“They Have to Adapt to Learn”: Surgeons’ Perspectives on the Role of Procedural Variation in Surgical Education

Tavis Apramian, MA, MSc, PhD^{*}, Sayra Cristancho, PhD^{*}, Chris Watling, MD, PhD^{*}, Michael Ott, MSc, MD[†], and Lorelei Lingard, PhD^{*}

^{*}Centre for Education Research & Innovation, Schulich School of Medicine & Dentistry, London, Ontario, Canada

[†]Department of Surgery, Schulich School of Medicine & Dentistry, London, Ontario, Canada

Abstract

OBJECTIVE—Clinical research increasingly acknowledges the existence of significant procedural variation in surgical practice. This study explored surgeons’ perspectives regarding the influence of intersurgeon procedural variation on the teaching and learning of surgical residents.

DESIGN AND SETTING—This qualitative study used a grounded theory-based analysis of observational and interview data. Observational data were collected in 3 tertiary care teaching hospitals in Ontario, Canada. Semistructured interviews explored potential procedural variations arising during the observations and prompts from an iteratively refined guide. Ongoing data analysis refined the theoretical framework and informed data collection strategies, as prescribed by the iterative nature of grounded theory research.

PARTICIPANTS—Our sample included 99 hours of observation across 45 cases with 14 surgeons. Semistructured, audio-recorded interviews ($n = 14$) occurred immediately following observational periods.

RESULTS—Surgeons endorsed the use of intersurgeon procedural variations to teach residents about adapting to the complexity of surgical practice and the norms of surgical culture. Surgeons suggested that residents’ efforts to identify thresholds of principle and preference are crucial to professional development. Principles that emerged from the study included the following: (1) knowing what comes next, (2) choosing the right plane, (3) handling tissue appropriately, (4) recognizing the abnormal, and (5) making safe progress. Surgeons suggested that learning to follow these principles while maintaining key aspects of surgical culture, like autonomy and individuality, are important social processes in surgical education.

CONCLUSIONS—Acknowledging intersurgeon variation has important implications for curriculum development and workplace-based assessment in surgical education. Adapting to intersurgeon procedural variations may foster versatility in surgical residents. However, the existence of procedural variations and their active use in surgeons’ teaching raises questions about the lack of attention to this form of complexity in current workplace-based assessment strategies.

Failure to recognize the role of such variations may threaten the implementation of competency-based medical education in surgery.

Keywords

technical decision making; procedural variation; surgical education; workplace-based assessment; competency-based education; evidence-based medicine

COMPETENCIES

Practice-Based Learning and Improvement; Medical Knowledge; Interpersonal and Communication Skills

INTRODUCTION

Surgical practices can vary broadly between surgeons. Clinical researchers routinely describe variations in procedural approaches^{1–4} and investigate their effect on procedural outcomes^{5,6} and system safety.⁷ Yet the role of procedural variation in surgical education has not received similar attention.⁸ We know little, for instance, about how intersurgeon procedural variation influences how surgeons teach postgraduate learners (residents) and assess their developing competence.^{9,10} Ignoring the potential effect of variations on learning threatens the implementation of competency-based workplace assessment reforms¹¹ such as entrustable professional activities^{12,13} in surgical education.^{14,15}

In a previous study,¹⁶ we explored senior surgical residents' perspectives on procedural variation and its influence on their learning. As they apprenticed with multiple staff surgeons, residents recognized procedural variation and made sense of it by distinguishing between absolute procedural rules, or *principles*, and interchangeable *preferences*. For residents in that study, understanding and adjusting to multiple staff surgeons meant identifying and negotiating *thresholds of principle and preference*. Failure to successfully identify and negotiate thresholds was perceived by residents to threaten their autonomy and their relationship with the staff surgeon.

Missing from that study, though, was the perspectives of surgical teachers on how procedural variation influenced the educational process. A robust understanding of an educational process requires the perspectives of learners and teachers, given the fundamentally social and transactional nature of education. In this study, we therefore explored how surgical faculty understand the relationship between procedural variation and resident learning.

METHODS

Our qualitative approach to these questions (i.e., grounded theory¹⁷) aims to explore a social process that has not previously received attention in surgical research—teaching of procedural variations—to create *concepts* and *theories* that resonate with practitioners and researchers.^{18,19} As concepts continue to emerge, the theories they belong to should be iteratively refined to improve their transferability. Transferability invites readers of qualitative research to make connections between elements of a study and their own

experiences.^{20,21} In line with this methodological approach, in the present study, we investigated the relevance of thresholds of principle and preference to a new population.

