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Surgical Procedural Map Scoring for Decision-Making in Laparoscopic Cholecystectomy

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Abstract

Introduction: The objective of this study was to determine whether decision-based procedural mapping demonstrates differences in attendings versus residents.

Methods: Attendings and residents were interviewed about operative decision-making in laparoscopic cholecystectomy (LC) using a cognitive task analysis framework. Interviews were converted into procedural maps. Operative steps, patient factors, and surgeon factors noted by attendings and residents were compared. Two scoring methods were used to compare map structures of attendings versus residents.

Results: Six attendings and six residents were interviewed. There were no significant differences in the number of patient or surgeon factors identified. Attendings had significantly more operative steps (29.67±1.9 vs. 23.3±1.9, p=0.04) and crosslinks (3.2±0.5 vs. 1±0.4, p=0.005) in their maps and a higher total score (90.2±8.4 vs. 63.2±3.8, p=0.015) than residents.

Conclusion: LC procedural map scoring for attendings and residents demonstrated significant differences in structural complexity and may provide a useful framework for assessing decision making.

Summary

The objective of this study was to determine whether decision-based procedural mapping demonstrates differences in attendings versus residents. Laparoscopic cholecystectomy procedural map scoring for attendings and residents demonstrated significant differences in structural complexity and may provide a useful framework for assessing decision making.

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Introduction

Decision-making in surgery is a complex phenomenon that provides the foundation for the more visibly apparent technical skills required to successfully perform an operation. Both novice and experienced surgeons can omit key steps or decision points of an operation from their conscious recall;[1,2] however, differences underlying those omissions are due to differences in cognitive processing at different levels of experience. Novice surgeons are more likely to have higher cognitive load and mental demand due to a need to be more highly engaged in task completion while technical skills, cognitive understanding, and stress management are put to the test in the operating room.[3,4] As experience increases, surgeons are able to begin to automate decisions based on recognition of intraoperative patterns. However, such automaticity can lead experienced surgeons to unintentionally omit upwards of 50–75% of their own knowledge when interacting with trainees.[5] Therefore, rigorous, standardized processes such as such as cognitive task analysis (CTA) are necessary to generate procedural and decision-making models of experienced surgeons.[1,3,6,7]

CTA has provided a wealth of information on key decision trees and relevant cues necessary to successfully complete procedures ranging from appendectomy to colonoscopy and have resulted in curricula to teach technical skills and decision points or checklists to ensure learners have demonstrated an understanding of the technical skills and decisions necessary to complete a task.[7,8] CTAs currently available in the literature are limited to decision structures that are largely linear. However, unexpected events (e.g. anatomic variation, equipment malfunction) or even expected events (e.g. bleeding, extensive fibrosis, bowel injury) can lead to multiple decision points that require more complex, non-linear representations of decision making. Thus, other methodologies may be necessary to represent non-linear decision-making processes.

Concept maps are graphical tools similar to flow charts that allow users to visually organize knowledge in a hierarchical (i.e. non-linear) manner. Concept maps allow for the representation of concepts (e.g. objects, events, or patterns of events represented in boxes) that can be linked in complex patterns and have been used to model expert and novice knowledge on concepts such as engineering, climate, and other scientific topics.[9–11] Research in general education has demonstrated that as knowledge and experience increase so too does the complexity of domain-specific concept maps.[12] However, little to no research has been conducted on the utility of procedural mapping (i.e. whether concept maps can be used for the visualization of procedural knowledge).

This study utilized CTA to capture surgeons' decision-making in the form of procedural maps. The primary objective of this pilot study was to compare two scoring systems for procedural maps in their ability to discriminate attending and resident surgeon conceptualizations of decision-making in laparoscopic cholecystectomy. We hypothesized that experienced attending surgeons would have significantly greater structural complexity and detail in their conceptualization of decision-making in laparoscopic cholecystectomy compared to resident surgeons.

Materials and Methods

Participants

Attending surgeons from a single academic institution, targeted to capture a mix of subspecialty experience, were recruited for participation in the study. General surgery residents from the same academic institution of varying post-graduate year were also recruited to participate. This study was exempt from review by the Partners Healthcare Institutional Review Board.

