Surgery 167 (2020) 241–249

Contents lists available at ScienceDirect

Surgery

journal homepage: www.elsevier.com/locate/surg

Defining the competencies for laparoscopic transabdominal adrenalectomy: An investigation of intraoperative behaviors and decisions of experts

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ARTICLE INFO

Article history:
Accepted 16 March 2019
Available online 22 October 2019

ABSTRACT

Background: Safe performance of laparoscopic transabdominal adrenalectomy requires the application of a complex body of knowledge and skills, which are difficult to define, teach, and measure. This qualitative study aims to characterize expert behaviors, decisions, and other cognitive processes required to perform laparoscopic transabdominal adrenalectomy.
Method: Hierarchical and cognitive task analyses for right and left laparoscopic transabdominal adrenalectomy were performed using semi-structured interviews and field observations of experts. Verbal data was supplemented with published literature, coded and thematically analyzed using constructivist grounded-theory by 2 independent reviewers.
Results: A conceptual framework was synthesized. Sixty-eight tasks, 46 cognitive behaviors, and 52 potential errors were identified and categorized into 8 procedural steps and 8 fundamental principles: anticipation, exposure, teamwork or communication, physiology, dissection techniques, oncologic margins, tactical modification, and error recovery. Experts emphasized the importance of creating a 3-dimensional mental model of the anatomy or pathology (eg, aberrant vessels, tumor location) that is consistently fine-tuned throughout the operation, with conscious awareness of danger zones (eg, medial arc). Despite variations in dissection techniques, experts highlighted 2 themes: macrodissection and microdissection, with emphasis on nonlinear motions and effective transitions between the 2 when appropriate.
Conclusion: This study defines behaviors and competencies that are essential to performing laparoscopic transabdominal adrenalectomy effectively and safely.
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Introduction

Evidence during the past 3 decades has shown an association between early surgical outcomes and intraoperative judgment .[1–3] Collectively, these findings suggest that the majority of adverse events in the operating room have root causes that link back to errors relating to advanced cognitive processes, such as from misinterpretation of unexpected or distorted anatomy leading to

Presentation at the 40th annual meeting of the American Association of Endocrine Surgeons, Los Angeles, CA, April 7–9, 2019.
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https://doi.org/10.1016/j.surg.2019.03.035
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decisions that have unintended consequences. In an effort to improve performance and outcomes, much effort has attempted to define these skills so that they can be better taught and measured, both during training and in practice. However, the complex thought patterns and behaviors that characterize the mental model of expert surgeons, allowing them to perform an operation safely and effectively, tend to be highly situation-dependent and difficult to characterize (ie, thinking like an expert). Although there is a general understanding of the importance of advanced cognitive skills and mental processes that are fundamental for the successful outcome of an operation, these constructs remain largely theoretical and currently offer very little in terms of improving performance and minimizing errors.

Increasing emphasis on patient safety, outcomes, and value-driven surgical care has led to many training programs and credentialing bodies questioning the optimal methods for measuring performance in a valid and reproducible way. Despite the availability of various performance assessment tools, typically in the form of rating scales, they tend to be either task-specific with a limited focus on cognitive behaviors, or far too generic to provide meaningful information to a learner or assessor about any particular behavior. Understanding the qualities, behaviors, and mental models of experts is at the heart of this problem, and there is a need for these complex and sometimes abstract concepts to be organized into a conceptual framework in order to better understand the construct of surgical expertise. We previously identified 21 universal core surgical principles that guide the intraoperative decisions and behaviors of surgeons.[4] Nevertheless, the application of these thought patterns were highly case-specific and variable among subspecialties, operative environments, and individual personalities, and it is therefore important to expand on this framework to describe how these behaviors are optimally applied in different situations. Such a framework can potentially be used to develop effective training programs, performance metrics that provide an accurate depiction of expertise, and quality-control interventions to minimize the risk of adverse events.

The purpose of this qualitative study was to define the mental model and cognitive behaviors of experts for performance of laparoscopic transabdominal adrenalectomy (LTA).

Methods

In order to map out the thoughts and practices that characterize effective intraoperative decision-making and judgment for performing left and right LTA, qualitative methodologies were used, followed by grounded theory data analysis.[5] The study protocol was approved by the institutional review board at Columbia University Medical Center (New York, NY), in accordance with Health Insurance Portability and Accountability Act guidelines.

Task analysis

Task analyses systematically deconstruct complex tasks into elemental components so that they can be better defined for training purposes.[6] Instructional designers and other behavioral scientists also use task analyses to identify potential human errors that can occur during a procedure, ascertain preconditions that can give rise to those errors, and suggest possible methods to reduce errors in order to perform the procedure successfully. In this study, 2 distinct types of task analysis were used in a complementary fashion: (1) hierarchical task analysis, and (2) cognitive task analysis (CTA). An hierarchical task analysis systematically defines concrete actions that are necessary to achieve specific outcomes for all the major tasks and subtasks of an operation in a top-down manner. The level of detail varies according to the level of granularity required to achieve the purpose of the analysis. Once this hierarchy of tasks was developed for LTA, a CTA was used to enhance the framework in order to develop a cognitive model of expert adrenal surgeons. Specifically, the CTA aims to define the underlying mental processes required to exercise sound judgment and decision-making during complex tasks, as opposed to focusing on observable actions.[6] This methodology has previously been reported in prior studies.[7,8]

Data collection

Qualitative methodologies were used to perform the task analyses and explore the behaviors of experts for performing both left and right LTAs. These techniques involved procedures designed to extract subject-matter experts' (SME) thoughts, opinions, and behaviors that underlie the operation: semi-structured interviews, field (in vivo) observations, and content analysis of the literature. SMEs were defined as individuals with $\geq$2 years of experience in independent practice, who perform at least 4 adrenalectomies per year, based on a prior study defining high-volume adrenal surgeons.[9] SMEs were sampled to represent diverse demographic and training backgrounds to optimize the breadth of data and capture as many practices as possible.

