A Simple and Low-cost Drilling Simulator for Training Plunging Distance Among Orthopedic Surgery Residents

Efi Kazum, MD, Oleg Dolkart, PhD, Yoav Rosenthal, MD, Haggai Sherman, MD, Eyal Amar, MD, Moshe Salai, MD, Eran Maman, MD, and Ofir Chechik, MD

Division of Orthopaedic Surgery, Tel Aviv Sourasky Medical Center, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

OBJECTIVE: Drilling through bone is a complex action that requires precise motor skills of an orthopedic surgeon. In order to minimize plunging and soft tissue damage, the surgeon must halt drill progression precisely following penetration of the far cortex. The purpose of this study was to create a low-cost and easy-to-use drilling simulator to train orthopedic residents in reducing the drill plunging depth.

DESIGN, SETTING, PARTICIPANTS: This prospective observational study was performed in the division of orthopedic surgery of a single tertiary medical center. The participants included 13 residents and 7 orthopedic specialists. The simulator consisted of a synthetic femur bone model and ordinary modeling clay, and the training unit consisted of a disposable plastic tube (~US$14), clamps (~US$58), and a power drill + drill bit (standard hospital equipment). Plunging depths were measured by the simulator and compared between orthopedic specialists, the 6 "senior residents" (3+ years) and the 7 "junior residents" during a training session. Measurements were taken again 2 weeks following the training session.

RESULTS: Initially, the plunging depths of the junior residents were significantly greater compared to those of the orthopedic specialists (7.00 mm vs. 5.28 mm, respectively, $p < 0.038$). There was no similarly significant difference between the senior residents and the orthopedic experts ([6.33 mm vs. 5.28 mm, respectively; $p = 0.18$). The senior residents achieved plunging depths of 5.17 mm at the end of the training session and 4.7 mm 2 weeks later compared to 7.14 mm at the end of the training session and 6 mm 2 weeks later for the junior residents.

CONCLUSIONS: This study demonstrated the capability of a low-cost drilling simulator as a training model for reducing the plunging depth during the drilling of bone and soft tissue among junior and senior residents. (J Surg Ed 76:281−285. © 2018 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEYWORDS: Drilling, Simulator, Plunging depth, Orthopedic residents

COMPETENCIES: Medical Knowledge, Professionalism, Practice-Based Learning and Improvement

ABBREVIATION: OR operating room

INTRODUCTION

Orthopedic surgery demands special and exacting motor skills, one of which is the complex action of drilling through bone and soft tissue, which is basic to a vast majority of orthopedic procedures.[1] In order to minimize plunging and soft tissue damage, an orthopedic surgeon must halt the progression of the drill precisely after the far cortex has been penetrated.[2] Plunging depth is defined as the distance a drill bit obtrudes the far cortex during the process of drilling through a bone.[2]

Orthopedic surgery has been traditionally taught within an apprenticeship setting in the operating room (OR).[3] Factors such as residents' hour regulations, concerns for patient safety, financial issues, and continuous pressure on surgeons to maximize efficiency have all contributed to a reduction in residents "hands-on" experience in the OR, thus emphasizing the need for an alternative means of gaining experience.[4,5] The numerous advantages of simulation training have led to their popularity as learning tools by most surgical specialties.[3] Simulators offer high availability, safety, and cost-effectiveness[5] and their use has been shown to improve

Correspondence: Inquiries to Oleg Dolkart, PhD, Orthopedic Surgery Division, Tel-Aviv Medical Center, 6 Weizman Street, Tel Aviv 6423906, Israel.; e-mail: dolkarto@gmail.com

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surgeons' technical skills in the OR.[6] In addition, it is believed that cognitive resources are liberated as automatic technical skills are acquired, allowing for more attention to be directed to other tasks, such as decision-making, problem solving, and planning.[7]

Orthopedic simulation has generally trailed behind other specialties, but it is reportedly beginning to catch up.[3] Cadaveric and virtual reality models are generally utilized in orthopedic simulations, and dry simulation models have continued to draw attention as well.[8]

The purpose of this study is to describe a very low-cost and easily constructed drilling simulator. We hypothesized that use of such a simulator for training residents in orthopedic surgery will be highly effective in reducing drill plunging depth.

METHODS

This pilot trial was performed in a single center and included a total of 20 participants.

A "Drill Measurement Simulator" (Figure 1) was designed to measure plunging depth during the drilling of bone with modeling clay representing the soft tissues. The simulator was created using a synthetic femur bone model (sawbones, Femur #1106, Malmö, Sweden) stabilized to a desk by a clamp (840607, KENDO). Modeling clay (Plastigan 250 g, OMEGA) was attached to the bone model using nylon cable ties (MD-300XS, ABS). An electric drill (Synthes Power drill) with a 2.7 mm drill bit was used to drill through the bone model, and a depth gauge measured the plunging depth (Figure 2).