Procedural Interview

An interviewer (C.G.A.) trained in focused cognitive task analysis for surgical procedures conducted all interviews, and an experienced concept mapper (D.A.H.) was present for each interview in case clarifications were required to assist in the mapping process. The interviewer used a standard script for each interview (Appendix 1). To help guide the interview, participants were shown the CTA-derived steps of a laparoscopic cholecystectomy (LC) (Table 1) and asked to describe their conceptualization of the steps of a LC.[8,13,14] To concentrate on the key decision points for LC, emphasis in the interview was placed on elucidating steps 4–8. The interviewer asked specific questions to determine the contribution of patient and surgeon factors to key operative steps. Patient-specific factors elicited included characteristics such as co-morbidity, pre-operative laboratory values, anatomy (e.g. aberrant hepatic arteries), disease process (e.g. inflammation, trauma, malignancy) while surgeon-specific factors included surgeon knowledge, laparoscopic skill, equipment, and use of staff/assistants. Participants were probed on the relative contributions of various patient and surgeon factors to decision-making that could affect the sequence or execution of operative steps. All interviews were transcribed.

Procedural Map Conversion for Individual Attending and Resident Maps

Transcriptions of each attending and resident interview were analyzed using a standard procedural mapping protocol (Appendix 2). CmapTools v6.02 (IHMC, Pensacola, FL) was utilized to construct procedural maps as an adaptation of concept maps. Two analysts (D.A.H. and C.G.A.) independently reviewed the transcripts and procedural maps for each participant to ensure adherence to the procedural mapping protocol. Any differences noted between the analysts were resolved through discussion and mutual agreement on the final procedural map for each participant.

For individual procedure maps for both attendings and residents, each attending and resident participant was emailed a draft of their procedural map for review. Each participant was given the opportunity to make corrections to their own map or to approve the map as constructed. Attending maps were then used to generate an attending consensus procedural map.

Attending Consensus Procedural Map

The open-source program GNU Image Manipulation Program (GIMP v2.8.22) and jquery package ImageMapster[15] were used to create an interactive web browser-based image of each attending procedural map. For their own procedural map, attendings were asked to mark each operative step or patient/surgeon factor that they considered to be key. Key steps or factors were defined as those that attendings would expect a chief resident to know of at the end of their residency training.

A modified Delphi process with the recruited attendings was utilized to develop a consensus procedural map. The Delphi process is a consensus building technique that uses questionnaires to elicit consensus from a panel of participants.[16] For the first round of the consensus process, all procedural maps for attendings were analyzed, and the frequency of mentions for operative steps and patient/surgeon factors were tallied for each individual attending procedural map. Steps and factors that were mentioned by 60% or more of attendings were included in a consensus procedural map. Steps and factors mentioned by only one attending were excluded from the consensus procedural map. Steps and factors mentioned by fewer than 50% of attendings but more than one attending were included in the consensus procedural map but marked as requiring further discussion to achieve consensus. Labeling of key steps/factors was based on the same criteria.

For the second round of consensus, the first-round consensus map was sent to attending participants for review. Attending participants were specifically asked to vote on inclusion of marked items that lacked consensus. Attendings were provided the current percent inclusion count for each marked step/factor. Steps and factors that were voted for inclusion by 60% or more of attendings were included in the final consensus map. Key steps/factors in the final consensus map were labeled on the same criteria. All attendings then reviewed and approved the final consensus map.

Procedural Map Scoring

Two scoring methods were utilized. The modified Novak and Gowin Scoring Method (NGSM) generated scores on structural complexity of the map, assigning a greater point value to crosslinks and hierarchy (general to more specific steps) (Table 2).[17] A crosslink denotes an operative step that could lead to multiple different operative paths. For example, in one attending map, ‘Exposing Calot’s Triangle’ could lead to bleeding, injury to a structure, or isolation of the cystic duct. Each of these outcomes is followed by a different operative path; thus, the step ‘Exposing Calot’s Triangle’ is a crosslink between those different paths (Figure 1). The NGSM does not score the specific content in the map (e.g. which specific operative steps are included). The NGSM was applied to each individual procedural map for attendings and residents. The mean NGSM score for attendings was compared to the mean score for residents.

The Procedural Map Scoring Method (PMSM) was based on a scoring system previously developed by Rye and Rubba (2002).[18] The PMSM was designed to score content against a consensus map that served as the “gold standard.” Using the attending consensus procedural map as a gold standard, individual resident and attending maps were assigned points based on the number of correct operative steps and patient/surgeon factors identified (Table 3). Steps and factors marked as key were worth more points. The top possible score for the PMSM was based on the score of the consensus map developed by attendings. A single scorer reviewed each map using both scoring systems. Mean score of each group using each method was compared.

Statistical Analysis

Statistical analysis was performed using STATA/IC 14.2 (Statacorp, College Station, TX). Distribution of procedure map scores was checked using the Shapiro-Wilk Test. Procedure map scores between residents and attendings were compared using independent t-tests. Alpha was set at 0.05. Score comparisons are presented as mean ± SD unless otherwise noted.

Results

Six attendings and six residents completed the study. All attending surgeons were board certified. Attending specialties were as follows: two in hepatopancreaticobiliary surgery, two in minimally invasive bariatric surgery, one in acute care surgery, and one in endocrine surgery. All residents were categorical residents in an academic general surgery program. Two were in the first month of their PGY2 year, three were research residents who had completed their PGY3 year in the month preceding their participation, and one was in the last month of chief year.

For the modified Delphi process, attending consensus was achieved for all included operative steps and patient/surgeon factors after two rounds. The consensus map consisted of 29 operative steps (22 key steps), 7 patient factors (7 key patient factors), and 7 surgeon factors (5 key surgeon factors) (Figure 1). The top possible score using the PMSM was calculated to be 231 points.

The NGSM demonstrated significant differences between attendings and residents in number of operative steps, crosslinks, and total score (Table 4). Using the PMSM, the mean score for attendings (170 ± 6.4) was significantly higher than for residents (117.5 ± 6.6, p=0.0002) (Figure 2). The higher score was due to attendings identifying a significantly greater number of operative steps (22 ± 1.3 vs. 14.67 ± 0.67, p=0.0005), key operative steps (18.83 ± 0.9 vs. 14 ± 0.7, p=0.002), key patient factors (4.3 ± 0.3 vs. 3.2 ± 0.4, p=0.0493), and surgeon factors (3.83 ± 0.3 vs. 2.67 ± 0.3, p=0.028) compared to residents. There was no difference in the number of key surgeon factors identified.

Discussion

Procedural mapping for laparoscopic cholecystectomy can demonstrate differences between attending and resident surgeons in the conceptualization of the steps of a laparoscopic cholecystectomy as well as the patient and surgeon factors that can influence those steps. Objective scoring methods provided further data on the structural differences in operative conceptualization and demonstrated differences in both the number of steps and factors considered as well as the structural complexity of decision processes between attendings and residents. By generating an attending consensus map of a diversely trained group of surgical faculty, this study provided a novel method for assessing a trainee’s knowledge against that of a consensus of experienced surgeons in both a visual and quantitative manner.

Differences in procedural maps between attendings and residents were seen with many aspects of the mapping process. When comparing the mean number of steps and factors across both groups using the NGSM, attendings were significantly more likely to list a greater number of operative steps and to have more structural complexity in their maps in the form of crosslinks. This finding is consistent with prior research on resident performance assessment that has demonstrated that interns have difficulty in formulating and verbalizing intraoperative decisions while chief residents can make critical decision errors that can prevent independent completion of a case.[13] Similarly, when using the PMSM, residents also identified fewer steps and factors of a laparoscopic cholecystectomy than attendings, suggesting that residents' operative conceptualization of laparoscopic cholecystectomy may not be as complete or as rich as those of faculty with more experience.

The "intermediate effect" describes the relationship of expertise level to recall of facts and explicit knowledge as an inverse U-shape. That is, novice and expert surgeons, sitting at opposite ends of the spectrum of knowledge and experience, have lower recall than intermediatelevel surgeons who are in the consciously competent phase of Burch's hierarchy of competence.[19] Unfortunately, this study was underpowered to further investigate differences in the procedural maps across residents with different levels of experience (approximated by postgraduate year); however, planned future work will recruit a larger number of residents for participation and subsequent analysis by year of training.

This study has limitations. The sample size is small, and the data was collected at a single institution. In addition, concept maps are typically generated by an individual on their own as a reflection of their knowledge.[12] In this study, we did not ask participants to generate their own concept maps. Instead, we used structured interviews from a cognitive task analysis framework to purposefully overcome the "unconscious" aspect of knowledge that experienced surgeons have, as this knowledge can influence operative decision-making. A single scorer reviewed each map using both scoring systems, preventing an evaluation of the reliability of the scoring system. However, this study was designed not to assess reliability but to assess the construct validity of two scoring systems to assess resident versus attending differences in construction of procedural maps. Future studies with larger sample sizes will be needed to assess inter-rater reliability of the scoring systems.

Stepwise training has been used successfully in the past to promote autonomy in surgical residents.[20] In future applications of this work, procedural maps may allow for attending surgeons to gauge a trainee's level of understanding preoperatively so that educational goals and expectations of autonomy can be established.[21] Maps may also allow trainees to gauge their understanding of the different factors necessary to safely proceed through an operation against that of an experienced surgeon and allow for smart, specific feedback and teaching to target knowledge deficiencies. Some surgical trainees may have a preference for visual or kinesthetic learning styles, and procedural mapping could serve as an adjunct to traditional methods of learning operations such as reviewing book chapters or atlases.[22] Maps could be updated as trainees progress through their training, and a follow up study should assess whether longitudinal changes made to trainee maps reflect increasing complexity of their knowledge. Outside of direct educational applications, procedural maps may serve as a representation of complex decision processes for training and testing of machine learning models; and scoring of the procedural map can help establish relative weighting of different decision points during an operation on which to train algorithms.[23]

Conclusion

Procedural maps provide a novel tool for the surgical educator to consider using with trainees. This study demonstrated that there are notable differences in the conceptualization of the steps of a laparoscopic cholecystectomy, and procedural maps may help to quantify those differences. By developing and testing a scoring system to compare attendings and residents, this study provides the foundation on which procedural mapping can be assessed for use in surgical education.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Concept maps are graphical tools that allow users to visually organize knowledge
- Procedural maps are modified concept maps designed for procedural knowledge
- Scoring of procedural maps can differentiate attendings versus residents
- Attending maps have more operative steps, decision factors, structural complexity

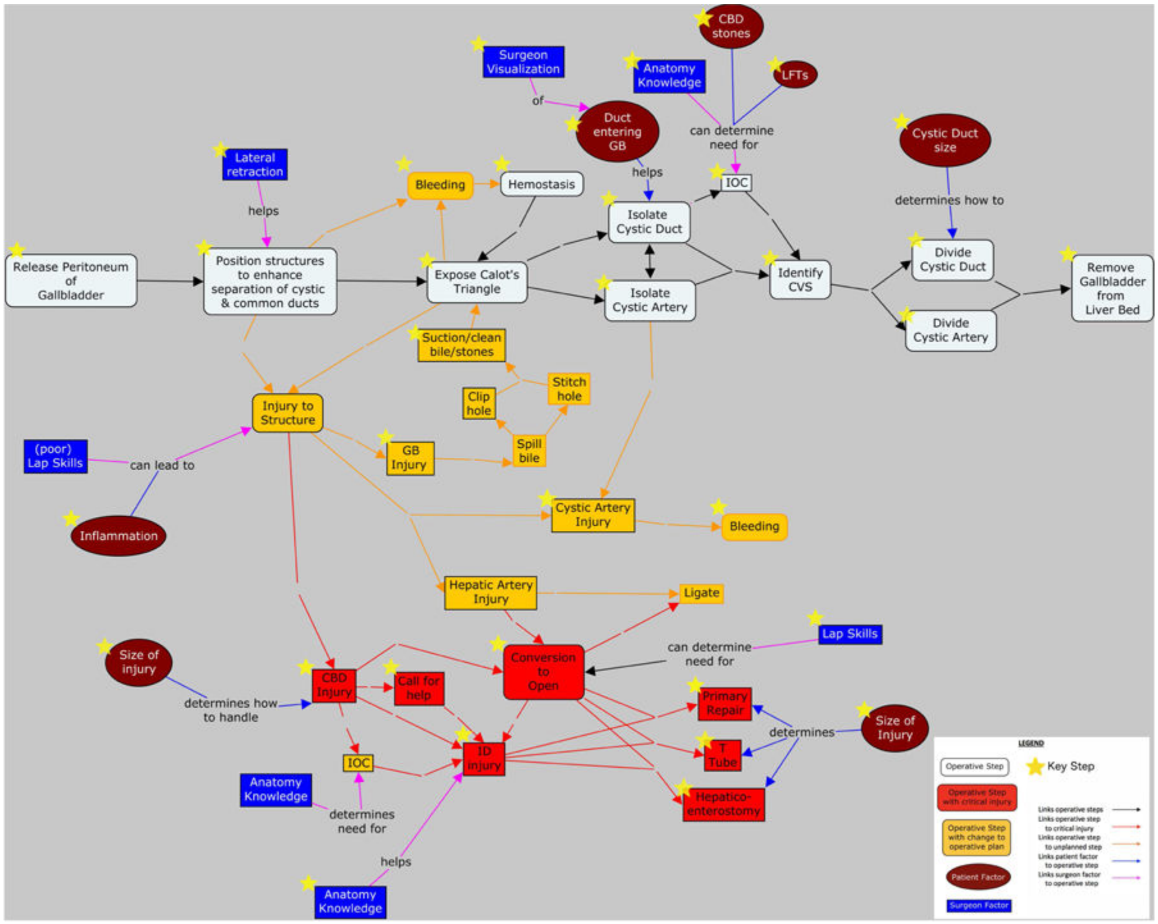

Figure 1.

Attending consensus procedural map for laparoscopic cholecystectomy. As detailed in the Figure Legend, white boxes represent operative steps in a straight forward cholecystectomy. Yellow boxes represent steps that may change the initial operative plan. Red boxes represent steps that involve or are a consequence of a critical injury, such as common bile duct injury. The maroon circles are patient factors that can affect the decision surrounding the operative step to which they are connected (by an arrow). Blue boxes represent surgeon factors that can affect the decision surrounding the operative step to which they are connected (by an arrow). Stars denote the step or factor that attendings agreed were "key" (i.e. steps or factors that those attendings would expect a chief resident to know of at the end of their residency training).

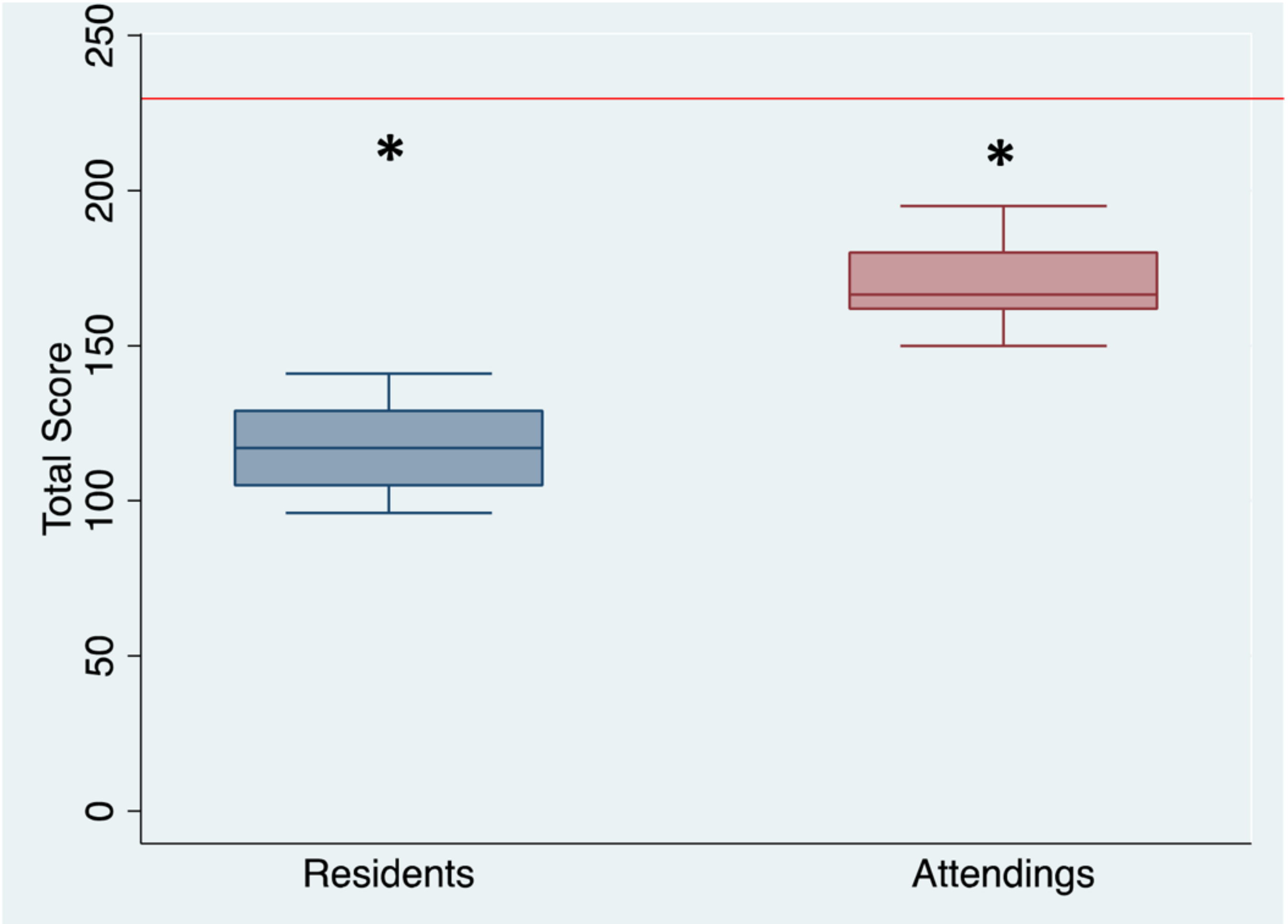

Figure 2.
Comparison of Resident and Attending scores using PMSM. Red line represents top possible score of 231. * represents p<0.05.

Table 1.

CTA-derived Laparoscopic Cholecystectomy Guide (Adapted from Stewart, Hunter et al. 2010; Parner, Peyre, et al. 2015; Pugh, DaRosa, 2013)

1. Create pneumoperitoneum
    - a. What are the special risks of inserting the Veress needle in thin or muscular patients?
        - i. How do you control Veress needle-associated injuries?
    - b. What structures should be inspected for injury immediately after initial trocar insertion?
2. Insert trocars, scope
    - a. How do you decide where to place the subxiphoid trocar?
    - b. Can dissection proceed safely laparoscopically?
    - c. What factors should determine whether a laparoscopic operation should be converted to open?
3. Position structures to enhance separation of cystic and common ducts
    - a. Are the cystic and common bile ducts identified?
4. Expose Calot's triangle
    - a. Is Calot's triangle exposed adequately?
5. Isolate cystic duct
    - a. Is the cystic duct in continuity with the infundibulum of the gallbladder?
6. Isolate cystic artery
    - a. Should an intraoperative cholangiogram be performed?
        - i. What are the criteria for using intraoperative cholangiography?
    - b. In what order should structures be divided?
    - c. With what instrument should structures be divided?
    - d. Where should structures be divided?
7. Divide cystic duct
8. Divide cystic artery
9. Remove gallbladder from liver bed
    - a. Does bleeding need to be controlled?
10. Ensure hemostasis
11. Remove gallbladder from peritoneal cavity
    - a. When should a specimen bag be used for extraction?
12. Aspirate residual irrigation fluid
13. Remove dropped gallstones
14. Close incisions
    - a. When should the fascia for trocar sites be closed?
    - b. List potential complications associated with port sites and describe how to prevent them.

Table 2.

Modified Novak and Gowin Scoring Method for procedural maps

Modified Novak & Gowin Scoring Method	
Operative Steps	0 points
Patient/Surgeon Factors	0 points
Propositions (link factors to steps)	1 point
Hierarchy	5 points
Crosslinks	10 points

Table 3.

Procedure Map Scoring Method modified from Rye and Rubba (2002)[16]

Procedure Map Scoring Method	
Key Operative Steps	6 points
Other Operative Steps	3 points
Key Patient/Surgeon Factors	6 points
Other Patient/Surgeon Factors	3 points

Table 4.

Comparison of attending and resident procedure map scoring using the Modified Novak and Gowin Scoring Method

	Attending (n=6)	Resident (n=6)	p
Operative Steps	**29.67 ± 1.9**	**23.3 ± 1.9**	**0.043**
Patient Factors	22.2 ± 2.3	19.2 ± 2.4	0.39
Surgeon Factors	8.5 ± 0.8	8.5 ± 0.7	1.0
Crosslinks	**3.2 ± 0.5**	**1 ± 0.4**	**0.005**
Hierarchy	5.83 ± 0.48	5.33 ± 0.56	0.511
Total Score	**90.2 ± 8.4**	**63.2 ± 3.8**	**0.015**