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Endoscopic Submucosal Dissection: A Cognitive Task Analysis Framework Toward Training Design

Sudeep Hegde, PhD[a,*], **Mark A. Gromski, MD**[b], **Tansel Halic, PhD**[c], **Melih Turkseven, PhD**[d], **Zhaohui Xia, PhD**[d], **Berk Çetinsaya, MS**[e], **Mandeep S. Sawhney, MD**[a], **Daniel B. Jones, MD**[a], **Suvranu De, PhD**[d], **Cullen D. Jackson, PhD**[a]

[a]Beth Israel Deaconess Medical Center, Harvard Medical School

[b]Division of Gastroenterology and Hepatology, Indiana University School of Medicine

[c]Department of Computer Science, University of Central Arkansas

[d]Rensselaer Polytechnic Institute

[e]Department of Computer Science, University of Arkansas at Little Rock

Abstract

Background: One of the major impediments to the proliferation of endoscopic submucosal dissection (ESD) training in Western countries is the lack of sufficient experts as instructors. One way to address this gap is to develop didactic systems, such as surgical simulators, to support the role of trainers. Cognitive task analysis (CTA) has been used in healthcare for the design and improvement of surgical training programs, and therefore can potentially be used for design similar systems for ESD.

Objective: The aim of the study was to apply a CTA-based approach to identify the cognitive aspects of performing ESD, and to generate qualitative insights for training.

Materials and Methods: Semi-structured interviews were designed based on the CTA framework to elicit knowledge of ESD practitioners relating to the various tasks involved in the procedure. 3 observations were conducted of expert ESD trainers either while they performed actual ESD procedures or at a training workshop. Interviews were either conducted over the phone or in person. Interview participants included 4 experts and 4 novices. The observation notes and interviews were analyzed for emergent qualitative themes and relationships.

Results: The qualitative analysis yielded thematic insights related to four main cognition-related categories: learning goals/principles, challenges/concerns, strategies, and decision-making. The specific insights under each of these categories were systematically mapped to the various tasks inherent to the ESD procedure.

[*]Corresponding author: Sudeep Hegde; sudeephegde@gmail.com, Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Boston, MA 02215.

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Conclusions: The CTA approach was applied to identify cognitive themes related to ESD procedural tasks. Insights developed based on the qualitative analysis of interviews and observations of ESD practitioners, can be used to inform the design of ESD training systems, such as virtual reality based simulators.

Keywords

Endoscopic training; Endoscopic Submucosal Dissection; Gastrointestinal Cancer; ESD; Human Factors; Cognitive Task Analysis

1. Introduction

Endoscopic submucosal dissection (ESD) is widely used in Japan and other Eastern countries, as a technique to resect pre-malignant and malignant gastrointestinal tumors. ESD is often preferred over other resection methods, such as endoscopic mucosal resection (EMR), due to a number of advantages. While in EMR, lesions larger than 20mm need to be removed in a piecemeal fashion, ESD allows for a significantly higher rate of *en bloc* resections [1, 2]. Resecting lesions *en* bloc allows for greater accuracy of detecting partial submucosal invasion during histopathological evaluation [3]. ESD is also associated with a lower tumor recurrence rate than EMR [4].

ESD involves a high degree of expertise in endoscopic control and electrocautery, and therefore requires extensive training. Studies of learning curves under supervision consistently show that it takes 30–40 supervised procedures to gain competency (measured in terms of en bloc resection rate, operating time and perforations) in ESD [5–7]. The challenge of training practitioners in ESD is further exacerbated in Western countries, where there are very few experts who could serve as mentors or instructors [8–10]. Furthermore, the occurrence of early neoplasias, which are considered to be ideal for learning ESD, occur very rarely in Western countries [11, 12].

Current training frameworks in the West include hands-on training workshops, animal model work, and when possible, observing and/or training under the few available experts. Iacopini et al. and Oyama et al. have proposed stepwise training approaches which focus on transitioning from coursework and observations of experts, to supervised practice on animal models, to complete independence in performing ESD [7, 13]. The extant literature on ESD training prescribes various principles for establishing ESD skills in trainees, including a textbook with didactic chapters by various ESD experts [7–9, 13–17]. However, research by cognitive psychologists has demonstrated that in free recall, experts are often unable to explicate the tacit underpinnings of their strategies and decision-making because of the automated and unconscious cognitive processes involved therein [18, 19]. Therefore, in designing a training system for ESD, there is a need to systematically capture and incorporate the cognitive components of learning and performing the procedure successfully.