After informed consent, semi-structured interviews were conducted in-person by 2 investigators (AM, KG) trained in qualitative research. SMEs were initially asked to identify the objectives of the procedure, to outline the major key steps and to list all tasks required to perform a laparoscopic transabdominal adrenalectomy. Subjects were then prompted to elaborate on each major section, their associated steps and cognitive functions (ie, describe their thoughts), with a focus on safety, error avoidance, and higher-order cognitive functions such as reasoning, perception, and intuition. SMEs were specifically asked to distinguish between routine and complicated adrenalectomies and how to troubleshoot when facing an unexpected course (eg, when not making progress, dealing with bleeding, or lost in a sea of fat). A template was used to guide the interviews (Table I), minimizing close-ended dichotomous questions in order to avoid bias or leading questions, and to encourage an in-depth and engaging discussion. Field observations of 2 SMEs (JHK and JAL) were also done, asking them to talk out-loud during an adrenalectomy while an independent observer recorded all commentary made during the surgery.

Data analysis

All recorded interviews and observations were transcribed verbatim. For triangulation, transcriptions were supplemented with content from textbook chapters and online video modules describing the technique for LTA in order to capture different dimensions of the underlying construct. This is a fundamental principle of qualitative research to minimize bias and subjectivity, while improving the overall validity of the results. This also served to identify competencies that may not have surfaced during individual interviews or field observations and to further ensure saturation of data. Two investigators (AM, KG) independently coded transcriptions according to sections of the operation, tasks, subtasks, cognitive behaviors, critical decisions, and potential errors. After data extraction, grounded theory methodology was used to compare, match, merge, and refine items, and synthesize themes of cognitive behaviors. Grounded theory is a method of qualitative data analysis that includes several rounds of iterative inductive analysis whereby data are coded and grouped in order to extract emerging, anticipated, and overarching themes of a particular underlying construct.[10] This was done using theoretical memoing and sorting at each stage of data collection, and these themes were then

Table I
Template of questions used throughout semi-structured interviews during the hierarchical and cognitive task analyses

Prompts
• Describe the steps of the procedure on a macro level
• What is the purpose of this task?
• What actions (subtasks) are necessary to complete this task, including their temporal relationship (sequential or concurrent)?
• What conditions must be present before starting this task?
• What errors can occur, what are some tips or tricks to avoid such error during this task, and can this error be avoided by heightened awareness?
• What decisions have to be made during this task, including their temporal relationship, the various options, and criteria to choose between various options?
• What knowledge or skills serve as the basis for an expert's approach to this task?
• What tools and instruments are required or optional to complete this task?
• What visual, audio or tactile cues are required to perform this task?
• What performance standards or quality indicators are used to ensure successful completion of this task?

The entire procedures (laparoscopic transabdominal left and right adrenalectomy) are initially divided into a sequence of tasks by the interviewee, after which he/she is prompted to discuss various factors related to each task.

used to develop a theoretical framework. Theoretical sampling was performed after each round of analysis using at least 2 interviews, in order to continuously assess emerging themes and guide additional data collection. Therefore, data analysis was performed throughout the data collection process. The data were considered saturated and the conceptual framework was finalized once no additional themes could be synthesized after 2 consecutive interviews. At this point, data collection was terminated.

This data was coded according to a 5-axis universal framework of intraoperative expertise,[4] whereby performance is described in terms of: (1) declarative knowledge, (2) interpersonal skills, (3) personal resourcefulness, (4) psychomotor skills, and (5) advanced cognitive skills. Items were further classified using a nomenclature for intraoperative decisions based on a naturalistic model that was initially derived from the airline industry.[11] Items related to situational awareness require the operator to perceive elements from the surgical field, interpret their meaning and project future states, whereas those related to decision-making involve the act of considering and selecting options for a given intraoperative situation. Action-oriented items were classified as tasks or subtasks. Quantitative data are reported as median (range) and *n* (%).

Results

A conceptual framework was developed to characterize behaviors of experts when performing a right and left LTA. A total of 10 SMEs participated (median age: 45 [35–63]; male: 50%), comprised of 10 academic endocrine and general surgeons. All SMEs were fellowship-trained and board-certified by either the American Board of Surgery or the Royal College of Physicians and Surgeons of Canada. Median years in practice was 10 (2–32). All SMEs were high volume adrenal surgeons, with a median annual adrenalectomy case volume of 25 (4–50), and a total adrenalectomy case volume of 235 (75–950). Data were obtained from 10 interviews (median duration 53 minutes [46–63]), 5 field observations of laparoscopic adrenalectomies and content analysis of 6 literary sources (3 textbook chapters and 3 online video modules).[12–17] SMEs comprised of North American surgeons who currently work at 9 different institutions (Canada: 1; Northeast: 3; South: 1; Midwest: 2; West: 3), and who received fellowship training from 5 different institutions (Northeast: 2; Midwest: 1; West: 2).