The practical training was carried out by drilling into a "Training Device" created from an ordinary plastic tube (polyvinyl chloride pipe, outside diameter 43 mm and inside diameter 37 mm) that was attached to a desk by clamps (Figure 3). Again, modeling clay (Plastigan 250 g, OMEGA) was attached to the Training Device using nylon cable ties (MD-300XS, ABS).

Study Groups

Three groups of surgeons were included:-

Junior Trainee Group—7 junior residents (in orthopedic training for fewer than 3 years)
Senior Trainee Group—6 senior residents (in orthopedic training for 3+ years)
Expert Group—7 orthopedic specialists—fully trained and regularly operating

Skill Being Assessed

Drilling through a long bone safely with minimal plunging beyond the distal cortex of the bone at the end of the drilling procedure.

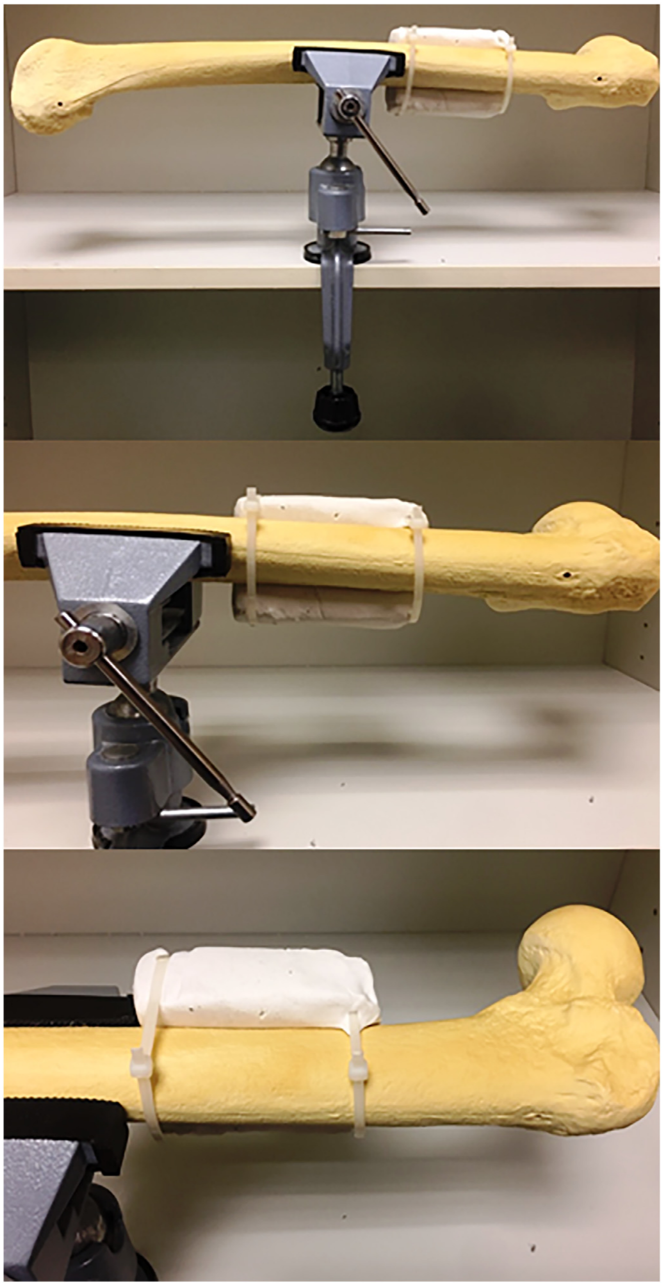

FIGURE 1. Simulator model.

Study Design

Participants were all evaluated at the start of the study using the "Drill Measurement Simulator."

Pre-training Evaluation

All three study groups (20 participants) were instructed to drill 10 straight holes through the plastic bone but stopping just after the distal cortex (the other side of the bone), with as little plunging through the bone as possible (to avoid damaging the soft tissues on the other side of the

FIGURE 2. Depth gauge measuring the plunging depth.

bone). The plunging depths of the 10 holes were measured using the depth gauge (Figure 2) and the mean and standard deviation for each participant was recorded. The values obtained by the Expert Group were used as the gold standard toward which training should be directed.

The Junior and Senior Trainee Groups (13 participants) were then provided with training using the Training Device. The 13 residents then practiced their drilling skill by drilling 10 holes on the training unit, with the plunging depths again measured in the modeling clay and documented. The drilling and measuring cycles were then repeated 8 times until there were 90 holes on the training model. The study duration was equal to 4 months.

