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Exhibit Selection

A Cost-Effective Junior Resident Training and Assessment Simulator for Orthopaedic Surgical Skills via Fundamentals of Orthopaedic Surgery

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Investigation performed at the Departments of Orthopaedic Surgery, Biomedical Engineering, and Anatomy and Neurobiology, Neuroscience Research Facility, University of California, Irvine, Irvine, California; Department of Orthopaedic Surgery, Washington University, St. Louis, Missouri; and Department of Orthopaedic Surgery, Wake Forest School of Medicine, Winston-Salem, North Carolina

Background: Psychomotor testing has been recently incorporated into residency training programs not only to objectively assess a surgeon’s abilities but also to address current patient-safety advocacy and medicolegal trends. The purpose of this study was to develop and test a cost-effective psychomotor training and assessment tool—The Fundamentals of Orthopaedic Surgery (FORS)—for junior-level orthopaedic surgery resident education.

Methods: An orthopaedic skills board was made from supplies purchased at a local hardware store with a total cost of less than $350 so as to assess six different psychomotor skills. The six skills included fracture reduction, three-dimensional drill accuracy, simulated fluoroscopy-guided drill accuracy, depth-of-plunge minimization, drill-by-feel accuracy, and suture speed and quality. Medical students, residents, and attending physicians from three orthopaedic surgery residency programs accredited by the Accreditation Council for Graduate Medical Education participated in the study. Twenty-five medical students were retained for longitudinal training and testing for four weeks. Each training session involved an initial examination followed by thirty minutes of board training. The time to perform each task was measured with accuracy measurements for the appropriate tasks. Statistical analysis was done with one-way analysis of variance, with significance set at p < 0.05.

Results: Forty-seven medical students, twenty-nine attending physicians, and fifty-eight orthopaedic surgery residents participated in the study. Stratification among medical students, junior residents, and senior residents and/or attending physicians was found in all tasks. The twenty-five medical students who were retained for longitudinal training improved significantly above junior resident level in four of the six tasks.

Conclusions: The FORS is an effective simulator of basic motor skills that translates across a wide variety of operations and has the potential to advance junior-level participants to senior resident skill level.

Clinical Relevance: The FORS simulator may serve as a valuable tool for resident education.

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Suturing speed and quality were assessed by giving each participant 240 seconds to place as many simple, interrupted sutures as possible into a PVC pipe. The participant drills five consecutive holes through the PVC pipe, minimizing their distance from the premarked location. This task was timed and scored on the basis of the distance from the center of the board.

Fluoroscopy

The fluoroscopy simulation task requires the participant to aim a drill-bit through a premarked 3.8-cm-thick block of wood with color-coordinated visible entry points vertically and horizontally. The participant triangulates the covered exit point by using color-coordinated guide-marks on perpendicular planes of the block. This exercise was timed and scored on the basis of the exit point's distance from the premarked location. The task highlights the importance of using fluoroscopy to properly triangulate a point that cannot be visualized.

3-D Drilling

The 3-D drilling and lag-screw-placement task requires participants to aim a drill-bit through a 3.8-cm-thick block of wood with three different color-coordinated entry and exit points. In this task, each color is drilled individually, with planning for each screw allowed. This exercise was timed and scored on the basis of the distance of the exit point from the premarked location.

Scoring

Each exercise was scored on the basis of efficiency (time) or efficiency and accuracy (penalty). A maximum time was given for each task. A time score was
calculated by subtracting the participant’s time from the maximum time. Accuracy was assessed on the basis of measured distances (in millimeters) from the desired point and multiplied by a constant factor. The accuracy score was subtracted from the time score to give the final result. When a negative score was received, a recording of zero was used.

Forty-seven medical students, fifty-eight orthopaedic surgery residents, and twenty-nine attending orthopaedic surgeons from three ACGME (Accreditation Council for Graduate Medical Education)-accredited orthopaedic surgery residency programs participated in the study. At each training site, replica FORS boards were built from materials purchased at local
TABLE I Scores on the Six Tasks Tested with the FORS Simulation Board*

<table>
<thead>
<tr>
<th>Task</th>
<th>Medical Students</th>
<th>Medical Students Trained</th>
<th>Junior Residents</th>
<th>Senior Residents</th>
<th>Attending Physicians</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture reduction</td>
<td>98.78 ± 11.60</td>
<td>213.10 ± 8.55</td>
<td>191.60 ± 6.18</td>
<td>219.80 ± 2.09</td>
<td>220.10 ± 2.87</td>
</tr>
<tr>
<td>Depth of plunge</td>
<td>9.10 ± 2.10</td>
<td>46.78 ± 3.53</td>
<td>24.50 ± 4.82</td>
<td>50.68 ± 4.05</td>
<td>52.14 ± 3.67</td>
</tr>
<tr>
<td>Drill by feel</td>
<td>20.91 ± 3.28</td>
<td>65.32 ± 3.51</td>
<td>42.14 ± 3.66</td>
<td>62.90 ± 3.33</td>
<td>53.95 ± 4.13</td>
</tr>
<tr>
<td>Fluoroscopy</td>
<td>13.35 ± 2.12</td>
<td>39.10 ± 3.79</td>
<td>10.22 ± 2.41</td>
<td>26.84 ± 2.90</td>
<td>25.14 ± 3.73</td>
</tr>
<tr>
<td>3-D drilling</td>
<td>30.47 ± 2.74</td>
<td>39.80 ± 3.44</td>
<td>35.52 ± 3.77</td>
<td>51.57 ± 1.88</td>
<td>48.85 ± 2.95</td>
</tr>
<tr>
<td>Sutures</td>
<td>2.94 ± 0.27</td>
<td>7.27 ± 0.34</td>
<td>7.47 ± 0.36</td>
<td>10.60 ± 0.31</td>
<td>10.48 ± 0.36</td>
</tr>
</tbody>
</table>

*The values are given as the mean and the standard error of the mean.

Results

Questionnaire Results

On the basis of the questionnaire answered by orthopaedic surgeons (Fig. 1), the highest rated skills necessary for a competent orthopaedic surgeon were fracture reduction, minimizing depth of plunge, drilling by tactile feedback, directional control of the drill, fluoroscopic drilling, correct lag-screw placement, and soft-tissue closure. These skills were thought to be applicable across a wide variety of orthopaedic procedures. As a result of this questionnaire, the FORS surgical skills board was created to incorporate these tasks for training and evaluation (Fig. 2).

Fracture Reduction

Compared with all other participants, untrained medical students had difficulty reducing the fracture (98.78 ± 11.60; p < 0.0001) (Table I, Fig. 4-A). Furthermore, junior residents performed significantly slower than senior residents (191.60 ± 6.18 versus 219.80 ± 2.09; p = 0.003). Trained medical students demonstrated significant improvement in their scores, which were also improved compared with junior residents (213.10 ± 8.55 versus 191.60 ± 6.18; p < 0.05). For the fracture reduction exercise, novice participants were able to achieve scores significantly better than junior residents and on par with senior residents after four weeks of training.

Depth of Plunge

The scores for novice medical students (9.10 ± 2.10) were significantly lower than those for all other groups when performing this task (p < 0.0001) (Table I, Fig. 4-B). In addition, junior residents scored significantly lower than senior residents (24.50 ± 4.82 versus 50.68 ± 4.05; p < 0.0001). Similarly, the scores for trained medical students (46.78 ± 3.53) were significantly better than those for junior residents as well (p < 0.001), with scores on par with those for senior residents.

Drill by Feel

Medical students were initially unable to drill by tactile feedback accurately, and therefore, their scores (20.91 ± 3.28) were significantly below those of all other participants (p < 0.0001) (Table I, Fig. 4-C). Moreover, senior residents significantly outperformed junior residents in this task (62.90 ± 3.33 versus 42.14 ± 3.66; p < 0.001). Similarly, once medical students were trained to perform this task properly, their score (65.32 ± 3.51) was significantly higher than that of junior residents (p < 0.0001). In fact, their score was higher than that of senior residents as well.

Fluoroscopy

The scores on the fluoroscopy test were significantly lower for medical students (13.35 ± 2.12) and junior residents (10.22 ± 2.41) than for senior residents (26.84 ± 2.90; p < 0.01) (Table I, Fig. 4-D). However, trained medical students were able to improve their scores significantly (39.10 ± 3.79; p < 0.05), not only above those of junior residents but also above those of senior residents.

3-D Drilling

On initial testing with 3-D drilling, both medical students and junior residents (30.47 ± 2.74 and 35.52 ± 3.77, respectively) were significantly outperformed by senior residents (51.57 ± 1.88; 219.80 ± 2.09).
p < 0.01) (Table I, Fig. 4-E). However, in this task, even when medical students were trained, they were unable to significantly improve their scores (39.80 ± 3.44). Thus, it is likely that certain tasks are unable to be replicated and simulated outside real-world experience and procedures.

Suturing

On initial assessment of their suturing ability, most medical students had not been previously taught how to properly suture and instrument tie. As a result, the scores for medical students (2.94 ± 0.27) were significantly lower than those for all other groups of participants (p < 0.0001) (Table I, Fig. 4-F). Moreover, junior residents were able to tie significantly fewer sutures than senior residents were in the allotted time period (7.47 ± 0.36 versus 10.60 ± 0.31; p < 0.0001). After medical students were trained in proper suturing techniques, they were able to significantly improve their scores (7.27 ± 0.34) to the level of junior residents. However, they were unable to reach the level of senior residents. Again, this is likely due to the experience that residents gain in suturing throughout the operating-room experience, and this skill likely requires a longer time period to improve to that upper echelon of scores.