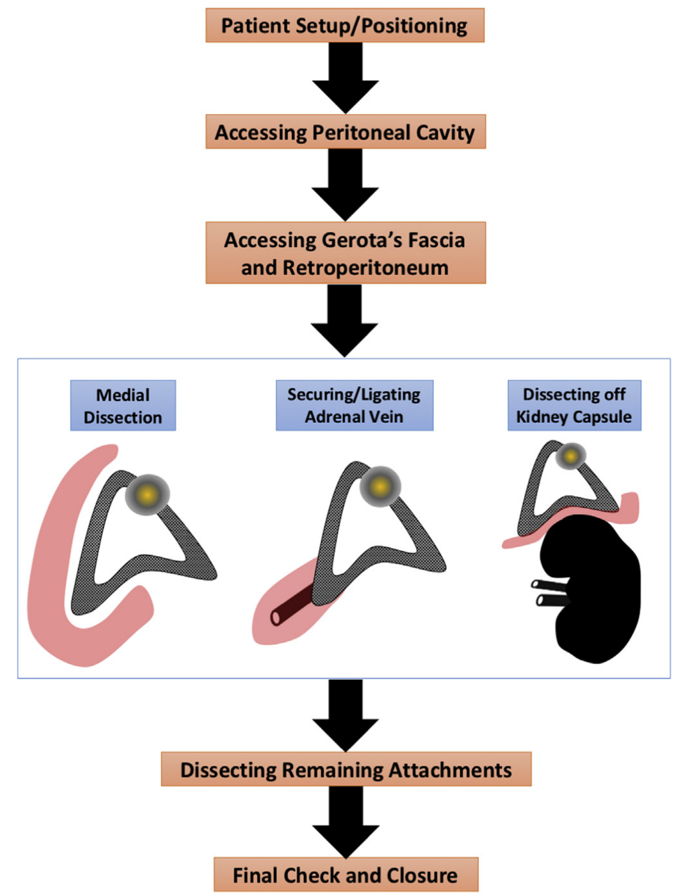

Fig 1. Overall procedural steps for performing a right and left laparoscopic transabdominal adrenalectomy. Based on the hierarchical task analysis, a total of 68 tasks (left: 58; right: 54) and 52 potential errors (left: 46; right: 41) were categorized throughout this framework.

Through the task analysis, a conceptual framework describing the mental model of expert adrenal surgeons was synthesized after 5 rounds of inductive data analysis using grounded theory. Agreement between reviewers for inclusion of items after the final round of analysis was 100%. A total of 68 tasks (left LTA: 58; right LTA: 54) and 52 potential errors (left LTA: 46; right LTA: 41) were identified and categorized into 8 procedural steps of the operation (Fig 1; Table II). Appendix 1 and Appendix 2 summarize all tasks and potential errors mapped to various areas of this framework.

Within the CTA, a total of 46 cognitive behaviors were identified and categorized into 8 general themes (Tables III and IV: teamwork

Table II
Summary of total items and potential errors during each section of the hierarchical task analysis (HTA) synthesized after the fifth round of data analysis for performing a laparoscopic transabdominal adrenalectomy

Section	HTA Items	Potential errors
Patient setup and position	9	9
Access to peritoneal cavity	11	5
Access to Gerota's fascia and retroperitoneum	13	14
Medial dissection	17	8
Ligating the adrenal vein	5	6
Dissection off kidney capsule and hilum	4	4
Dissection of remaining attachments	3	2
Final check and closure	6	4
Total	68	52

Table III
Cognitive behaviors for performing a laparoscopic transabdominal adrenalectomy, categorized into 8 general themes