The grounded theory study we report here used observational and interview-based data collection strategies. Observational data were collected using marginal participant observation²² to record detailed fieldnotes and reflexive memos across 99 hours of observation in 45 cases. Our sample included 14 surgeons at 3 tertiary teaching hospitals in Ontario, Canada. Semistructured interviews were conducted with surgeons immediately following the observational period. In 2 cases, logistical and patient care concerns necessitated conducting the interviews at a later date. The subject matter explored in the interviews was drawn from the fieldnotes recorded from the day's observation, data from the larger body of broad observational data, and semistructured prompts from an evolving interview guide. The 14 interviews, lasting an average of 39 minutes, were audio recorded and transcribed.

The first 6 interview transcripts were coded using an open, line-by-line approach.¹⁷ The line-by-line codes were compared with one another to create categories unique to this study. Those categories were “constantly compared”²³ with categories from previous research by our group¹⁶ to develop and iteratively refine a focused coding framework.¹⁷ Following standard grounded theory practice, core categories resonating across these data and the resident data¹⁶ were used to iteratively inform ongoing data collection toward theoretically saturating these patterns in the data set.^{24,25} The focused coding framework was used to iteratively analyze the remaining 8 interviews, the fieldnotes, and the reflexive memos as each were collected. Finally, theoretical coding was used to reanalyze all 14 interviews to close gaps in the framework and consolidate categories. The analysis of the interviews was supported by NVivo10 qualitative data analysis software. The study was approved by the Research Ethics Board of Western University.

RESULTS

We broadly defined “procedural variation” as an intra-operative technique that had the potential to be performed differently by 2 surgeons. Our participants unanimously reported that procedural variations abound in surgery, that some variations matter more than others do, and that understanding variation is relevant to learning to become a surgeon. Procedural variations were recognized as a means to both provide residents with a broad catalog of approaches to challenging procedural situations and to cultivate in residents a respect for the culture of surgery.

Variations Abound in Surgery: “More Than One Way to Skin a Cat”

All participating surgeons acknowledged that there are variations between their own practices and those of their peers. For example, the insistence that there is “more than one way to skin a cat”^(S14) was a common idiom used by surgeons to acknowledge that for each procedure, “although we say we do it the same way, we all do it a little bit differently.”^(S20) Surgeons observed that the residents coming on to their teams had to discern how they wanted things done compared with how their colleagues might have insisted they be done:

In each team they learn different techniques, different skills, different judgments. They have to adapt, and they probably don't like that, but that's the only way for them to learn. If I tell him [or her], 'no, we're going to do it this way,' then he [or she] needs to do it that way. The person who is making the decisions here is me, not him [or her]. I have seen some residents—when they come to my team and then when they leave—their technique is total different, totally different, totally different. When [after they leave my team], if for some reason they come back and I see them operate, [I know] they will have switched something. (S12)

The surgeons laid claim to their own “style,” (S12) “method,” (S11) and “ways” (S18) of approaching a procedure. They perceived their personal set of variations as based in “expert opinion” (S14); however, they maintained that “doesn't mean my method is better than anybody else's” (S11). Rarely did our participants criticize the variations of other surgeons during interviews; rather they perceived that each surgeon has “their comfort zone” (S18) gained through years of experience.

Not All Variations Are Equal: “I Want It Done This Way”

Yet, not all variations were seen as equal. Surgeons reported that some of the varying movements and decisions surgeons make represented inviolable principles, whereas others represented interchangeable preferences. For example, surgeons were unanimous that “tearing veins, making knots leak, cutting things you should not have cut, cauterizing things too deep or too shallow, [putting] ports in the wrong place, not dissecting out things properly, and clipping things wrong” (S8) were inviolable principles. By contrast, preferences included variations like instrument and suture choice, knowing different “little tricks,” (S20) and “style things...[like] he takes his little bovie and bends the edge to curve it.” (S5)

Identifying Principles—Principles superseded preferences in surgeons' accounts of what matters in intraoperative teaching. From the emphasis surgeons placed on principles, and their extensive discussion of them, we identified 5 common principles (Table). The first was *knowing what comes next*, or exercising sufficient “judgment” (S3) to anticipate procedural progression. The second principle was *choosing the right plane*, or having the anatomical knowledge needed to “follow the planes perfectly” (S12) and build “3-D images” (S3) of the field. The third principle was *handling tissue appropriately*, or demonstrating the technical acumen “to understand the amount of tension pressure on tissue.” (S5) The fourth principle was *recognizing the abnormal*, or having the “common sense” (S18) to identify challenging cases and novel pathology. The final principle was *making safe progress*, or continually moving the case forward while avoiding or exhibiting care in “challenging areas.” (S12)

Although these common patterns emerged around what variations belonged to the realm of principles, surgeons retained the right to exercise “expert opinion” (S14) and enact principles by balancing the best interests of the patient and the learning needs of the resident.

In my own mind I am asking for perfection from residents. But what is perfection in my mind?... If they keep doing the same thing and they make their incisions in the wrong place some surgeons say ‘okay, you get into trouble and I'll bail you out,’ but one of the things that they may not take into account is what is happening

to the patient...The apprenticeship principle works on the fact that you work with me and you follow what I do.(S16)

Given that variations could present as either principles or preferences, surgeons recognized that part of the residents' responsibility was discerning which kind of variation they were facing with a particular surgeon in a particular situation: "you just teach them what you know, and you teach them why you do it, and then they will decide for themselves,"(S9) but it remained an open question whether "the decision they make to add something or throw something away is based on well thought out grounds."(S5) Residents were expected to understand that "there are things where, 'yes, I want it done this way,' and others where they can do whatever the hell they want."(S7)

Enacting Principles—Principles were often expressed like this by surgeons, in the first person, as "my" way, not "surgery's way," although there was a tacit implication that their colleagues would share them. For example, according to one surgeon in our sample, while "I try to instill in them *what I think are principles*,"(S5) the idea that there were variations that "all of us would hold very dear"(S5) remained prominent. Despite that espoused consensus, our participants prioritized enacting these principles differently in their teaching. Some surgeons talked about prioritizing "efficiency,"(S5) others most wanted residents to have "elegant... tissue handling,"(S7) and still others felt "exposure, to have very clear dissection of the tissues"(S12) was the critical teaching point. Although they all agreed on principles, what to do with those principles was more ambiguous.

Many of the surgeons in our sample felt that part of their job was to provide support to residents as they learned to identify principles through hands-on work: "that's my educational philosophy, as long as it's not dangerous I want him [or her] to try to work out his [or her] own understanding."(S5) Others felt that dictating principles to residents was part of their fiduciary duty to the patient that residents "should not be practicing in the operating room."(S11) Surgeons recognized that they gave residents "more rope... [and] autonomy"(S18) around preferences than they did around principles, and they also acknowledged that it could be challenging for residents to determine what is inappropriate "practice" and what is appropriately "working out their own understanding." As one surgeon put it: "who decides I am very good? That is my own judgment right? Say I do the operation with another surgeon. He [or she] might say 'no, no, do it the other way.' And that is the problem residents have."(S16) Ultimately, though, the surgeons in our sample expected that the challenge of adapting to each surgeons' preferred procedural variations was a difficult but functional element of surgical education.

Variations Are Educationally Valuable: "Earn Their Autonomy"

Our participants believed that adapting to procedural variations helped residents to build a broad catalog of procedural approaches and to synthesize multiple approaches effectively. They perceived value in pushing the residents to "put all this information together and decide how they want to do it"(S18) as they develop into surgeons in their own right:

I think it would be very poor training if everyone did everything exactly the same every time because no two operations are identical. No two surgeries are identical.

If you become so rigid in your performance that when there's an abnormality and you don't know how to deal with it, then you're no good... Trying to stamp out all variation is not positive. There are different things that different surgeons do that residents can either add to their armamentarium or discard.^(S5)

Surgeons reported that “the trainee should be able to adapt”^(S11) to different surgeons' procedural variation. For surgeons, teaching residents to perform their variations provided the residents information about which variations could threaten the safety of patients and which were safely interchangeable. More importantly, for our participants, residents performing procedural variations reinforced the necessity of versatility in an arena where the unexpected is a regular occurrence: “you have to learn different ways”^(S7) to become a versatile surgeon and to “have a better appreciation of what you're doing... [to see] that some things work better in different scenarios.”^(S7) Surgeons maintained that exposing residents to variety both between surgeons and to the different ways the same surgeon can perform a procedure was educationally valuable because it fostered such versatility.

Variations and Versatility—Variety was seen as not only serving this technical purpose of fostering procedural versatility but also in serving a sociological purpose. Surgeons suggested that, by learning to adapt to their thresholds of principle and preference, residents gained insight into their place in the broader surgical environment. Residents' efforts to interpret for each surgeon which variations were negotiable and which were not was perceived to be tantamount to demonstrating “respect for the surgeon.”^(S7) Surgeons suggested that adapting to particular staff-sanctioned variations was expected “not so much because... those things are important to the outcome”^(S5) of the procedure but rather because such adaptation signaled that “when I'm with him [or her] I want to do the thing that he [or she] wants me to do because I respect him [or her] so much.”^(S5) Every participant suggested that part of professionalism is developing such respect for surgical culture.

Variations and Cultural Learning—This professionalism, in turn, demands an understanding that procedural variations exist in an arena where clinical evidence is often ambiguous:

If I get a resident on my service, and I'm trying to teach them how I do what I do then... it would be highly unprofessional to throw your colleagues under the bus. All you can do is help residents understand that there is a diversity of practice out there and that reinforcing the importance of evidence-based surgery is part of embodying the professionalism that makes a surgeon a surgeon... Even though there is very clear evidence that some of the approaches are not as effective as others... I don't spent time dwelling on the other surgeon... all I can say is ‘that would not be considered the standard of care’... [or] ‘that's not really supported by the evidence,’ or ‘this is my preference’.^(S9)

Just as residents do, surgeons find themselves negotiating intersurgeon variations in a context where, on one hand, sometimes “a lot of it is surgical preference”^(S11) and “hocus pocus... with no evidence.”^(S14) and, on the other hand, sometimes “there is very clear evidence.”^(S9) Variation, therefore, becomes a complex issue in the operating room, both a matter of standard of care and a matter of professional autonomy. Surgeons' expectations

around their procedural variations are used to teach residents about the kind of care that is expected when discussing colleagues: “everyone has little variations in what they do...most residents try to do it the way you want them to do it... [that’s] why there is certification before they let you loose on the public. You have to earn that right to operate.”^(S16) Replicating such professional expectations teaches residents that surgical training is underpinned by the premise that residents must “earn their autonomy.”^(S9) And that autonomy is earned, in large part, by learning how to behave successfully in relation to variations.

DISCUSSION

In a previous article, we reported that residents recognize procedural variation in surgery and work to negotiate it successfully.¹⁶ The findings we have reported here illustrate that surgeons also recognize intersurgeon variation, appreciate that residents are working to negotiate it, and endorse the use of variation and its negotiation for teaching purposes.

Finding Clarity in Complexity

Our surgeons reported, like the residents before them,¹⁶ that not all variations are created equal. At one end of the spectrum of variations live obvious errors that no surgeon would deliberately use and at the other live entirely inconsequential variations. The complexity exists between these 2 poles. Some variations are enacted in teaching as nonnegotiable principles that, if broken, threaten the safety of the patient and the success of the procedure. Others are enacted as interchangeable preferences that either surgical tradition or clinical evidence suggests lead to equivalent outcomes. However, differentiating between the 2 is not always a straightforward matter. The construct of thresholds of principle and preference and the process of thresholding describe this phenomenon.¹⁶ In thresholding, residents continuously look for the line between principles and preference. These thresholds are different for each surgeon, they must be found for each new step of a procedure that the resident is permitted to perform, and they shift over time as residents progress through their programs. The study we report here answers our previous questions about the role of surgeons in this phenomenon: surgeons recognize the constructs of principles and preferences and their influence on surgical education. But the surgeons in our sample also provided a new finding: procedural variations are endorsed in surgical learning.

Surgeons approach variation as a valuable dimension of surgical education. Their expectation—that learning the different approaches surgeons take for the same procedures creates a catalog for residents to draw on in future independent practice—signals a shared philosophy about variation: diversity is not only defensible it is also necessary for the expertise that is the hallmark of the competent surgeon. Fostering procedural versatility may well play a role in helping surgeons account for the additional variation in patient anatomy, logistical factors, and learner characteristics that they would face in the future as surgeons and faculty members.^{26–28} This finding provides empirical support for the use of current theories of adaptive expertise²⁹ and naturalistic decision making³⁰ in the surgical education literature.^{26,27,31,32} In these 2 theories, developing impressions of workplace-based experiences that can be intuitively applied to challenging situations is a critical element of

expert practice. In contrast to traditional cognitive understandings of expertise, defined by acquisition and recall of abstract knowledge, adaptive expertise interprets problem solving as an intuitive and creative enterprise influenced by multiple complex factors such as organizational culture.²⁹ Our participants proposed that teaching residents to adapt to the variation between surgeons helps residents to make sense of the patient and system factors that make clinical work complex.^{33,34} For the surgeons in our study, fostering this adaptive form of learning was part of their responsibility as faculty members.

Acknowledging Challenges in Assessment

Focusing on cultivating adaptation to variations may exact some unexpected consequences for communication between surgeons and residents. The findings of our study indicate that although there is a pattern to what surgeons consider a principle, the pattern is not made up of only black and white. The parts of the pattern that do appear to be distinct (i.e., the principles identified in our study) include the following:

- knowing what comes next
- choosing the right plane
- handling tissue appropriately
- recognizing the abnormal
- making safe progress

This pattern of principles overlaps with some published rubrics. Objective structured assessment of technical skill includes “respect for tissue.”³⁵ Surgical training and assessment tool assesses based on “knowledge” and “skill.”³⁶ Procedure-based assessment includes “exposure” and “technique.”³⁷ And the Ottawa Surgical Competency Operating Room Score uses “knowledge of procedural steps.”³⁸ But none of these rubrics fully capture the pattern of principles represented in this study. Moreover, many of the rubrics include potential procedural variations that could be both principle and preference. Objective structured assessment of technical skill, for example, includes “knowledge of instruments.”³⁵ Sorting out such ambiguity may be challenging for learners and may poorly attend to the inherent variation in surgeon-assessors’ procedural approaches.

Considering the Role of Culture

Ultimately, learners too develop their own ways of doing things. Their approaches would be built on the principles of the surgeons they have learned from and overlaid with their own preferences. Reaching this state, however, requires them to navigate an often murky line between principles and preferences as they train and interact with their clinical teachers. This process is complicated by the cultural constructs of autonomy and individuality. These constructs are deeply embedded in the surgical teaching environment and they influence how surgeons and residents speak about principles, preferences, and thresholds. Both cultural constructs may contribute to blurring the line between principles and preferences for learners, leaving learning outcomes uncertain. Although there are risks of oversimplification associated with making tacit learning explicit,^{39,40} surgeon-educators developing curricula

may wish to consider how more direct discussion about variations and thresholds could improve intraoperative teaching.

Surgical autonomy enables surgeons to prioritize safety by imposing a certain procedural variation on residents at a given moment.^{41–43} In such a circumstance, a variation that one surgeon considers a preference can become a principle for another. For example, although 2 surgeons may begin 1 step of a procedure by working down different planes, the first surgeon may insist that a resident perform the variation they prefer whereas the second may allow the resident to decide. In effect, the resident must then try to understand whether in the first instance the surgeon's direction reflected an inviolable safety principle (i.e., "choosing the right plane") or simply a personal preference around procedural sequencing.

Surgical individuality enables one surgeon to treat as a principle what another might treat as a preference.^{44,45} For example, the use of a particular type of suture at a particular stage of a particular operation may be a principle for one surgeon and a preference for another. If the surgeon insists that residents in their operating room use the suture they prefer, the resident must determine whether the apparent nonnegotiability of suture selection in this instance makes the variation a principle or rather simply an instance of a strongly held preference.

Navigating Those Norms

Surgeons themselves tread lightly around the role of evidence in distinguishing principle from preference. As expressed earlier, "even though there is very clear evidence that some of the approaches are not as effective... all I can say [to residents] is 'that would not be considered the standard of care'... [or] 'that's not really supported by the evidence,' or 'this is my preference'." "Because surgical culture relies heavily on autonomy and individuality, intra-operative critiques of variations used by fellow faculty remain oblique. Residents are left in these moments to side for themselves on the application of evidence to variations or the primacy of surgeon individuality. Research on morbidity and mortality rounds shows that more explicit attention to practice variations and evidence is expected of surgeons and residents,^{46,47} as in other specialties,⁴⁸ outside the operating room. Once inside the confines of the operating room, however, our findings suggest that residents learn to remain attuned to the role of evidence in procedural learning but only insofar as that attunement does not prevent them from enacting surgical culture's basic assumptions of autonomy and individuality.

Residents engage in a complex and largely tacit social process of finding the line between principles and individual surgeons' preferences—a process we have called "thresholding." If, as this study suggests, residents must engage in thresholding for surgeons to perceive them as competent, then learning to speak about principles and preferences in a manner that accounts for surgical autonomy and individuality has significant consequences. Given that both residents and faculty acknowledged that a dominant feature of residents' workplace learning is the navigation of thresholds, surgical education should prioritize teaching residents how to negotiate the nuanced variations they would encounter between patients, cases, and surgeons when operating.^{49–51} The findings of this study indicate that the sociocultural constructs of surgical education may complicate this work.

LIMITATIONS

Choosing to use grounded theory to explore variations allowed us to draw attention to unacknowledged concepts in surgical education research. Therefore, our grounded theory research was not designed to investigate principles in a manner that affords generalizations across surgical practice. Future research using observational, chart review, and survey-based approaches would be necessary to measure both what surgeons believe about implementing principles and how they affect patient outcomes.

IMPLICATIONS FOR FUTURE RESEARCH

Grounded theory research often creates more questions than it answers, and this study is no exception. What is at stake for learning when residents and surgeons negotiate variations intraoperatively? What are the consequences of disagreement? What role does thresholding play in intraoperative workplace-based assessment? Exploring these questions may be crucial to the successful implementation of competency-based reforms in surgical education.^{14,15}

CONCLUSIONS

Variation is ubiquitous in surgical education, and according to our participants, it is essential too. Developing an understanding of how surgical teachers and trainees understand and negotiate variations is critical in an era of increasing workplace-based education and assessment. The findings of this study confirm that surgeons endorse the use of thresholds of principle and preference to teach residents a broad catalog of procedural approaches and help them adapt to new procedural situations. In surgical education, the design of our curricula, the teaching strategies we create, and the assessment policies we implement may be improved by taking a considered look at the role of thresholds and thresholding from both sides of the operating table. Deciding whether to explicitly address thresholds or allow the process of thresholding to remain an implicit but foundational concept in surgical education would be an important next step for the profession.

Acknowledgments

The primary author (T.A.) wishes to thank the surgeons who volunteered themselves and their operating rooms for this research. This study was funded in part by a Canadian Institutes of Health Research (CIHR) MD/PhD Studentship, a CIHR Strategic Training Initiative in Health Care Technology & Place (HCTP) Doctoral Fellowship, and a Schulich School of Medicine & Dentistry Faculty Support for Research in Education Grant.

References

1. Walter A, Buller J. Variability of reported techniques for performance of the pubovaginal sling procedure. *Int Urogynecol J*. 2002; 13:160–164.
2. Kerver A, Leliveld M, Theeuwes H, Verhofstad M, Kleinrensink G. Inter-surgeon variation in skin incisions for tibial nailing in relation to the infrapatellar nerve. *Injury*. 2010; 41:131–166.
3. Bernstein M, Khu KJ. Is there too much variability in technical neurosurgery decision-making? Virtual tumour board of a challenging case. *Acta Neurochi*. 2009; 151:411–413.
4. Reames BN, Shubeck SP, Birkmeyer JD. Strategies for reducing regional variation in the use of surgery: a systematic review. *Ann Surg*. 2014; 259:616–627. [PubMed: 24240626]

5. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. *N Engl J Med*. 2013; 369:1434–1442. [PubMed: 24106936]
6. Schlomm T, Huland H, Graefen M. Improving outcome of surgical procedures is not possible without adequate quality measurement. *Eur Urol*. 2014; 65:1017–1019. [PubMed: 24332348]
7. Amalberti R, Vincent C, Auroy Y, de Saint Maurice G. Violations and migrations in health care: a framework for understanding and management. *Qual Saf Health Care*. 2006; 15(suppl 1):i66–i71. [PubMed: 17142612]
8. Posner G. “The Physician as Chameleon”: the hidden role of the resident physician. *J Obstet Gynaecol Can*. 2015; 307:301.
9. Shalhoub J, Vesey AT, Fitzgerald JE. What evidence is there for the use of workplace-based assessment in surgical training? *J Surg Educ*. 2014; 71:906–915. [PubMed: 24831439]
10. Beasley SW, McBride C, Pearson ML. Use of the operative logbook to monitor trainee progress, and evaluate operative supervision provided by accredited training posts. *Surgeon*. 2011; 9(suppl 1):S14–S15. [PubMed: 21549984]
11. Frank J, Snell LS, ten Cate O, et al. Competency-based medical education: theory to practice. *Med Teach*. 2010; 32:638–645. [PubMed: 20662574]
12. Ten Cate O. Entrustability of professional activities and competency-based training. *Med Educ*. 2005; 39:1176–1177. [PubMed: 16313574]
13. van Loon KA, Driessen EW, Teunissen PW, Scheele F. Experiences with EPAs, potential benefits and pitfalls. *Med Teach*. 2014; 36:698–702. [PubMed: 24804911]
14. Ferguson PC, Kraemer W, Nousiainen M, et al. Three-year experience with an innovative, modular competency-based curriculum for orthopaedic training. *J Bone Joint Surg*. 2013; 95(e166):161–166.
15. Sonnadara RR, Mui C, McQueen S, et al. Reflections on competency-based education and training for surgical residents. *J Surg Educ*. 2014; 71:151–158. [PubMed: 24411437]
16. Apramian T, Cristancho S, Watling C, Ott M, Lingard L. Thresholds of principle and preference: exploring procedural variation in postgraduate surgical education. *Acad Med*. 2015; 90(11):S70–S76. Available at: <http://dx.doi.org/10.1097/ACM.0000000000000909>. [PubMed: 26505105]
17. Charmaz, K. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. 2. Thousand Oaks, CA: SAGE Publications; 2014.
18. Watling CJ, Lingard L. Grounded theory in medical education research: AMEE Guide No. 70. *Med Teach*. 2012; 34:850–861. [PubMed: 22913519]
19. Kuper A, Whitehead C. The practicality of theory. *Acad Med*. 2013; 88:1594–1595. [PubMed: 24072104]
20. Tracy S. Qualitative quality: eight “big-tent” criteria for excellent qualitative research. *Qual Inq*. 2010; 16:837–851.
21. Tavakol M, Sandars J. Quantitative and qualitative methods in medical education research: AMEE Guide No 90: Part II. *Med Teach*. 2014; 36:838–848. [PubMed: 24845954]
22. Hammersley, M., Atkinson, P. *Ethnography: Principles in practice*. London: Routledge; 2007.
23. Glaser BG. The constant comparative method of qualitative analysis. *Soc Probl*. 1965; 12:436–445.
24. Glaser, BG. *Theoretical Sensitivity: Advances in the Methodology of Grounded Theory*. Mill Valley, CA: Sociology Press; 1978.
25. Strauss, A. *Qualitative Analysis for Social Scientists*. Cambridge: Cambridge University Press; 1987.
26. Cristancho SM, Vanstone M, Lingard L, LeBel ME, Ott M. When surgeons face intraoperative challenges: a naturalistic model of surgical decision making. *Am J Surg*. 2013; 205:156–162. [PubMed: 23331980]
27. Cristancho SM, Apramian T, Vanstone M, Lingard L, Ott M, Novick RJ. Understanding clinical uncertainty: what is going on when experienced surgeons are not sure what to do? *Acad Med*. 2013; 88:1–6. [PubMed: 23267212]
28. Bogdanovic J, Perry J, Guggenheim M, Manser T. Adaptive coordination in surgical teams: an interview study. *BMC Health Serv Res*. 2015; 15:128. [PubMed: 25889397]

29. Mylopoulos M, Woods NN. Having our cake and eating it too: seeking the best of both worlds in expertise research. *Med Educ*. 2009; 43:406–413. [PubMed: 19422487]
30. Klein G. Naturalistic decision making. *Hum Factors*. 2008; 50:456–460. [PubMed: 18689053]
31. Alderson D. Developing expertise in surgery. *Med Teach*. 2010; 32:830–836. [PubMed: 20854159]
32. Gélinas-Phaneuf N, Del Maestro RF. Surgical expertise in neurosurgery: integrating theory into practice. *Neurosurgery*. 2013; 73(suppl 1):S30–S38.
33. Plsek PE, Greenhalgh T. Complexity science: the challenge of complexity in health care. *Br Med J*. 2001; 323:625. [PubMed: 11557716]
34. Schraag JM. Dealing with unforeseen complexity in the OR: the role of heedful interrelating in medical teams. *Theor Issues Ergon Sci*. 2011; 12:256–272.
35. Martin J, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg*. 1997; 84:273–278. [PubMed: 9052454]
36. Roach PB, Roggin KK, Selkov G Jr, Posner MC, Silverstein JC. Continuous, data-rich appraisal of surgical trainees' operative abilities: a novel approach for measuring performance and providing feedback. *J Surg Educ*. 2009; 66:255–263. [PubMed: 20005497]
37. Marriott J, Purdie H, Crossley J, Beard JD. Evaluation of procedure-based assessment for assessing trainees' skills in the operating theatre. *Br J Surg*. 2011; 98:450–457. [PubMed: 21254025]
38. Gofton WT, Dudek NL, Wood TJ, Balaa F, Hamstra SJ. The Ottawa Surgical Competency Operating Room Evaluation (O-SCORE): a tool to assess surgical competence. *Acad Med*. 2012; 87:1401–1407. [PubMed: 22914526]
39. Eraut M. Non-formal learning and tacit knowledge in professional work. *Br J Educ Psychol*. 2000; 70:113–136. [PubMed: 10765570]
40. Lingard, L., Haber, RJ. Learning medical talk: how the apprenticeship complicates current explicit/tacit debates in genre instruction. In: Coe, R.Lingard, L., Teslenko, T., editors. *The Rhetoric and Ideology of Genre: Strategies for stability and change*. Cresskill, NJ: Hampton Press; 2002. p. 155-170.
41. Pope C. Contingency in everyday surgical work. *Sociol Health Illn*. 2002; 24:369–384.
42. Prentice R. Drilling surgeons the social lessons of embodied surgical learning. *Sci Technol Hum Val*. 2007; 32:534–553.
43. Bosk, CL. *Forgive and Remember: Managing Medical Failure*. Chicago, IL: University of Chicago Press; 2003.
44. Svensson MS, Luff P, Heath C. Embedding instruction in practice: contingency and collaboration during surgical training. *Sociol Health Illn*. 2009; 31:889–906. [PubMed: 19843272]
45. Moulton CA, Regehr G, Lingard L, Merritt C, Macrae H. Operating from the other side of the table: control dynamics and the surgeon educator. *J Am Coll Surg*. 2010; 210:79–86. [PubMed: 20123336]
46. Gore DC. National survey of surgical morbidity and mortality conferences. *Am J Surg*. 2006; 191:708–714. [PubMed: 16647366]
47. Mitchell EL, Lee DY, Arora S, et al. SBAR M&M: a feasible, reliable, and valid tool to assess the quality of, surgical morbidity and mortality conference presentations. *Am J Surg*. 2012; 203:26–31. [PubMed: 22088267]
48. Kuper A, Nedden NZ, Etchells E, Shadowitz S, Reeves S. Teaching and learning in morbidity and mortality rounds: an ethnographic study. *Med Educ*. 2010; 44:559–569. [PubMed: 20604852]
49. DaRosa DA, Zwischenberger JB, Meyerson SL, et al. A theory-based model for teaching and assessing residents in the operating room. *J Surg Educ*. 2013; 70:24–30. [PubMed: 23337666]
50. Meyerson SL, Teitelbaum EN, George BC, Schuller MC, DaRosa DA, Fryer JP. Defining the autonomy gap: when expectations do not meet reality in the operating room. *J Surg Educ*. 2014; 71:e64–e72. [PubMed: 24924583]
51. Teman NR, Gauger PG, Mullan PB, Tarpley JL, Minter RM. Entrustment of general surgery residents in the operating room: factors contributing to provision of resident autonomy. *J Am Coll Surg*. 2014; 219:778–787. [PubMed: 25158911]

TABLE

Principles: A Selection of Representative Quotes

Knowing what comes next	<p>“You had to anticipate the next maneuver. You had to be thinking one step ahead. That’s what surgery is. You shouldn’t have to stand back and think well, gee, what do I do now? It should become routine towards the end of your training.”^(S11)</p> <p>“As the resident and I do more cases together I say ‘okay, now I know his technical stuff, now I know he’s seen how I do [common procedures] a couple of times.’ The third or fourth time, I’m then assessing his or her judgement, because the technical stuff we know, my routine he knows, and now I want to see how he’s applying that. And then, as I get further along, I leave them to start or finish for a longer period of time so that they can start to do that. And I walk in and say ‘okay, what have you done?’”^(S3)</p>
Choosing the right plane	<p>“My priority is to have exposure, and to have a very clean dissection of the tissue and follow the planes perfectly. I try to avoid, as much as possible, blood in the field. For me, it seems very important to be able to see the edges of the structure, to see exactly where my instrument is going to go, and for that, I need it to be very dry.”^(S12)</p> <p>“So what I’m looking for in an operation like that is ‘do they have a perception of what we’re going to do in three dimensions in that area?’”^(S18)</p>
Handling tissue appropriately	<p>“Then the intraoperative stuff would be a lot of different things, from getting the principles and the knowledge of the procedure ahead of time and getting a basis of anatomy. Your tissue handling, how are you with the tissues. Not just the way you pick things up, but just the way you can retract things, set things up.”^(S7)</p> <p>“Tissue handling I think is very important. Finding a plane is just knowing where the anatomy differentiates to the other. Tissue handling is knowing exactly how much push, pull, tension and pressure I can place on something before it rips, and that sounds easier than it is. The same tissues for the same place in the anatomy will have very different handling properties in someone who is eighty versus someone who is twenty, someone who is malnourished versus someone who is not, [etc.].…Recognizing those, how much I can push, pull, and do without causing damage, that’s something that takes a while.”^(S5)</p>
Recognizing the abnormal	<p>Normally, it’s a nice soft tissue plane and you just slide through without having to do very much cutting at all and it separates beautifully. There, it was like somebody had poured crazy glue in and welded the two together and he knew that. He recognized that and that was the key thing for me. He picked up on the fact that, even though you think you’re okay, you cut, cut, cut; he knew you had to keep stopping and checking and eventually we would get the tear. We had to stop and he recognized at that point he shouldn’t put the device in and that’s great. He’s got a good head on his shoulders. He’s got a lot of common sense.^(S18)</p> <p>“He knows, he has common sense…Because probably some residents would say ‘just push it, just push it, just do it, I can do it.’ Maybe it will work, but maybe it wouldn’t, and he didn’t know, so he’s not going to do something if he doesn’t know is going to work.”^(S12)</p>
Making safe progress	<p>“As soon as I feel like they are deviating from the correct tissue plane, or causing too much bleeding, or taking too long then I will occasionally step in.”^(S9)</p> <p>It would be a couple of things [that...]. One, just a failure to progress, where we’re just trying to dick around and can’t figure out where to go and what to cut, what plane to be in, and really not being able to progress, or getting into the wrong planes. When we get into the wrong planes, that’s when you get into bleeding and everything else. So those would be reasons why I would go over to the other side.”^(S7)</p>