Use of a surgical rehearsal platform and improvement in aneurysm clipping measures: results of a prospective, randomized trial

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OBJECTIVE The field of neurosurgery is constantly undergoing improvements and advances, both in technique and technology. Cerebrovascular neurosurgery is no exception, with endovascular treatments changing the treatment paradigm. Clipping of aneurysms is still necessary, however, and advances are still being made to improve patient outcomes within the microsurgical treatment of aneurysms. Surgical rehearsal platforms are surgical simulators that offer the opportunity to rehearse a procedure prior to entering the operative suite. This study is designed to determine whether use of a surgical rehearsal platform in aneurysm surgery is helpful in decreasing aneurysm dissection time and clip manipulation of the aneurysm.

METHODS The authors conducted a blinded, prospective, randomized study comparing key effort and time variables in aneurysm clip ligation surgery with and without preoperative use of the SuRgical Planner (SRP) surgical rehearsal platform. Initially, 40 patients were randomly assigned to either of two groups: one in which surgery was performed after use of the SRP (SRP group) and one in which surgery was performed without use of the SRP (control group). All operations were videotaped. After exclusion of 6 patients from the SRP group and 9 from the control group, a total of 25 surgical cases were analyzed by a reviewer blinded to group assignment. The videos were analyzed for total microsurgical time, number of clips used, and number of clip placement attempts. Means and standard deviations (SDs) were calculated and compared between groups.

RESULTS The mean (± SD) amount of operative time per clip used was 920 ± 770 seconds in the SRP group and 1294 ± 678 seconds in the control group (p = 0.05). In addition, the mean values for the number of clip attempts, total operative time, ratio of clip attempts to clips used, and time per clip attempt were all lower in the SRP group, although the between-group differences were not statistically significant.

CONCLUSIONS Preoperative rehearsal with SRP increased efficiency and safety in aneurysm microsurgery as demonstrated by the statistically significant improvement in time per clip used. Although the rest of the outcomes did not demonstrate statistically significant between-group differences, the fact that the SRP group showed improvement in mean values for all measures studied suggests that preoperative rehearsal may increase the efficiency and safety of aneurysm microsurgery. Future studies aimed at improving patient outcome and safety during surgical clipping of aneurysms will be needed to keep pace with the quickly advancing endovascular field.

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KEY WORDS aneurysm; surgical rehearsal platform; education; quality improvement; vascular disorders

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The field of neurosurgery has undergone numerous advancements and changes that are constantly modifying the landscape. In particular, the paradigm for aneurysm treatment has experienced a shift toward endovascular approaches. Having the capability and training to clip aneurysms remains essential, however, as certain aneurysms are currently not favorable for endovascular treatment. With the increased risk associated with surgical approaches to intracranial aneurysms, it is important to advance training that decreases complications and im-
proves morbidity and mortality. The shift toward endovascular treatment over 2 decades is supported by multiple studies demonstrating decreased referrals of less technically complex aneurysms and increased referrals of aneurysms not amenable to coil embolization approaches to tertiary care centers, presumably due to advancements in endovascular approaches. This trend, combined with work-hour restrictions, has limited trainees’ exposure to surgical approaches. Beyond this, however, is the desire to rehearse patient-specific techniques, which even experienced, well-trained surgeons will find valuable. As such, the need to introduce new techniques for adequate and efficient training and to promote retention of skill and improved patient satisfaction in microsurgical procedures is more prominent than ever.

Surgical simulation is one such method that provides surgeons the opportunity to operate in a safe environment and gain the necessary proficiency to be able to perform procedures effectively and safely in actual patients. In addition, focused and concentrated simulations allow the training to be targeted and efficient. These surgical applications are of particular interest to neurosurgeons because the vulnerability and delicacy of nervous tissue significantly reduces the margin for error. In a meta-analysis of virtual reality (VR) simulation in neurosurgery, it was found that there has been a significant increase in publications concerned with VR simulations over the last 22 years, suggesting that the need for advancement in training is clearly being recognized throughout the field.