Section	Cognitive behaviors*
Teamwork and communication	Effectively communicating with all team members to consistently obtain and provide data or feedback (eg, hemodynamic changes) and make management decisions (eg, resuscitation) as a team
	Coordinating with the entire team the availability of resources (human and material) that may be needed if the operation proceeds in an unintended course (eg, in case of massive hemorrhage: clips, blood products, suction, open and vascular sets, etc ready for use)
Assessment and management of patient physiology	Correcting any metabolic abnormalities perioperatively (eg, hypokalemia)
	Correcting any hemodynamic abnormalities perioperatively (eg, antihypertensive drips or vasopressors)
	Minimizing tumor manipulation to decrease any metabolic and hemodynamic changes when dealing with a possible functional adrenal lesion
Anticipation, tactical re-evaluation, and identification of safe planes and danger zones	Consistently developing a 3-dimensional mental model of the anatomy and pathology (eg, anticipating and having a thorough understanding of the relative location of the adrenal gland, the tumor, kidney and renal hilum, adrenal vein, adrenal arteries, and other surrounding structures)
	Consistently maintaining awareness for the possibility of misinterpreting anatomy (eg, anatomic anomaly, multiple adrenal veins, accessory vessels)
	Preoperative planning and preparation based on anatomic factors (eg, body habitus, body-mass index, and retroperitoneal fat) and pathologic factors (eg, biochemical profile, signs of local invasion, proximity to important structure)
	Identifying the medial arc surrounding the adrenal/periadrenal fat (superio-medial, medial, inferio-medial) and all of its vasculature, including feeding arteries, adrenal vein, renal artery or vein, inferior phrenic vein, inferior vena cava
	Assessing for signs of locoregional invasion with obliteration of safe dissection planes using both visual and tactile cues
	Maintaining vigilance and conscious awareness of structures located outside the laparoscopic field of view that are at risk of injury (eg, duodenum, colon, small bowel)
	Proceeding with the dissection cautiously, starting from a territory that is anatomically clear, and dissecting progressively, precisely and meticulously toward unchartered territory (ie, known to unknown), while maintaining the dissection in the correct plane
	Using tactile cues to feel for the planes and other structures (eg, kidney, empty spaces, or avascular planes)
	Decision point: If the planes of dissection cannot be identified due to difficult anatomy or due to difficult pathology, use intraoperative laparoscopic ultrasound to identify various landmark structures
	Decision point: If the planes of dissection cannot be identified due to difficult anatomy or due to difficult pathology (locoregional invasion with obliteration of planes, or difficult location), convert to open
Obtaining exposure	Optimizing exposure of dissection planes and important structures (eg, vessels) by providing the best traction or counter-traction (eg, traction on adrenal or periadrenal fat when performing the medial dissection)
	Making effective use of gravity to obtain exposure and access to the adrenal or periadrenal fat in the retroperitoneum
	Providing traction and counter-traction using wide surface area instruments to push, pull or lift without grabbing or traumatizing tissues
	Consistently assessing and fine-tuning the exposure and counter-traction provided by assistants (eg, liver, spleen)
	Optimally placing working trocars (ports) to triangulate the target of dissection with the maximum degree of freedom as possible for each trocar
	Decision point: If the exposure is suboptimal, insert additional trocars as necessary to provide appropriate retraction necessary to regain exposure
	Decision point: If the exposure is suboptimal, insert a hand port to provide appropriate retraction necessary to regain exposure
	Decision point: If the exposure is inadequate for safe dissection, convert to open
Dissection techniques and choice of instruments	Decision point: Effectively deciding when to use blunt dissection techniques versus dissection using an energy device
	Decision point: Effectively deciding when to use macrodissection techniques (eg, large sweeps, using the heel of the hook electrosurgical device over longer lengths) versus microdissection techniques (eg, dissecting subtle planes with a or hooking thin layers of tissues at a time)
	Choosing the best instrument for blunt dissection
	Performing effective or safe movements for blunt dissection in avascular planes using spreading motions, or sweeping nonlinear motions
	Choosing the best instrument for dissection with an energy device
	Performing effective or safe movements for dissection with an energy device, using an advances sealing device to desiccate and cut, or using electrosurgery
	Choosing the best method to ligate vessels (eg, using an advanced energy sealing device, electrosurgery, clips)
Resection/oncologic margins	Obtaining an appropriate amount of periadrenal fat to obtain all macro and microscopic disease with negative margins as appropriate for the case
	Avoiding tearing or compromising the capsule of the adrenal gland or tumor
	Decision point: If the operation cannot be performed safely without compromising oncologic margins, convert to open
Tactical modification	Routinely reassessing with a global view of the anatomy and pathology to determine whether the dissection has so far proceeded successfully or if any modifications need to be made to the approach (eg, getting lost in a sea of retroperitoneal fat, asking oneself "Am I in the correct plane?")
	Effectively adapting the approach to the surgery when encountered with a hostile or dangerous scenario (eg, large tumor, mass effect on surrounding structures, enlarged liver or spleen)
	Having insight to understand when not making progress or if an approach has failed, and reconsidering an alternative approach to proceed with the dissection
Error/injury recognition, rescue and recovery	Framing the problem: diligently and thoroughly assesses a situation that has deviated from the expected course (eg, bleeding, lack of progress)
	Develops a tactical approach in conjunction with other members of the operating team to address a situation that has deviated from the expected course with appropriate contingency plans
	Bleeding
	Apply direct pressure
	Increase insufflation and pneumoperitoneum
	Apply hemostatic clips, ensuring 5 or 10 mm clips are available on the set
	Use an energy device to desiccate and seal the bleeding vessel(s)
	Use an energy device to fulgurate superficial bleeding from the spleen, liver, or kidney
	Use topical hemostatic agents
	Laparoscopic suturing
	Decision point: If hemostasis cannot be obtained, convert to open, ensuring an open set, vascular set, retractors, nonabsorbable sutures, and adequate help are all available

* Items in this cognitive task analysis were synthesized after the fifth round of data analysis.

Table IV
Representative quotations for various cognitive behaviors for performing a laparoscopic transabdominal adrenalectomy