Post-training Evaluation

The plunging depth of a mean of 10 attempts was again measured on the Drill Measurement Simulator 2 weeks following the training session in order to detect whether there had been a sustained learning effect. All measurements were performed and documented by the primary investigator (EK).

Statistics

Data were analyzed by calculating means and percentages for establishing trends and summarized as means. Student's *t* test was implemented to compare continuous variables. A 2-sided p value of 0.05 was considered statistically significant. Statistical analysis was performed using SPSS, version 21.0 (SPSS).

RESULTS

Baseline Plunging Depth

The mean baseline plunging depth of the junior residents was significantly greater compared to that of the orthopedic specialists (7.00 mm vs. 5.28 mm; $p < 0.038$). There was no significant difference in the mean baseline plunging depth between the junior and senior residents (7.00 mm vs. 6.33; $p = 0.7$) or between the senior residents and the orthopedic specialists (6.33 mm vs. 5.28 mm; $p = 0.18$).

Plunging Depth Curve During the Training Session

The average plunging depth of the senior and junior residents throughout the training session displayed a general improvement (Figure 4). The senior residents achieved a plunging depth of 5.17 mm at the end of

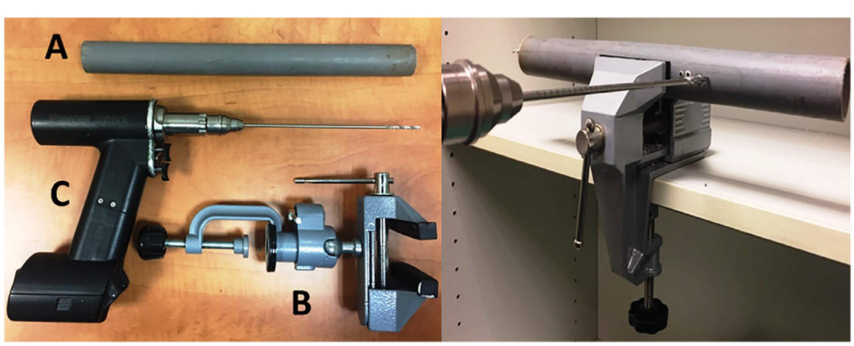

FIGURE 3. Training unit. (A) plastic tube—US$14.2; (B) clamps—US$58.2; (C) Power drill + drill bit (hospital properties).

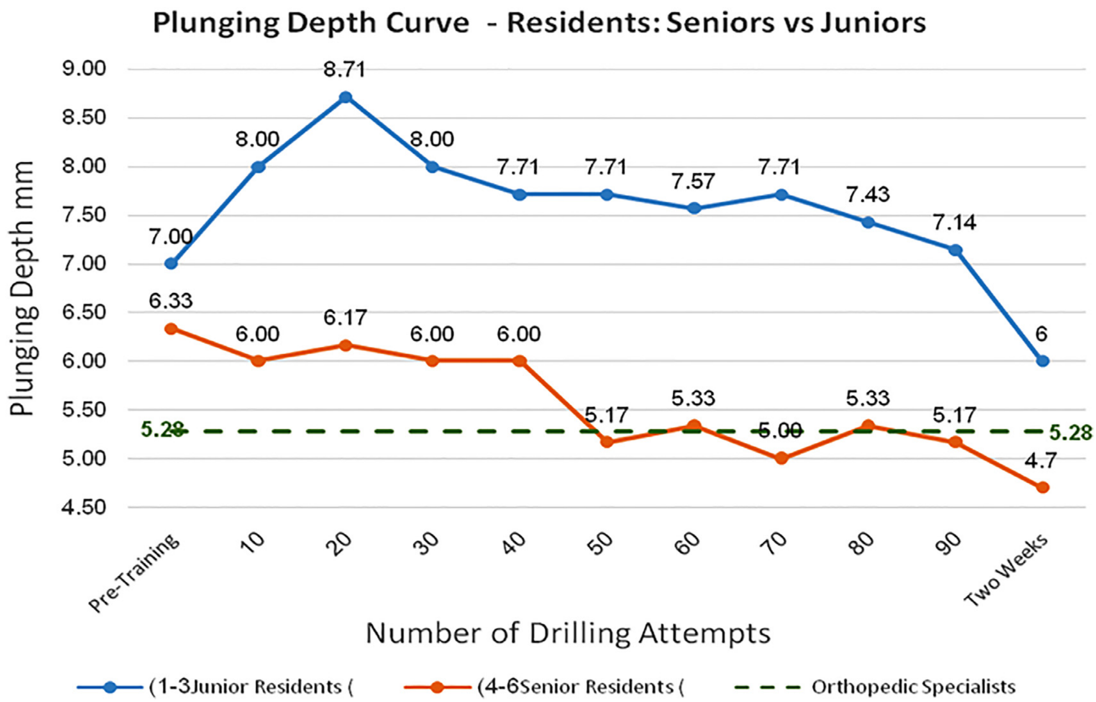

FIGURE 4. Plunging depth curve. Results are presents as means and standard deviation. Dotted line represents the gold standard achieved by the Orthopedic Specialists at the time of the pre-training session.