Until now, most simulation in neurosurgery has largely been limited to specific task-oriented functions and has sacrificed realism for real-time interactivity or vice versa. Because of the challenge of accurately simulating the tactile feedback that surgeons experience and the forces associated with an actual case, the limited haptic feedback has subsequently lent support for these technologies in minimally invasive neurosurgery (i.e., endoscopic procedures). In addition, these technologies have been used in spinal surgery and dural repair procedures as well. Although endoscopic, laparoscopic, and endovascular platforms have been constantly refined and updated, simulation training in neurosurgical microvascular cases is a relatively new concept. Several platforms, including NeuroTouch (CAE Healthcare and National Research Council of Canada) and ImmersiveTouch, have been used in attempts to simulate specific patient cases based on radiological data, but few have been targeted for microsurgical cerebrovascular or tumor surgery. In a 2013 study by Clarke and colleagues, a VR simulator based on NeuroTouch was used in the successful resection of a left frontal meningioma. In another study by Alaraj and colleagues, published in 2015, a VR aneurysm clipping simulator was developed using the ImmersiveTouch technology, and the results showed that most neurosurgical residents found the novel VR simulator to be helpful in their training.

The SuRgical Planner (SRP), a novel surgical rehearsal platform developed by Surgical Theater LLC, is a surgical simulator that addresses some of the concerns discussed above and offers the opportunity to rehearse a surgery prior to entering the operative suite. This study is designed to determine whether use of the SRP in aneurysm surgery is helpful in decreasing aneurysm dissection time and clip manipulation of the aneurysm (see Chowdhry et al: Surgical rehearsal to improve efficiency in clipping of cerebral aneurysms, presented at the Military Health System Research Symposium, Fort Lauderdale, Florida, 2012). By incorporating images that depict specific key anatomical findings in actual patients, this simulation provides realistic rehearsal for any given case for residents as well as experienced surgeons. In addition, the extensive haptic feedback from instruments that is necessary to provide a realistic experience is an important aspect of this platform. Although in its infancy, the SRP has shown promise in the reduction of surgical time and number of clip applications associated with microvascular intracranial surgery.

**Methods**

**Study Design**

This study is a blinded, prospective, randomized study comparing key effort and time variables in prospective SRP cases to the same variables in control cases. It is designed to evaluate the efficiency and efficacy of this simulation platform by comparing it with cases done without preoperative rehearsal. The study was approved by the University Hospitals Institutional Review Board. Randomization occurred in groups of 4 to help balance the entry time into the study across treatment groups. Initially, the study population was to consist of 40 patients. Due to differences in complexity of some of the cases and the differences in surgical approaches between the 2 attending surgeons who participated in this study, as well as patient opt-out, a total of 15 patients were excluded (Fig. 1). Of the remaining group, 8 patients were undergoing treatment for ruptured aneurysms, while the remaining 18 patients were undergoing elective procedures. The initial power analyses were conducted based on assessment of clipping attempts from a sample of neurosurgical video recordings of historical controls. Based on the following mean calculations—reduction of clipping attempts to 2 with a standard deviation (SD) of 3.0 compared with the pre-study sample mean of 5.4 (SD 5.384)—the projected power for a 2-sided Type I error of 0.05 with a sample of 20 SRP and 20 control cases was 0.714. With the reduction in sample sizes, the power was reduced to 0.48.

Descriptive statistics were calculated for both the SRP and the control groups. Two attending neurosurgeons performed all surgeries with the assistance of a chief-level resident. Both attending neurosurgeons are experienced cerebrovascular neurosurgeons, and there was no significant discrepancy in their amounts of surgical experience. Prior to surgery, the attending neurosurgeon and resident rehearsed preoperatively with the SRP for cases in which patients were assigned to the active treatment group. All microsurgical steps in study patients were performed either by the attending neurosurgeon or by the resident under direct supervision. To maximize the degree of learning expected for surgical rehearsal, the chief resident performed at least 50% of the microsurgical steps in all study cases, as determined by the total microsurgical operating time. Following aneurysm clipping, analysis utilizing indocyanine green videoangiography was used to...
confirm aneurysm occlusion and normal vessel patency. A neurosurgeon who was blinded to group assignments and was not directly involved in the surgical cases performed the video analysis. This analysis was conducted for both the simulation and non-simulation groups and included measurements of total microsurgical time, number of clip attempts, and total number of clips used. Video analysis took place in 2 batches. The phenomenon of “batch effect” was controlled for and assessed when comparing treatment groups. It is important to note that this study was not designed to evaluate additional patient outcome measures such as adverse outcomes or complication rates attributable to lack of rehearsal. The goal of this study was to determine whether intraoperative performance is improved with this rehearsal platform. Keeping this in mind, we tested the hypothesis that the intraoperative parameters mentioned above would all show significant reductions with the use of SRP.

**Simulation Set-Up**

Surgical Theater’s FDA-approved surgical rehearsal platform (SuRgical Planner [SRP]) provides a patient-specific virtual surgery theater that allows neurosurgeons to plan, rehearse, and perform aneurysm clipping with interactive tools in a 3D environment. FDA approval was granted on February 13, 2013 (510 K No. K123023), with indication for use as a software interface and image segmentation system and as preoperative software for simulation and evaluation of surgical treatment options.

There are multiple components of the SRP that allow it to function as a useful surgical platform. The entire system consists of the SRP software, 2 liquid-crystal diode monitors, 3D controllers, and 3D glasses to allow for 3D visual representation of the pertinent surgical anatomy, allowing for a realistic simulation of the surgical environment. The SRP system also contains unique SensAble Technologies PHANTOM Omni haptic controllers to allow for realistic interaction and manipulation of the 3D model. The system further has the ability to display or hide various tissues based on Hounsfield units, thereby allowing for visualization of relevant surgical anatomy, including bone, blood vessel, brain, and soft tissues. Patient-specific data may be uploaded to the SRP, where the imaging modalities are integrated into the dynamic model, which may be manipulated to display pertinent patient anatomy. The 3D glasses allow the surgeon and surgical team to view the anatomy in 3D, allowing for a more realistic visualization and rehearsal. The haptic controller allows the surgeon to...
to alternate between multiple surgical instruments to rehearse surgical techniques based on the patient’s uploaded images (Figs. 2–4).

Results

The mean values of the descriptive parameters in addition to their significance values are displayed in Table 1. As displayed, one of the variables (time per clip used) demonstrated statistical significance with a p value of 0.05. This suggests improved performance and increased efficiency with the SRP. Specifically, reduction in time per clip is an indirect measurement of improved surgical efficiency. In addition, the ratio of the number of attempts at clip placement to the number of clips used (which trended toward significance) may be indicative of an elevated level of comfort with the instrumentation (Figs. 5–7).

Discussion

The use of simulation platforms in the field of neurosurgery has expanded greatly over the past several decades. Improvements in technologies (i.e., use of patient-specific images of pathology and haptic feedback from microsurgical instruments) have allowed for advancement from traditional uses in laparoscopic and endovascular procedures to the realm of microvascular procedures.3,5 In particular, the SRP was designed with the goal of providing trainee neurosurgeons with the opportunity to plan, rehearse, and perform aneurysm clipping procedures. The application goes beyond the initial education of trainees, however; with the ability to preoperatively rehearse patient-specific microneurosurgery, experienced surgeons may plan clip reconstruction for specific cases with more accuracy and ease. With the recent rise in endovascular procedures and

FIG. 2. A: Preoperative CT angiogram depicting a pericallosal artery aneurysm. B–E: Varying views demonstrating application of clips during preoperative surgical planning with SRP. F: Intraoperative view demonstrating clip reconstruction based on preoperative planning. Figure is available in color online only.

FIG. 3. Intraoperative view (A) and SRP (B) comparison demonstrating usefulness of the surgical rehearsal platform. Figure is available in color online only.
a downward trend in the practice of aneurysm clipping, there is legitimate concern that current and future neurosurgical residents may not be adequately trained in this area; hence, advanced and efficient training in neurosurgical residencies is essential, with the goal of improving operative performance and clinical outcomes. The SRP was designed to address this issue.

This study is the first of its kind to prospectively and blindly review operative videos of patients randomized to either a rehearsal group (SRP group) or a control group. Although the power in this study was limited due to the diminished sample size, the overall trend reflects the increased efficiency in the SRP group. Mean values demonstrate reduced time per clip placement attempt, time per clips used, and ratio of clip placement attempts to clips used. The lack of significance should be interpreted with caution, once again, due to the lack of statistical power. In addition, the presence of more complex cases (and the differences in surgical approaches that may have resulted due to this), varying operative techniques between the surgeons, and the presence of outliers could have certainly distorted the results as well. Several variables, including the ratio of the number of clip placement attempts to the number of clips used, demonstrated a trend toward significance. A limiting factor in this study is the potential that varying complexity of cases was seen in the different treatment groups, potentially impacting the final results adversely given the small sample size. Posterior circulation aneurysms were omitted in order to minimize this possibility. Nevertheless, outliers were noted in some of the remaining cases and seemed to be more prevalent in the rehearsal group. These could once again be attributed to differing levels of complexity resulting in an adverse effect on the results. In specific cases, these outliers were noted in the number of clips used and total microsurgical time—neither of which showed a statistically significant difference between the 2 groups.

Analysis of aneurysm occlusion rates and complication rates was also performed. Both intraoperative indocyanine green videoangiography and postoperative imaging with CTA or conventional angiography demonstrated complete obliteration of all aneurysms with normal patency of parent vessels. Complication rates were also evaluated by comparing the control and experimental arms. One patient in the SRP group developed altered mental

TABLE 1. Comparison of mean values for variables assessed

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Group</th>
<th>SRP Group</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of clip attempts</td>
<td>6.09 ± 3.7</td>
<td>5.07 ± 2.78</td>
<td>0.57</td>
</tr>
<tr>
<td>No. of clips used</td>
<td>1.36 ± 0.67</td>
<td>1.79 ± 0.97</td>
<td>0.32</td>
</tr>
<tr>
<td>Total time (secs)</td>
<td>1521 ± 598</td>
<td>1320 ± 884</td>
<td>0.15</td>
</tr>
<tr>
<td>Ratio of no. of clip attempts to no. of clips used</td>
<td>4.97 ± 3.7</td>
<td>3.13 ± 2.19</td>
<td>0.18</td>
</tr>
<tr>
<td>Time per clip used (secs)</td>
<td>1294 ± 678</td>
<td>920 ± 770</td>
<td>0.05</td>
</tr>
<tr>
<td>Time per clip attempt (secs)</td>
<td>376 ± 300</td>
<td>321 ± 223</td>
<td>0.89</td>
</tr>
</tbody>
</table>

FIG. 5. Total surgical time for the SRP group (14 cases) and the control group (11 cases). Figure is available in color online only.
status and encephalopathy of unknown etiology with no evidence of seizure, infarct, or metabolic derangement. Three patients in the control group developed infarcts following surgery. One of these 3 patients developed severe vasospasm not responsive to treatment and resultant infarction of the caudate head. The second and third patients developed infarcts unrelated to vasospasm or clip stenosis. All patients who developed complications were patients with ruptured aneurysms. The remaining patients had no significant complications and were discharged with good neurological and functional status, with modified Rankin Scale scores of 0–1.

Because this study only analyzes intraoperative performance, long-term follow-up is needed to demonstrate improvement in clinical outcomes related to shorter operative times, shorter temporary clip occlusion, and less intraoperative error. With the goal of improving patient outcomes and safety during surgical clipping of aneurysms, future studies should involve multiple centers to achieve greater sample sizes and a more accurate view of outcomes and performance nationally. Larger-scale trials will be needed not only to validate the use of rehearsal platforms but also to keep pace with the quickly advancing endovascular field. The hope is that SRP and other similar platforms can provide a means of enhancing the microvascular training experience for young neurosurgeons at a time when the need is great. Eventually, this software will be adapted for the rehearsal of transnasal pituitary tumor resection, microvascular decompression, and resection of skull base meningiomas and acoustic neuromas—all modules that have already been developed for use within the SRP.

Conclusions

Preoperative rehearsal with a surgical rehearsal platform increased efficiency and safety in aneurysm microsurgery as demonstrated by strong trends toward decreased operative times, fewer clip application attempts, and decreased time per clip. Future studies aimed at improving patient outcome and safety during surgical clipping of aneurysms will be needed to keep pace with the quickly advancing endovascular field.

References


![FIG. 6.](image1.png) FIG. 6. Number of clip placement attempts per clip used. Figure is available in color online only.

![FIG. 7.](image2.png) FIG. 7. Surgical time per clip used. The experimental group was significantly faster compared with the control arm of the study (p = 0.05). Figure is available in color online only.

**Disclosures**

Surgical Theater, which owns the SuRgical Planning (SRP) platform, donated research support for the study. Dr. Selman reports an ownership relationship with Surgical Theater. Dr. Singer reports a consultant relationship with Surgical Theater.

**Author Contributions**

Conception and design: Bambakidis, Selman. Acquisition of data: Bambakidis, Chugh, Pace, Singer, Tatsuoka, Hoffer, Selman. Analysis and interpretation of data: Bambakidis, Chugh, Pace, Singer, Tatsuoka, Hoffer. Drafting the article: Chugh, Pace. Critically revising the article: Bambakidis, Chugh, Pace, Singer, Tatsuoka, Selman. Reviewed submitted version of manuscript: Bambakidis, Pace. Approved the final version of the manuscript on behalf of all authors: Bambakidis. Administrative/technical/material support: Chugh, Pace.

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