Theme	Representative quotations
Teamwork and communication	SME 3: "…if you're doing a pheochromocytoma operation, you got to make sure to communicate. With your anesthesiologist that you clip the vein because it's, usually following that, the patient will get hypotensive. And so they have to be ready with fluids and vasopressors. So good line of communication with your anesthesiologist for every case, but especially for pheochromocytomas." SME 4: "We have a timeout before case and I will talk to them about how when I get to the vein I will stop the case and there I will expect that they don't have a shift change and I introduce everyone so all members of the team know each other. Names are important so you don't just call out 'hey anesthesia' doesn't go too far. We really want to have everyone knowing each other well."
Assessment and management of patient physiology	SME 1: "Communication with anesthesiologist: depends on pathology. For pheochromocytomas/paragangliomas, very important to tell anesthesiologist when you are about to ligate adrenal vein, as this will change their management of hemodynamics. Be receptive to feedback from anesthesia and they should feel comfortable to tell you that the patient is very hypertensive, stop, as long as it is safe to stop to avoid tumor manipulation as this could increase catecholamine release."
Anticipation, tactical re-evaluation, and identification of safe planes and danger zones	SME 1: "If you feel resistance when taking instruments in and out, your port may have dipped down, and grabbed bowel, so make sure you are not putting through bowel." SME 6: "…tactile cues like in any laparoscopy it helps you when you get a sense of how much tension you are putting on tissues with your retracting hand. With your dissecting hand you get a sense of when you are not in a plane when you are pushing through tissues." SME 6: It's not an exact science for port placement as in you don't always put it in exactly the same place. You look at the body habitus (height, BMI, how high spleen and adrenal are in retroperitoneum). You have to tailor it to the patient." SME 2: "When you get in, you have a mental image of where is the gland, pathology, all surrounding structures and you calculate where to best place the ports to optimally access the target. Generally, you know where it will be, but you can fine tune it to be optimal, when you have for instance a large adrenal mass." SME 10: "As you open up the book, you get to the spine of the book and at the spine of the book, are all the vascular connections and it is the key part of the operation – it is all in the spine of the book. On the right side, at the spine of the book, there will be a venous connection (vein draining to vena cava) and 3 sets of arterial connections (sometimes more than one). And I picture these arterial connections as sets of springs that connect the adrenal gland to the medial part of the stuff like the vena cava area. And your job is to keep an eye on the vein (that's the most important part of it), but detach the 3 sets of springs and as you detach each set of spring, the book sort of opens up at the spine more and more. I describe it as opening the book and reading from the top down". SME 4: "Common things that get you into trouble are aberrant veins, or additional vein (tricky because you take your main vein and you think you are done) and you end up with another one. That's why I mention I use a hook cautery when I am trying to sort out the anatomy…taking thin layers one layer at a time so I know I am not cutting through a vein. Second thing is I have some expectations even aberrant veins where they come from. For example, aberrant vein, the furthest north they would come from is the right hepatic vein, and lowest they would come off is the renal vein. It's within that arc medially…the danger zone…that's a red flag every time you approach that region."
Obtaining exposure	SME 3: "…want to be careful not to put the retracting instrument into the spleen to get into bleeding. We have these cigarette sponges (Kittner sponges). Sometimes I will grab one of them and use it as a peanut. I use a wavy grasper and grab the tip of the sponge so it is not flopping around and has lots of friction on it without traumatizing it." SME 1: "…most important thing in surgery is what your left hand does not what your right hand does. That's just another way of saying it is all about retraction and exposure, positioning IS exposure. You can do the operation if you do not have perfect positioning, but it will give you that extra 5% to 10% improvement in performance. May not be that important, but it will help optimize and you never know when that 5% to 10% improvement will come in handy (curveballs, large tumors). This is a controllable factor.…" SME 1: "…a 5 [5 mm port] is free". SME 8: "Your retraction is highly dynamic and you are constantly moving it around to show you that plane." SME 4: "The way I envision removal of the adrenal is that the whole idea of a lap transabdominal operation is to use gravity to help you pull away the stuff that covers the adrenal." SME 10: "I rarely grab anything. I almost never do that because you never know if you are getting into tumor or can cause bleeding too."
Dissection techniques and choice of instruments	SME 7: "…Make sure you are around it [adrenal vein] and take it. Can use a ligasure or other fine-tip dissector to bluntly dissect around it. The pitfall is poking into the vein. The question becomes whether or not you can develop your plane well enough without the finer tip or curvature. Use both visual and tactile cues to feel your way into the right plane, and just keep spread above or below and serially enlarging that track until I see my tip on the other side. If it does not feel right, then I spread on the other side and usually that does the trick, and if I can't I will switch to Maryland. SME 5: "Often I will also use the blunt tip of my grasper. I don't even open the tip. It's a more as a probe so I can feel my way. I feel for the artery (feels hard), vein feels like vein, and anything else that is easily dissected sometimes when you put something there it just opens up. We typically prefer to see it, but feeling is just as important."
Resection/oncologic margins	SME 1: "Tumor size is another reason why I would consider converting, if it's too large to get around. I don't have a very hard and fast rule regarding size, but it is so tied into concept of oncologic principles. So past a certain size, you would be worried about cancer. Most of the time I would still start laparoscopic, unless it is very large and body habitus if it's favorable. But even then I would typically start laparoscopically and get some of the mobilization done as long as you don't erode or violate the capsule."
Tactical modification	SME 3: "…questions I ask is whether or not to convert to open. 'Can I complete this operation safely without compromising oncologic margins. Am I in the wrong plane?' If so I may try dissecting from somewhere else, lateral approach, or from the kidney and make sure to get into the right plane. But if I really think that there is local invasion, then that is a time to consider converting to open for those reasons: you don't want to have complication, injuries, bleeding, and you don't want to violate the capsule..." SME 8: "If you get lost in a sea of fat, or if there's a bit of bleeding or it looks a bit treacherous, what I might do is place a sponge there and go work somewhere else for a while and come back to it. I don't generally try to struggle for too long in one place. I think that's a pretty general rule in surgery anyway. If you are having trouble in one place, generally speaking there is another place you might work that may make it easier or it might take your mind off of it and get a fresh look when you come back. So if I am having trouble finding the vein or I'm struggling a bit, I would place a cigarette sponge and go work somewhere else." SME 9: "…reasons why I would consider converting to open…adherence…tumor is super stuck and you are not making progress…"

(*continued on next page*)

Table IV (*continued*)

Theme	Representative quotations
Error/injury recognition, rescue and recovery	SME 3: "…If I get into bleeding from IVC, first increase intra-abdominal pressure, place pressure with sponge. My threshold for conversion is pretty low. If the bleeding is from tumor surface, liver surface or kidney surface or some of the surrounding structures, then I generally place pressure. I try not to Bovie or ligasure and that will make it worse. You have to fight the urge, take your time, deliberate, frame the problem and develop a plan of attack to find the bleeding and control it appropriately.