Cognitive Task Analysis (CTA) is a framework from the Human Factors and Cognitive Systems Engineering disciplines, developed *"…for identifying cognitive skills, or mental demands, needed to perform a task proficiently. The product of the task analysis can be used to inform the design of interfaces and training systems."* [20]. CTA methods typically involve observations and interview questions designed to identify both the implicit and explicit knowledge of experts, and the cognitive processes involved in decision-making. CTA has long been used for improving design in healthcare, particularly, for surgical training [21–25]. CTA methods have been shown to capture critical details about procedural steps that are usually omitted during free recall [26]. Clark et al. showed that CTA methods helped capture information from expert trauma surgeons that was 70% more ‘complete’ than free-recall interviews [27]. CTA-based interventions have also been shown to improve technical skills training in surgery [23, 25].

The purpose of this study was to apply a CTA framework toward augmenting training design in ESD. The study aims to generate findings from the CTA, that highlight the learning needs of novices toward the development of expertise. Additionally, interview participants would span the continuum of experience from novice to expert, both as general gastrointestinal and specifically ESD surgeons. Therefore, it is expected that the CTA will yield learning needs and other cognitive insights specific to different classes of learners/practitioners, as determined by the experience levels in ESD, with and without expertise in other GI/endoscopic procedures. Finally, the study also aimed to systematically represent the findings from the CTA, so as to enable translation into practicable insights for the design of a training system, such as a surgical simulator.

Materials and Methods

Interview Development: Interview questions were developed with the aim of understanding the cognitive aspects of the ESD procedure, such as the aims and objectives, challenges, skills, techniques, strategies, and decisions involved. The questions were organized in the order of tasks performed during ESD. This task-structure was available as a result of a hierarchical task analysis (HTA) of ESD produced by a previous study [28]. The HTA breaks down the ESD procedure into a sequence of stages from preparation to retrieval of the lesion and sending it for histopathology. Each stage is further described as a list of tasks and sub-tasks. The HTA served as a rubric for systematically developing the CTA questions for each task and sub-task level. Questions were also designed to learn about gaining competency, e.g. “which skill or technique takes the longest to learn”; and to elicit differences in skills and knowledge between practitioners with different levels of experience in both gastrointestinal procedures, as well as ESD itself, e.g. “which GI skills are transferrable to ESD and which ones are unique to ESD and need to be learnt?”, and “what are some of the nuances of technique you use as an expert, that a novice would be unfamiliar with?”. The interviews were semi-structured in that the interviewer would start with a broad question (e.g. “what are the specific challenges in avoiding a perforation?”), and ensuing questions flowed based on the response, to clarify, or deepen the interviewer’s understanding, or to relate to a previous response or issue (e.g. “please elaborate on your strategy to overcome visual barriers in avoiding perforation”). Further question-probes are used to help the respondent unravel the tacit parts of their cognitive processes, such as automated responses and intuitive decisions (e.g. “other than seeing the muscularis, what visual or non-visual cues let you know that your dissection plane is lower than optimal?”). Exemplar questions from the interviews for each stage of ESD are provided in Figure 1. Interviews were conducted either in person or over the phone. Some of the in-person interviews were conducted during observations of procedures.

Data were recorded through handwritten notes and audio-recording, and later transcribed into text for analysis. Observations were conducted for a total of 29 hours. Phone or in-person interviews were conducted for a total of about 8 hours. The study was approved by the institutional review board (IRB) under the expedited review protocol at Beth Israel Deaconess Medical Center (BIDMC). All participants were briefed on the study objectives and protocol and their consent for participation was obtained.

