Assessing residents' operative skills for external ventricular drain placement and shunt surgery in pediatric neurosurgery

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OBJECTIVE The authors previously demonstrated the use of a validated Objective Structured Assessment of Technical Skills (OSATS) tool for evaluating residents' operative skills in pediatric neurosurgery. However, no benchmarks have been established for specific pediatric procedures despite an increased need for meaningful assessments that can either allow for early intervention for underperforming trainees or allow for proficient residents to progress to conducting operations independently with more passive supervision. This validated methodology and tool for assessment of operative skills for common pediatric neurosurgical procedures—external ventricular drain (EVD) placement and shunt surgery—was applied to establish its procedure-based feasibility and reliability, and to document the effect of repetition on achieving surgical skill proficiency in pediatric EVD placement and shunt surgery.

METHODS A procedure-based technical skills assessment for EVD placements and shunt surgeries in pediatric neurosurgery was established through the use of task analysis. The authors enrolled all residents from 3 training programs (Baylor College of Medicine, Houston Methodist Hospital, and University of Texas—Medical Branch) who rotated through pediatric neurosurgery at Texas Children's Hospital over a 26-month period. For each EVD placement or shunt procedure performed with a resident, the faculty and resident (for self-assessment) completed an evaluation form (OSATS) based on a 5-point Likert scale with 7 categories. Data forms were then grouped according to faculty versus resident (self) assessment, length of pediatric neurosurgery rotation, postgraduate year level, and date of evaluation ("beginning of rotation," within 1 month of start date; "end of rotation," within 1 month of completion date; or "middle of rotation"). Descriptive statistical analyses were performed with the commercially available SPSS statistical software package. A *p* value < 0.05 was considered statistically significant.

RESULTS Five attending evaluators (including 2 fellows who acted as attending surgeons) completed 260 evaluations. Twenty house staff completed 269 evaluations for self-assessment. Evaluations were completed in 562 EVD and shunt procedures before the surgeons left the operating room. There were statistically significant differences (*p* < 0.05) between overall attending (mean 4.3) and junior resident (self; mean 3.6) assessments, and between overall attending (mean 4.8) and senior resident (self; mean 4.6) assessment scores on general performance and technical skills. The learning curves produced for the residents demonstrate a stereotypical U- or V-shaped curve for acquiring skills, with a significant improvement in overall scores at the end of the rotation compared with the beginning. The improvement for junior residents (Δ score = 0.5; *p* = 0.002) was larger than for senior residents (Δ score = 0.2; *p* = 0.018).

CONCLUSIONS The OSATS is an effective assessment tool as part of a comprehensive evaluation of neurosurgery residents' performance for specific pediatric procedures. The authors observed a U-shaped learning curve, contradicting the idea that developing one's surgical technique and learning a procedure represents a monotonic, cumulative process of repetitions and improvement.

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KEY WORDS resident education; neurosurgery; operative skills; shunt surgery; education assessment; hydrocephalus

ABBREVIATIONS EVD = external ventricular drain; OR = operating room; OSATS = Objective Structured Assessment of Technical Skills; PGY = postgraduate year.

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DEVELOPMENT of residents' operative skills is a key component of neurosurgical training. Currently, little is understood about residents' performance in the operating room (OR), how this develops over the course of training, and how to quantify operative skills.^{1,10,24,28} We previously published a first foray into this dilemma of how to evaluate residents' operative skills in pediatric neurosurgery¹¹ by using the Objective Structured Assessment of Technical Skills (OSATS) instrument.⁹ This tool was selected because it is well known, widely used, and has been studied in the laboratory and validated for use in the clinical setting.^{19,20,35,38}

Our aims in this study were to implement a tool that comprehensively assesses neurosurgical residents' technical performance in the OR for external ventricular drain (EVD) placement and shunt surgery—common pediatric neurosurgical procedures—and to determine the feasibility and reliability of such a tool as it relates to self-assessment, postgraduate year (PGY) level, and motor learning, skill acquisition, and repetition through a pediatric neurosurgical resident's rotation.