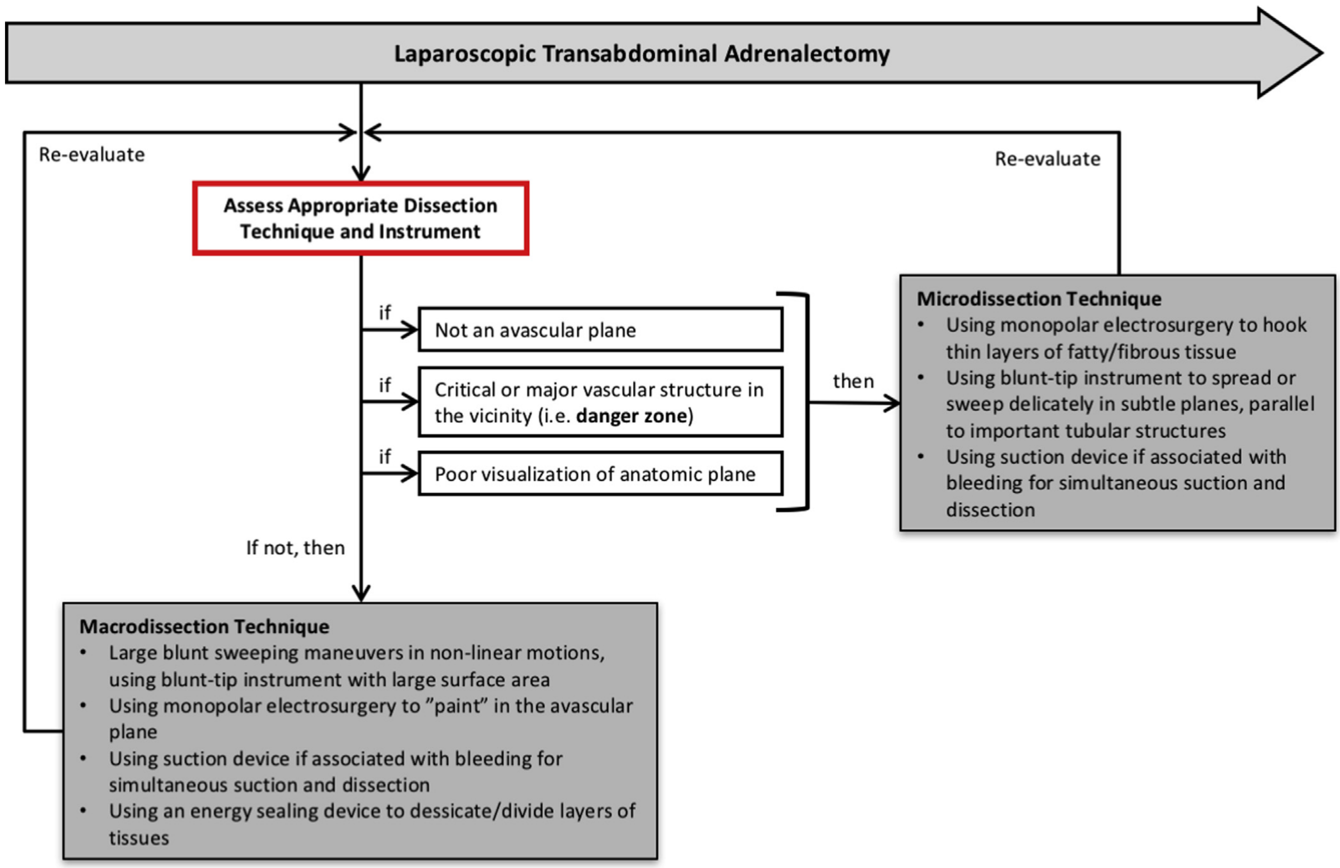

Fig 2. Dynamic decision tree for deciding what type of instrument or technique to use during the dissection of a laparoscopic transabdominal adrenalectomy. Despite some variations in techniques amongst subject matter experts, 2 general themes were highlighted: macrodissection and microdissection.

and communication ($n = 2$), assessment and management of patient physiology ($n = 3$), anticipation, tactical re-evaluation, and identification of safe planes and danger zones ($n = 10$), obtaining exposure ($n = 8$), dissection techniques and choice of instruments ($n = 7$), resection or oncologic margins ($n = 3$), tactical modification ($n = 3$), error or injury recognition, rescue, and recovery ($n = 10$). Experts unanimously reported the importance of creating a 3-dimensional mental model of the anatomy or pathology (eg, aberrant vessels, tumor location) that is consistently fine-tuned throughout the operation, with conscious awareness of danger zones (eg, medial arc surrounding the adrenal gland or periadrenal fat). Surgeons described methods to optimize exposure and accentuate safe planes, such as using gravity and dynamic traction or counter-traction via pushing, pulling, and lifting maneuvers in the axis of areolar and fibrous attachments. Despite variations in dissection techniques, experts highlighted 2 themes: macrodissection (large sweeping motions) and microdissection (fine dissection of thin layers), with emphasis on nonlinear motions and effective transitions between the 2 when appropriate (Fig 2). Surgeons stressed the importance of tactical modification when faced with failure of progression, hemorrhage, suboptimal exposure, and loss of bearings (Fig 3). Teamwork and effective communication were also consistently described as essential for avoiding and managing physiologic changes, or to coordinate contingency plans when required.

Discussion

Performing an operation requires the effective application of a complex body of knowledge and skills that are adapted to various patient-specific and environmental factors, and there is increasing evidence that surgical outcomes are associated with these advanced cognitive functions. Despite surgeons' strong reliance on higher-order cognition to achieve the objectives of any operation, these competencies are often difficult to characterize, teach and measure, and current methods in postgraduate training and continuing medical education have significant limitations. As a result, it is becoming increasingly clear that the traditional domains of knowledge, skills, and attitudes need to be better developed in such a way to incorporate these important behavioral skills and mental processes (eg, decision making, judgment, situation awareness, pattern recognition). As a first step to address this