Fig. 3

Figs. 3-A through 3-F Photographs showing the six tasks that are tested by the FORS simulation board. Fig. 3-A The fracture reduction task, which utilizes shortening and rotational forces to simulate intraoperative fracture reduction. Fig. 3-B The depth-of-plunge minimization task, in which the participant learns to restrict the depth to which he or she plunges past the plastic PVC pipe. Fig. 3-C The drill-by-feel task, in which the participant utilizes tactile feedback from the drill to guess where the center of the longitudinal width of the board is located. Fig. 3-D Fluoroscopic simulation, which is performed with the participant drilling from a known start point to a covered exit point by using two reference points perpendicular to each other on a block of wood. Fig. 3-E The 3-D drilling task simulates lag-screw placement as the participant drills from a visible start point to a visible exit point. Fig. 3-F The suturing exercise utilizes PVC pipe insulation as the soft-tissue envelope to simulate wound closure.
Fig. 4-A Fracture reduction results. *P < 0.05. **P = 0.003.

Fig. 4-B Depth-of-plunge results. ***P < 0.001. *****P < 0.0001.

Fig. 4-C Drill-by-feel results. ***P < 0.001. ****P < 0.0001.

Fig. 4-D Fluoroscopy results. *P < 0.05. ****P < 0.0001.

Fig. 4-E 3-D drilling results. *P < 0.01. **P < 0.05.

Fig. 4-F Suturing results. ****P < 0.0001.

**Figs. 4-A through 4-F** Graphs showing the scores for medical students, medical students after a training course, junior residents, senior residents, and attending physicians. Data are presented as the mean and the standard error of the mean.
Overall, stratification among medical students, junior residents, and senior residents and/or attending physicians was found in all tasks after testing on the FORS board.

**Discussion**

The current medicolegal climate and public perception of patient safety both restrict the ability of the junior resident to learn basic operative skills inside the operating room. As such, it is critical that there is appropriate training outside the operating room. As the task is repeated over an extended period of time, long-term structural modifications occur in the brain. Furthermore, simulation allows for regular interval training to accelerate acquisition of correctly performed motor skills, thereby increasing the learner’s ability to retain those skills and building learner confidence in a low-stress environment.

There is ample evidence in surgical subspecialties to support surgical simulation for the learning and acquisition of new skills as well as improving operative performance. In regard to simulation for orthopaedic surgery, there are a small number of virtual reality simulators that can serve as an alternative to standard cadaver laboratories and synthetic bone exercises. However, most residency educational programs do not have substantial disposable income and must carefully scrutinize each training tool to determine if it will be maximally beneficial to resident education.

The FORS simulator was developed to help increase the practice of relevant orthopaedic tasks by junior residents in a cost-effective manner and thereby allow universal access to all residents. The overall importance of the FORS simulator is that it allows for multiple repetitions of important orthopaedic skills in a short period of time with objective feedback. As many junior residents may have had limited access to an operative drill while on an orthopaedic surgery rotation, they will be able to perform multiple repetitions of pertinent motor skills with a minimal time investment with the use of this simulator. Once developed at a site, this simulator is available for use at any hour of the day and thereby allows residents to train at their own pace in a low-stress environment.

The strength of the FORS simulator is the ability to train novice participants to improve above the performance level of junior residents (postgraduate years 1 and 2) on the simulator. Although medical students had initially scored significantly lower than our more senior cohorts, data on our trained medical students demonstrated overall improvement as well as significant improvement above junior resident scores in four of six exercises with only four weeks of training in short regular intervals. The two tasks with results that did not reach significance were 3-D drill control and suturing. Although the improvement in the scores on the 3-D drilling task did not achieve significance, there was a trend in the overall correct alignment and significant results would likely be achieved if the training period extended beyond the four-week block used in this study. Suturing, a task commonly performed by junior residents, was the one of these two skills that the medical students were unable to improve on. This was expected as junior residents routinely suture in the operating room.

Face validity, the ability for the simulator to contain realism, was tested with the use of materials purchased from local hardware stores. Many of the tasks involve drilling through a material that is not hollow and does not have the same density or thickness as bone. This distracts from a realistic operating-room experience. Although cylindrical objects were used initially on most of the tasks, no significant difference in accuracy was able to be ascertained. The blocks of wood help to increase distance as well as increase participant error, allowing for stratification within our testing population. The principles of triangulation and drilling, which include spatial awareness and coaxial movements with the drill-bit, are maintained with these exercises. With the use of these materials, the simulator cost is below $350, and all parts for each task are able to be resupplied at local hardware stores, allowing for unlimited repetitions.

Lastly, although we had a total of 134 participants, the medical student group was the largest, at forty-seven. In order to draw more significant conclusions, larger participant numbers need to be obtained. In regard to our attending physician group, nearly all of the attending physicians at each institution participated (those who were not available were not tested); however, there were no community physicians within the testing group.

In conclusion, the FORS, which includes six psychomotor tasks that cross over a multitude of orthopaedic surgeries, objectively demonstrated that attending physicians and senior residents performed on average at a higher level than junior residents and novice medical students. Longitudinal training of medical students demonstrated that this could be an important training tool for resident education. Ultimately, it is our hope that junior-level orthopaedic surgery residents learn motor skills intrinsic to orthopaedic surgery on low-cost simulators prior to performing operations on patients.

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