the training session and 4.7 mm 2 weeks later. The junior residents achieved a plunging depth of 7.14 mm at the end of the training session and 6 mm 2 weeks later. The senior residents reached the target plunging depth set by the orthopedic specialists after 50 practice drills, and maintained their level of improvement to finally surpass the orthopedic specialists' mean plunging depth (4.7 mm and 5.28 mm, respectively). The junior residents did not reach the target plunging depth but they did show an improvement of 1 mm between the first and last drilling sessions (7 mm and 6 mm, respectively).

DISCUSSION

This study aimed to create a low-cost and easily constructed drilling simulator for the training of orthopedic residents in reducing the plunging depth when drilling through bone and soft tissue. As expected, there was a significant difference in baseline plunging depth between the junior residents and the orthopedic specialists. Both the junior and senior residents displayed an improvement in plunging depth scores at the end of the study. Moreover, following 100 drills, the senior residents equaled and even surpassed the target set by the orthopedic specialists.

The training setup described in this study required no supervision of any kind. It allowed the residents to independently practice their skills in minimizing plunging depth. Their efforts were later on measured on a sawbone model which has been proven efficient in the literature.[2]

Bicortical bone drilling is a basic procedure performed during various orthopedic surgeries as an essential step of hardware fixation. Medical errors reportedly account for over 1 million injuries to patients in the United States alone, where 4.1% of hospitalized orthopedic patients have some type of adverse event.[2,9] The complications of exceeded drilling as a preparation for bicortical screw placement are well documented in the literature[10] among them vessel and nerve injuries.

Our results are in agreement with other studies on drilling simulators. Clement et al.[10] aimed to accurately measure the depth to which surgeons drill, including the projection of the drill bit beyond the far cortex. Similar to the current study, they used a generic artificial bone model. Polystyrene plates were mounted on the far cortex of the bone to allow for exact measurement of the overpenetration of the drill bit. Each participant performed 3 bicortical drillings, and the average projection of the drill bit beyond the far cortex was 6.31 mm.

Ruder et al.[2] demonstrated a significant reduction in plunging depth with the use of a low-cost training model and a formal instructive and skills session on proper drilling technique that can effectively be led by senior residents. The mean depth before the educational session was 15 mm and this dropped to 5 mm following the educational session ($p < 0.05$).

An additional finding of the current study was a significant improvement in plunging depth by the time of the second drilling session which took place 2 weeks following the first one. This is in line with Karni et al.'s statement that even a limited training experience can induce behaviorally significant changes in brain activity and initiate important long-term effects that may provide the basis for the consolidation of the experience.[11]

Many residency programs attempt to bridge the gap between observation and autonomy by utilizing surgical simulation, but surgical simulation can be quite expensive. Cadaveric simulation requires specimens and facilities: space is often limited, and the cost of a cadaver ranges from US$1000 to US$2000. Arthroscopic simulators and virtual reality programs are also expensive, ranging from a less expensive video box (with standard arthroscopic equipment) to a virtual reality haptic simulation costing a residency program as much as US$80,000.[12] Drilling simulators with haptic feedback have also been introduced, but they also require expensive complex computer systems.[13] Our drill plunging simulator can be built at a very low cost.

There are several limitations to this study. First, the number of the participants was relatively small and so validation of the conclusions requires a larger study population. The setting in which this model was used does not accurately mimic the standard operating theatre atmosphere. Finally, the optimal number of drills required in order for the junior residents to reach the target plunging depth was not determined.

In conclusion, a low-cost and easily constructed drilling simulator is demonstrated as being efficient in reducing drill plunging depth among junior and senior orthopedic surgery residents. It offers a reliable and highly reproducible training modality for orthopedic residents prior to implementing drilling maneuvers in patients as well as in honing drilling skills.

AUTHOR CONTRIBUTIONS

Drs. Kazum E., Chechik O., Dolkart O., and Maman E. participated in the design of the study, data analysis, and writing of the manuscript. Drs. Amar E., Sherman H., and Rosental Y. contributed to the design of the study, data analysis, and editing of the manuscript. Professor Salai M. contributed to the study development, data interpretation, and editing of the manuscript.

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