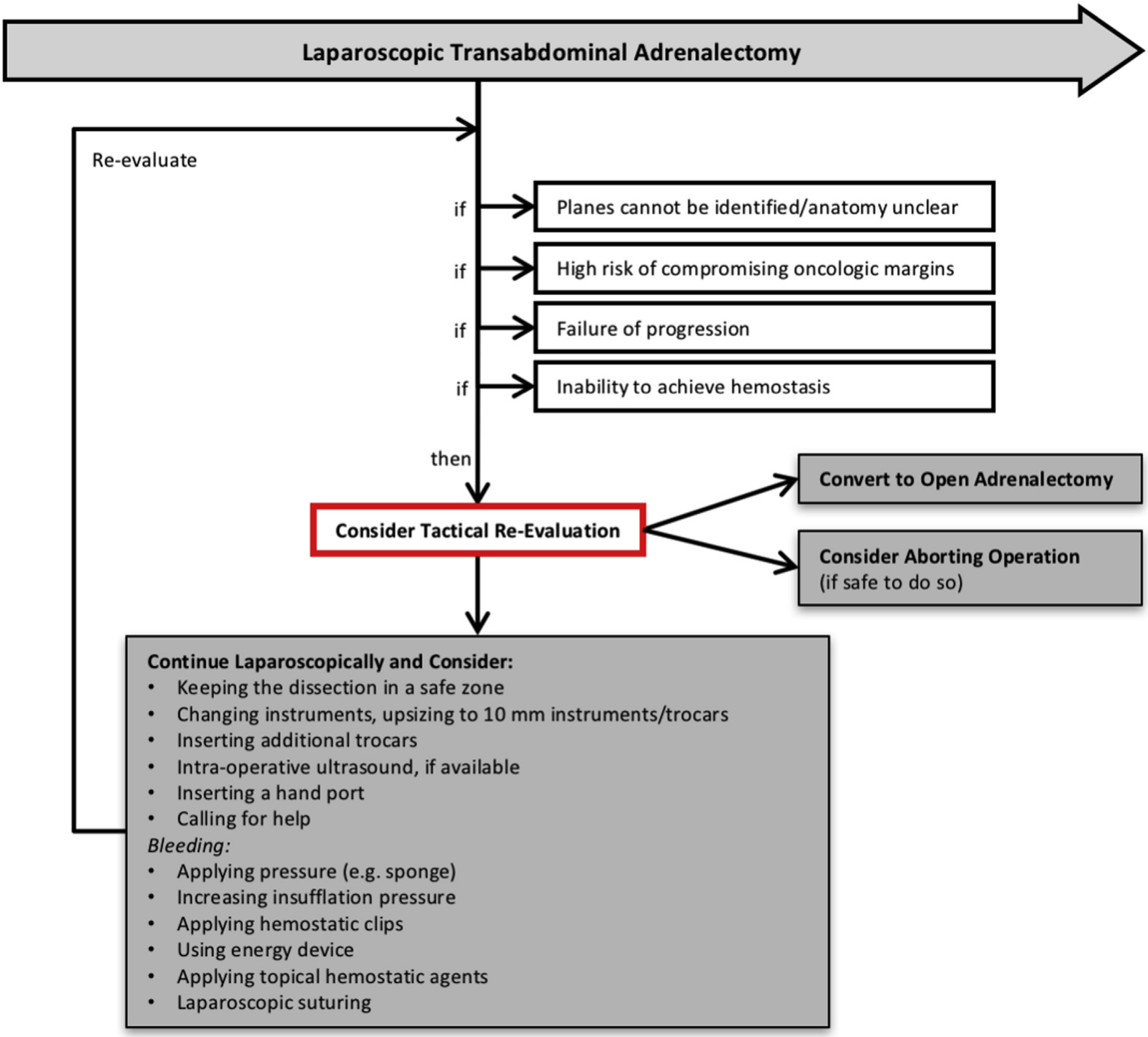

Fig 3. Dynamic decision tree derived from the cognitive task analysis, depicting experts' consistent habit of maintaining situation awareness to identify scenarios that have deviated from the expected course of the operation, and various tactical modifications to address them.

problem, there is a need to understand the qualities and cognitive factors that reflect the mental model of a safe and effective surgeon. This qualitative study defined the behaviors, decisions, and other higher-order cognitive functions required to perform a left and right LTA.

Although the general steps of most operations tend to be well established (albeit some variation between individuals and institutions), the actual skillset required to achieve these tasks is significantly more complex than a simple list of sequential actions and explicit knowledge that can be recited. Expert performance relies very heavily on a vast amount of tacit and hidden knowledge. Evidence from educational psychology literature suggests that mental models of experts (ie, their internal mental representations of the anatomy, surgical field, and operative environment) tend to be chunked into core concepts and principles, regardless of their professional domain.[18,19] In surgery, these core principles are integrated and applied to an infinite breadth of unique operative scenarios that allows surgeons to make decisions and perform tasks. Specifically, experts' mental models tend to be highly structured with a deep conceptual understanding of surgical principles, developed through years of experience and repeated practice, allowing them to recognize anatomic structures, planes, patterns and hazards, as well as to plan the operation and make difficult on-the-spot decisions. One of the common themes described in this study was the consistent habit of developing a 3-dimensional representation of the anatomy, such as the relative location of the adrenal gland, tumor, and surrounding structures, including their planes of separation. SMEs greatly emphasized this principle when discussing the medial arc surrounding the adrenal gland and periadrenal fat, constantly evaluating for the presence of the adrenal arteries, adrenal vein, aberrant veins, renal vessels, inferior vena cava, and inferior phrenic vein. Most subjects described this process as beginning with preoperative imaging and continuously updating and fine-tuning their mental model throughout the operation.

In addition, experts have the ability to automate thought processes with a fraction of the mental effort compared to more novice surgeons, allowing them to use greater stores of declarative and tacit knowledge more efficiently, creatively, and flexibly.[20] This principle of adaptive performance is a hallmark of surgical expertise, allowing surgeons to tackle complex situations. In this study, SMEs discussed a variety of approaches to modifying their tactic when faced with a case that is not routine, or that has deviated from its planned course, such as when there is a failure of progression, difficult anatomy, bleeding, or signs of locoregional tumor invasion. Much of the data from this study also emphasized the need to exercise situational awareness and the insight to understand when there is a need for tactical modification, or the incessant need to utilize both visual and tactile cues to guide surgeons' understanding of the anatomy (eg, finding avascular planes, or the empty space on either side of an adrenal vein).