Participants:

In order to gain diverse perspectives of practitioners with varying experience levels, interviews were conducted of participants ranging from novice level to super-experts. Participants, who were in or completed ESD-focused fellowships within 6 months prior to the interview, were considered as novices. Participants, who had been regularly performing ESDs independently for more than 6 months at the time of the interview, were considered as experts. The expert group included surgeons who had been regularly performing and teaching ESD for several years, and were nationally and internationally recognized for their expertise in ESD – members of this subset were considered as ‘super-experts’.

Analysis:

A content analysis of the qualitative data from the interviews and observations was conducted, primarily by a single researcher (SH) who has substantial experience in qualitative data analysis methods. The analysis was done using the Atlas.ti qualitative analysis software [29]. The data was initially reviewed to identify high-level thematic categories. Based on the initial review, four high-level categories were identified: learning goals/principles/criteria, challenges/concerns/barriers, strategies, and decision-making. This was followed by a deeper content analysis of the data to identify themes related to the cognitive aspects of ESD-tasks. These themes were identified and organized within the four high-level categories, for each task-step of the ESD procedure.

As cognitive and motor skills tend to vary depending on experience, a separate analytic framework was developed to delineate competencies between different experience-levels. Three broad categories of experience were identified as combinations of GI and ESD experience: GI-novice/ESD-novice, GI-expert/ESD-novice, and GI-expert/ESD-expert. For the purpose of classification, participants who fit the ‘novice’ category were those who were currently in or just completed (less than 6 months ago) fellowship programs, or those who explicitly identified themselves as novices, i.e. either in ESD or GI procedures in general. Competencies were defined based on the participants’ responses, i.e., depending on whether a participant described a certain skill or technique to be advanced or fundamental. For instance, an expert surgeon describing nuanced techniques which were learned over years of experience, and what a novice would do instead.

The themes extracted through the content analysis, as well as the competency analysis were reviewed at multiple stages by a second researcher (CDJ). Any disagreements or ambiguities related to the interpretation of findings were listed as questions for our participants. At the end of the initial round of thematic analysis, the findings were distributed to the participants to clarify or confirm the researchers' interpretation of the data and ask any additional questions that may have come up during the analysis. Additionally, a post-analysis interview was conducted with one participant for clarification of themes.

Results

A total of 10 participants were interviewed or observed. 8 participants were interviewed either over the phone or in-person, including 4 experts and 4 novices. The observations were conducted by a single observer of 3 experts at a hands-on training workshop. One of these experts was also one of the interviewees. 1 interview-participant was highly experienced in gastrointestinal (GI) procedures, but had only done 2 ESD procedures over his career. This participant was considered a GI-expert/ESD-novice.

The interviews helped elicit descriptions of ESD procedural steps from the perspectives of the ESD practitioners themselves. Therefore, several details and nuances about ESD steps were revealed, from a cognition standpoint, which reflect how practitioners actually perform the various tasks. This also includes the experience of learning the various skills involved, and advancing from a novice stage towards expertise. For the review of findings, three participants responded with feedback, which involved confirming, modifying or correcting the researchers' interpretation, as represented in the CTA results.

Based on the analysis of the data, four broad thematic categories were identified for the various stages of the ESD procedure:

- **Learning goals:** Key skills, rules, and insights that should be part of the practitioner's awareness as they learn ESD steps and advance toward proficiency. E.g. Knowing how to choose the optimal plane of dissection, such that the resection achieves the maximum possible submucosal depth while remaining adequately above the muscularis. Themes in the Learning Goals category form the basis for strategies and decisions, and are therefore fundamental to any design criteria in terms of training.
- **Challenges & concerns:** Typical or routinely encountered difficulties and barriers to safe and effective execution of procedural tasks. These include anatomy & physiology-related barriers, such as the narrow width of the submucosal layer within which to maneuver the surgical knife; skill & competency-related challenges, such as knowing which vessels to preemptively coagulate (to avoid bleeding) and which ones to leave alone; and equipment & material-related challenges, such as the low 'holding strength' of injectates like saline, causes it to easily overflow, necessitating frequent injecting to maintain lift of the lesion-flap above the submucosa. From a cognitive task perspective, it is important to identify the key challenges at each stage, and incorporate them into the design considerations for a training system. This would allow the trainee to hone their ability to recognize and anticipate critical barriers while proceeding with ESD, and develop their decision-making and strategic adaptation accordingly.