Methods

Cases and Research Subjects

We included all pediatric shunt procedures for CSF diversion performed during a 26-month period from January 1, 2014, to February 28, 2016 (Table 1). At Texas Children's Hospital, these procedures are posted under 1 of 5 attending neurosurgeons with board certification in pediatric neurosurgery, or a fellow who holds a faculty appointment as a clinical instructor and has independent OR privileges. Most cases are performed with a junior (PGY 1–3) or senior (PGY 4–6) neurosurgical resident during his or her 3- to 6-month rotation. Residents who rotated for less than 3 months on the pediatric neurosurgery service were excluded. Faculty and residents completed the evaluation immediately after the operation. Evaluations completed after leaving the OR were not considered valid for the purposes of this study, and consequently were excluded.

Our hospital's institutional review board granted us an educational exemption for this project. All neurosurgical residents were notified of the study and allowed to decline participation.

Assessment Tool

Our evaluation form is based on the OSATS global

TABLE 1. Number of EVD placements and shunt procedures in our study

Procedure	No. of Procedures	No. of Assessments
EVD placement	127	44
New VP shunt placement	146	150
New VA shunt placement	12	25
New subgaleal shunts	3	7
Shunt revision	274	303
Overall	562	529

VA = ventriculoatrial; VP = ventriculoperitoneal.

rating scale (Fig. 1). The validated Global Rating Scale of Operative Performance includes a 5-point Likert scale with 7 categories analyzed: respect for tissue, time and motion, instrument handling, knowledge of instruments, flow of operation, use of assistants, and knowledge of specific procedure. Faculty evaluators agreed on operative performance interpretation and evaluation in the context of this form.

We averaged assessments in the 1st month of the rotation and labeled them as “first.” Likewise, we averaged assessments in the final month of the rotation and labeled them as “last.”

Statistical Analysis

All assessments that were included in the study were pooled and analyzed. There were some surgeries that only had a resident's or attending's assessment, but not both. We evaluated procedure-based construct validity by measuring the difference in scores between junior and senior residents' performance overall for EVD placements and shunt surgeries, and after faculty assessment and self-assessment. We followed their scores over the course of their 3- to 6-month pediatric neurosurgery rotation to evaluate the effect of repetition and motor learning in the acquisition of surgical skills proficiency. All statistical analyses were performed using the SPSS program, version 20.0 (IBM, Inc.).

Results

Feasibility of the Assessment

Over the course of 26 months, 529 distributed assessments were returned for a 55.75% return rate. Each of the 5 faculty-level surgeons completed between 18 and 64 evaluations; 172 evaluations were completed for the junior residents, and 97 evaluations were completed for the senior residents. Each of the 20 neurosurgery residents who rotated through pediatric neurosurgery completed between 0 and 22 evaluations after EVD placement and shunt surgery.

Construct Validity

Overall, for EVD placements and shunt surgeries, there was a statistically significant difference between junior and senior residents' scores at the beginning of the rotation for both attending evaluations ($p = 0.001$) and self-assessments ($p = 0.002$) (Table 2). All domains were statistically significant between junior and senior residents when evaluated by the attending. For the self-assessment evaluation there were no significant differences in the following domains: flow of operation ($p = 0.052$), and use of assistants ($p = 0.108$).

Interrater reliability between the attending surgeon and the resident for each procedure was low, especially for junior residents (Tau-b Kendall coefficient 0.244, $p = 0.433$). The scores for each domain from the attending physicians' evaluations differed from junior residents' self-assessments, and this difference maintained statistical significance throughout the rotation. For senior residents, the differences in scores for each domain between the attending evaluation and the self-assessment did not reach significance, except for the domain “flow of operation” at

Housestaff name: _____ PGY Level _____
 Date: _____
 Procedure: _____
 Attending: _____
 Who is completing this form (circle)? Housestaff _____ Attending _____

Global Rating Scale of Operative Performance				
Respect for tissue				
1	2	3	4	5
Frequently used unnecessary force on tissue or caused damage by inappropriate use of instruments		Careful handling of tissue but occasionally caused inadvertent damage		Consistently handled tissue appropriately with minimal damage
Time and motion				
1	2	3	4	5
Many unnecessary moves		Efficient time/motion but some unnecessary moves		Clear economy of movement and maximum efficiency
Instrument Handling				
1	2	3	4	5
Repeatedly makes tentative or awkward moves with instruments by inappropriate use of instruments		Competent use of instruments but occasionally appeared stiff or awkward		Fluid moves with instruments and no awkwardness
Knowledge of instruments				
1	2	3	4	5
Frequently asked for wrong instrument or used inappropriate instrument		Knew names of most instrument and used appropriate instrument		Obviously familiar with instruments and their names
Flow of operation				
1	2	3	4	5
Frequently stopped operating and seemed unsure of next move		Demonstrated some forward planning with reasonable progression of procedure		Obviously planned course of operation with effortless flow from one move to the next
Use of assistants				
1	2	3	4	5
Consistently placed assistants poorly or failed to use assistants		Appropriate use of assistants most of the time		Strategically used assistants to the best advantage at all times
Knowledge of specific procedures				
1	2	3	4	5
Deficient knowledge. Needed specific instruction at most steps		Knew all important steps of operation		Demonstrated familiarity with all aspects of operation

FIG. 1. Our evaluation form or data collection sheet for evaluation of a resident's operative skills.

the beginning of the rotation. Residents, particularly the junior residents, consistently rated themselves lower than did the attending evaluators.

Pattern of Acquiring Surgical Skills Proficiency

Over the course of the rotation, a stereotypical U- or V-shaped learning curve was found in the residents' scores, with a dip in the 3rd month of the rotation (Fig. 2). There is a steep portion of the learning curve between the beginning and 2nd month of the resident rotation. There is then an apparent decline in the learning curve between the 2nd and 3rd months of the rotation. Finally, the learning curve seems to recover between the 3rd and 4th months of the rotation. Junior residents had a larger improvement in

overall scores between the start (4.0) and end (4.5) of the rotation that reached statistical significance ($p = 0.002$), compared with the senior residents' overall scores at the start (4.7) and end (4.9) of the rotation ($p = 0.018$) (Table 2).

Duration of Rotation

Junior and senior residents who spent a greater portion of time on the pediatric neurosurgery service (≥ 4 months) had higher overall scores compared with those junior residents who rotated for < 4 months ($p < 0.001$).

Discussion

Even for a straightforward, oft-performed procedure

TABLE 2. The mean scores of junior and senior residents overall and for each domain of the OSATS for shunt surgeries in pediatric neurosurgery

Domain	Attending Surgeon's Evaluation								Self-Assessment				Self-Assessment vs Attending Surgeon's Evaluation (p value)			
	PGY-3			PGY-5			PGY-3 vs PGY-5 (p value)		PGY-3		PGY-5		PGY-3		PGY-5	
	First	Last	p Value	First	Last	p Value	First	Last	First	Last	First	Last	First	Last	First	Last
Respect for tissue	4.4	4.5	0.722	4.9	4.9	0.208	0.002	0.316	3.4	3.8	4.6	4.9	0.001	0.001	0.184	0.414
Time and motion	3.9	4.5	0.243	4.6	4.8	0.727	0.011	0.446	3.3	3.8	4.2	4.8	0.005	<0.001	0.065	0.867
Instrument handling	3.6	4.5	0.067	4.4	4.9	0.110	0.036	0.182	3.3	3.8	4.3	4.9	0.004	0.025	0.161	0.414
Knowledge of instruments	4.2	4.5	0.434	4.9	5.0	0.208	0.001	0.193	3.6	4.0	4.5	4.9	0.001	0.022	0.073	0.495
Flow of operation	3.8	4.5	0.155	4.9	5.0	0.266	<0.001	0.170	3.4	3.8	4.3	4.8	0.052	0.001	0.040	0.299
Use of assistants	3.9	4.4	0.147	4.6	4.9	0.140	0.001	0.073	3.5	3.8	4.2	4.8	0.108	0.004	0.086	0.414
Knowledge of specific procedure	3.9	4.5	0.206	4.8	5.0	0.160	0.001	0.201	3.4	3.9	4.4	4.8	0.016	0.006	0.035	0.299
Overall	4.0	4.5	0.002	4.7	4.9	0.018	<0.001	<0.001	3.4	3.8	4.4	4.8	0.001	<0.001	<0.001	0.045

First = 1st month of rotation; Last = last month of rotation.

Boldface type indicates statistical significance.

such as placement of a ventriculoperitoneal shunt, there are infinite iterations and combinations of operative steps, depending on the neurosurgeon. Furthermore, the surgery is delicate, with postoperative outcomes highly dependent on exquisite and careful surgical technique.^{15,22,37} How do you objectively judge intangible metrics such as “time and motion” and “flow of operation”? Currently, there is no gold standard with which to compare the trainee. The assessment and evaluation of operative skill is, to a large degree, subjective. More importantly, we currently have no feedback on how effective we have been as educators in the OR. There is significant interest in the objective assessment of these skills.⁸

We have previously attempted to quantify residents' operative skills in pediatric neurosurgery by using a validated instrument—the OSATS.¹¹ Despite the comprehensive nature of this tool, we were able to show that it was feasible and easily incorporated into the OR workflow. Until now, however, there has been no procedure-based validation for OSATS in pediatric neurosurgery.

Procedure-based construct validity for EVD placements and shunt surgeries in pediatric neurosurgery was demonstrated by the statistically significant differences between the junior and senior residents overall, and for select domains of the tool. In addition, there was an improvement over the course of the rotation, adding to the validity of the construct. Residents are expected to improve their performance through motor learning of surgical procedures over a subspecialty-focused rotation.¹⁰ Motor learning refers to improvement of motor skills through practice, and is composed of motor adaptation and skill acquisition elements.¹⁶

U-Shaped Learning

Interestingly, the learning curves produced for the residents (Fig. 1) demonstrate a stereotypical U- or V-shaped curve for acquiring skills. The U-shaped curves seem to contradict the idea that improved performance and learn-

ing have a direct relationship to time and the accumulation of experience and knowledge. The regression shown by U-shaped curves has become a challenge for cognitive development theories to explain.^{5,21}

Thus, on the one hand, a U-shaped course of development is initially characterized by correct performances based on a lack of knowledge, followed by incorrect performances as a result of incomplete knowledge. These phases are then replaced by correct performances based on advanced knowledge and experience.^{29,30}

However, U-shaped learning could also be explained by the adoption of novel processing strategies. This adoption may initially result in cognitive overload and in a temporary loss of cognitive processing efficiency. Once novel processing strategies have been completely adopted, they may lead to more efficient cognitive processing.^{3,36} This theory seems to explain the pattern of quantified operative skills scores in our study. The process of adoption and inculcation of new surgical procedures and techniques by residents takes time, an evolution from rote memorization to understanding surgical concepts. Once the concept is understood and ingrained, however, the result is a more efficient performance of the procedure. We expect to find the same U-shaped pattern of learning for other surgical procedures.

Interestingly, U-shaped learning has been observed by cognitive and developmental psychologists during the development of select physical, artistic, and cognitive skills.^{5,21} These patterns have been found for perception-related abilities,^{18,27,36} motor coordination,⁴ eye-hand coordination,^{12,33,34} verbal skills,^{14,32} and even the development of creativity.⁶ Most of them are skills necessary for the development and learning of a surgical procedure.

During training for complex procedures, the time needed to process the new strategies to attain proficiency remains controversial. Several authors have suggested that plateaus derived from learning curves can be used to determine appropriate training durations.^{16,26} Our study

FIG. 2. Graphs showing score average rated by the attending evaluators and the residents' self-assessment during the months of rotation. Each category of the OSATS rating scale and the overall score are represented. The numbers on the y axis represent the skill grade. Eval = evaluator; NS = attending neurosurgeon. Figure is available in color online only.

seems to suggest that resident rotations in pediatric neurosurgery of ≥ 4 months provided statistically significantly more skills proficiency than rotations of lesser duration.

In addition to fulfilling the requirements of the governing bodies of neurosurgical resident education, we plan to use this tool to improve resident feedback. By providing timely and structured feedback to residents, deliberate goal-oriented practice, as described in the acquisition of expertise in other disciplines, may be used to accelerate the learning curve.^{7,10,17} Use of deliberate practice to achieve expertise involves more than routine practice; it

also requires constant feedback to continuously create well-defined performance goals set beyond learners' current abilities so that they can continue to be challenged and avoid arrested development.^{7,10} While in residency, trainees are challenged with increasing performance goals, although many times their goals are not well defined, or associated with detailed feedback.^{10,25,31} By providing more timely and structured feedback through the use of assessment tools such as the one described in this study, teaching faculty can help residents move toward mastery.

Clinical Implications

We do not know how the absolute scores for junior and senior residents translate into neurosurgical clinical outcomes, nor do we know the clinical significance of a change in assessment score on the order of 0.2–0.5 between the first and last evaluations for a given resident. To the best of our knowledge, there has only been scant literature addressing this provocative topic.

Birkmeyer et al.² found that surgeons with the highest skill ratings had fewer complications in bariatric surgery compared with surgeons with the lowest skill ratings. This suggests that efforts to improve surgeon proficiency are an important but understudied aspect of outcomes research.

Similarly, Hogg et al.¹³ showed that technical scoring of a surgeon's performance independently predicts patient outcomes in pancreatic surgery. The authors in that study modified the global rating scale to create a more procedure-specific assessment tool. Therefore, it would be difficult to compare their results directly with our data.

Limitations of the Study

This study was performed assessing a single procedure type at a single institution. However, it should be noted that the case mix that we used in our analysis was somewhat heterogeneous, requiring similar but not identical skill sets—EVD placement; first-time ventriculoperitoneal, ventriculoatrial, and subgaleal shunt insertions; and shunt revision surgery. Moreover, it is possible that this assessment tool may produce different results if it is used to evaluate residents' operative skills for other procedures or at another institution. The low response rate of 55.75% for distributed evaluations is also a major flaw of our study, with the possibility of introducing significant bias. This study was also limited by the number of residents who rotate through the pediatric neurosurgery service and faculty members on the pediatric neurosurgery staff, and the duration of the resident rotation. It is very likely that motor learning and surgical skill acquisition continues past training and into independent practice, which is not measured by our study. Moreover, the evaluators were the surgeons who operated with the resident, and they were not blinded to residents' identities, which may affect the results. Future directions for research may lead us to a blinded video-based assessment that can probably negate this type of bias.

The so-called Holy Grail of surgical education is represented by the question: does improving how we teach surgeons lead to better technical skill and improved patient outcomes? Unfortunately, answering this question requires much preliminary work to first establish a validated method of assessing operative skills for specific procedures, and then correlating with clinical metrics such as OR time, estimated blood loss, or complication rates. Our work is but a small step toward this penultimate goal. The answer to the Holy Grail is beyond the scope of our present study.

Also, applying the assessment to attending physicians themselves may serve to prove or disprove the U-shaped learning theories. Attending physicians would not be expected to have any significant learning curve for these procedures, given their much larger experience. However, one caveat for the studies that lie ahead is that the OSATS was evaluated and validated for learners rather than for experts.

Conclusions

The OSATS tool has been previously validated for evaluation of general surgery residents' operative performance.²³ We recently used this scale for evaluation of neurosurgery residents' performance during the pediatric neurosurgery rotation.¹¹ The present study serves to further research into neurosurgery resident education by validating the OSATS tool for specific and common pediatric neurosurgical procedures—EVD placement and shunt surgery. For the first time, we have quantitatively documented the stereotypical course of acquiring surgical proficiency for EVD placement and shunt surgery. Interestingly, we observed a U-shaped learning curve, contradicting the idea that developing a performance and learning a surgical procedure represent a monotonic, cumulative process of repetitions and improvement. Although further work is warranted to confirm the validity of this tool as a standardized procedure-based assessment of resident skill in neurosurgery, based on these findings it seems that this tool can provide meaningful information about residents' competence and progress, and furnish feedback to guide resident education.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Jea, Aldave, Briceño, Luerssen. Critically revising the article: Jea, Aldave, Hansen, Briceño. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Jea. Statistical analysis: Jea, Aldave, Hansen, Luerssen. Administrative/technical/material support: Luerssen. Study supervision: Jea.

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