The cognitive map derived in this study provides tremendous opportunities for instructional design. Given the current reforms in surgical education and the increasing demand for observable and measurable competencies,[21] there is a need for defining sound judgment and effective decision-making in various contexts (such as in this study for LTA) and for developing pedagogic models that reinforce such behaviors. A curriculum can be designed to target nonexperts to think and behave like experts, with modules that provide the means to deliberately practice cognitive behaviors (eg, where and what angle to retract, choosing the appropriate tool[s] for a specific aspect of the medial dissection, how to deal with major bleeding, identifying vascular landmarks, recognizing the avascular planes). This form of training can also be combined with technology-enhanced learning environments to immerse learners in scenarios that require them to interpret and process environmental cues, and commit themselves to making decisions. By providing trainees with immediate feedback and ample opportunities for repetition, such training could potentially accelerate the development of a nonexpert's mental model and ultimately the acquisition of expertise.[22,23] Similarly, the findings from this framework can be used to develop performance metrics to objectively measure the ability to exercise sound judgment and make safe decisions when performing an LTA. Most available tools tend to focus on performance of observable actions and not on the underlying mental processes required for safe task completion. Assessment tools that incorporate such metrics can add significant value to postgraduate training for residents, fellows or surgeons in independent practice wishing to augment their performance. Furthermore, establishing safety standards and implementing high-stakes performance assessments can help ensure that trainees entering independent practice possess the minimal standards of competency. The findings of this study can serve as the foundation necessary to develop testable content and assessment blueprints. Likewise, postoperative debriefings with video analysis as part of a surgical coaching program has shown significant value, and adopting these metrics can also potentially improve the adoption of expert behaviors.[24] Finally, this task analysis can be used for quality-assurance purposes by allowing surgeons and other members of the operating team to understand how errors occur and to develop interventions to mitigate those risks. This can be in the form of a checklist to include important items such as the availability of equipment when faced with major hemorrhage, or an intraoperative time-out prior to the ligation of the adrenal vein.

Potential weaknesses of this study include inherent limitations in qualitative methodologies and possible inconsistency of results.[10] Furthermore, one of the study investigators (AM) who performed interviews and analyzed data is a clinical fellow in endocrine surgery in the same training program as 2 of the SMEs, potentially biasing the results. To limit this effect, a second investigator (KG; junior surgical resident), with no relationship to any SMEs and with limited experience in endocrine surgery, also performed the interviews and analysis, thereby improving reliability. Field observations were only done at 1 institution with 2 SMEs, 1 of which trained the other. It is likely that this limited the breadth of data. Also, despite having a comprehensive framework, it is unclear which of these elements have greater relative importance. Given the wide range of expert opinions, controversies, and operative approaches, consensus on the most important items needs to be defined prior to using these data for instructional design and assessment blueprints. Future studies that survey a broader and more diverse group of expert adrenal surgeons (eg, minimally invasive surgeons, surgical oncologists, and urologists) are warranted to establish the widespread generalizability of these results.

In conclusion, this study defines behaviors and competencies that are essential to performing LTA effectively and safely. With an emphasis on patient safety, effective decision-making, and sound judgment, this conceptual framework may serve as the basis for developing educational curricula, quality-improvement initiatives, and robust performance metrics that provide meaningful feedback to learners for deliberate practice, self-reflection, and coaching purposes.

Funding/Support

There were no sources of funding for this study.

Conflict of interest/Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

Acknowledgments

We acknowledge the surgeons who participated in interviews and field observations

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.surg.2019.03.035.

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Discussion

Dr Bradford Mitchell (Lansing, MI): Since you describe the laparoscopic approach, did you exclude robotic techniques in your modeling?

Particularly, you described tactile feedback. I wonder if the surgeons who are doing adrenalectomy by both laparoscopic and robotic techniques would distinguish between tactile feedback, benefits of 3D visualization, etcetera. It might get to the question of the prior presenter about capsular disruption. It could be very important.

Dr Amin Madani: For this study, we restricted the analysis purely to the laparoscopic approach because the moment you consider open, robotic, or retroperitoneal, it starts to become very complicated. Of course there are commonalities and principles that you can identify. So maybe in the future we can do that, but we wanted to keep it more focused for this study.

That being said, for laparoscopy, tactile feedback is a huge thing, and you can appreciate it when you watch experts operate and even when they describe themselves doing it.

Dr Barry Inabnet (New York, NY): Very interesting data and great work. Having been involved with training many MIS Fellows and Endocrine Surgery Fellows over the last several years, I have observed that Fellows mature at different levels of their training. Some come in and almost immediately have a skill set where they can adopt a technique and go with it, and others take a little bit more time.

In your modeling, how do you take into consideration that sort of human side of things where people just learn at different paces?

A lot of the work you are describing is apropos of the surgical black box concept out of Toronto where cameras are in the operating room. They take video of the operation and actual video of the people in the operating room and then send that to a team in Toronto who do an analysis. And they come up with machine learning breakdowns of where complications and stresses during intervention can occur. One of the most common stresses of an operation was interruptions of the team during the operation where you have people coming in and out of the operating room during a procedure that breaks the concentration of the team or a change of team during a critical part of an operation.

It is important to take those type of things into consideration when modeling. Maybe you would address that as well.

Dr Amin Madani: Those are excellent points. I will tackle the first one, which is how do you make up for different learning curves amongst different trainees? This model does not really address that. This is really about the expert mind, the optimal way to do the operation. So the onus is upon educators who are developing the curriculum to make up for the differences in learning patterns. This is sort of the final output, if you will.

So our aim is that hopefully people who become adrenal surgeons will develop an expert mental model that looks like this. How they get to it is another question altogether. But this represents a framework upon which you can build curricula.

Regarding your comments about the OR black box, we factored in interpersonal skills and teamwork and communication. That was a whole component of this mental model. It is definitely represented highly in there. What you just said represents what I meant by quality improvement. You can design interventions aimed at tackling specific things that can happen in the operating room where errors can occur. I completely agree with that.