- **Strategies:** In our analysis, 'strategies' are defined as methods, techniques, plans of action that should be employed to effectively and safely execute each step in the procedure. This includes ways to achieve the objectives for each stage of the procedure, while overcoming specific challenges and concerns. For instance, a strategy used by experts to avoid a larger number of blood vessels during dissection, is to cut as low, i.e. close to the muscularis, as possible. The basis of this strategy is that vessels are fewer and wider near the muscularis, and therefore easier to detect and coagulate, than near the mucosa, where they are more branched out, numerous and thinner, and therefore harder to see and avoid or coagulate. Execution of any strategy, of course, involves having or developing the skill to do so. Therefore, from a training-design perspective, it is important to identify, the set of strategies necessary for ESD, as well as the requisite skills to enable successful execution of the strategies.

- **Decision making:** The procedure involves a high degree of adaptation based on the dynamics of the field. Therefore, there are several decisions involved at various stages, in terms of choosing between strategies or plans of actions. E.g. To pursue circumferential resection or tunneling. Appendix 1 provides decision-making tables which describe the various decisions indicated in the Tables 1A–D. The decision-making criteria dictate the strategies to be used in the ensuing steps of the procedure. Therefore, these criteria should be considered in concert with the other thematic categories when designing the training system.

Detailed themes under each of the above categories are described and mapped to the various steps of the ESD procedure and represented in Tables 1A–D. This format allows for a sufficient representation of context for each category of cognitive insights for each stage of the procedure. That is to say, the learning goals, challenges, strategies and decisions, can be viewed and understood in relationship to each other for a given task, within the hierarchical task-structure. For instance, under the Stage 2.0 of the procedure – "Demarcate the area for dissection", one of the early tasks is to, "Identify the size and type of the lesion". One of the learning goals, apart from familiarity with classification schemes, is to be able to decide whether the lesion is suitable for ESD or not. However, the challenge is that it is difficult to make this decision until the procedure actually starts, as the deeper margins and 'pit-pattern' are not perceptible until that point. Therefore, a strategy that could be used is to better visualize the pit-pattern is to use near-focus magnification endoscopy, which would enable the surgeon to decide earlier in the procedure whether or not to proceed with ESD. The content in each cell can be much more detailed given the varying complexity of each task and sub-task. However, the key insights are represented here at a level of detail that is sufficient to guide the design of a training system. If required, and within the scope of design, more detailed description can be developed.

Themes by Experience Levels:

Participants in the study had varying levels of experience in both GI procedures and ESD itself. As a result, differences were found in learning requirements, competencies, and strategies used, based on previous experience and familiarity. Table 2 lists the competencies for each category of ESD learners/practitioners in each of the ESD steps. The table distinguishes between high competency or adeptness (green cells) and low to moderate competency (yellow cells), with description of the challenge, learning requirement, or strategy used for several steps. In general, practitioners in the novice category have low competency in almost all steps of ESD, indicating a need for basic-level training in all stages, whereas practitioners in the expert category are generally adept in all stages, requiring only advanced or highly nuanced training in certain tasks (e.g. clip-and-line traction technique).

The lone participant who was a GI-expert/ESD-novice stated that the prime skill that would be transferable from experience as endoscopic surgeons would be the control and maneuver of the endoscope. This skill would lend itself to high competency in the stages leading up to the marginal incision phase, such as locating the lesion and marking its boundaries. While surgeons may be experienced in other procedures involving resections in the colon, the key skill unique to ESD, is to operate precisely within the submucosal layer. This requires specific skill-development, including familiarizing oneself with the vasculature of the submucosa, and adapt cutting and electrocautery techniques accordingly, in order to avoid bleeding.

Discussion

Interviews and observations of ESD surgeons conducted within a CTA framework helped identify and systematically represent the cognitive processes involved in learning and performing the various procedural tasks in ESD. These mainly include learning goals, challenges/concerns, strategies, and decision involved with each stage and task of the ESD, as defined by a previous hierarchical task analysis (HTA) [28]. