drill stopper effectiveness.

Finally, drill stoppers specifically designed for medical use are not readily available. This could limit the immediate applicability of our findings in a clinical setting. However, the results of this study could help inform the development of such tools in the future.

However, this study has several important strengths. Each participant performed a relatively large number of drilling trials (12 times for each surgeon) to minimize errors. Considering that the experiment was performed on the osteoporotic bone model, the anticipated effect of using a drill stopper in actual clinical settings seems more promising. Finally, this study introduces a novel method that can most reliably prevent drill penetration injury. Although the experiment was conducted on a model bone, this technique is relatively intuitive and simple and can control plunging depth during drilling, allowing high reproducibility regardless of surgeon experience. Therefore, we expect the result to be similar even in actual clinical practice.

5. Conclusion

The drill stopper has proven to be useful in orthopedic surgeries, especially in reducing the risk of injuries caused by medical intervention. Based on our data, it appears that this method provides a dependable means of controlling the depth of drilling, resulting in safer and more accurate surgeries. Although it is a cost-effective tool that has the potential for widespread adoption, it is evident that further research is required. Our main aim is to enhance patient safety during orthopedic surgeries. Tools such as the drill stopper could be crucial in achieving this goal.

Data availability statement

Data included in article/supp. Material/referenced in article.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Jung Hwan Choi: Data curation, Writing – original draft. **Young Seok Lee:** Formal analysis, Writing – original draft, Writing – review & editing. **Kyu-Tae Hwang:** Data curation, Formal analysis. **Young-Hoon Jo:** Formal analysis, Writing – original draft. **Hyun**

Sik Shin: Formal analysis, Visualization. **Jihwan Kim:** Formal analysis, Visualization. **Ki-Chul Park:** Conceptualization, Methodology, Project administration, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20772.

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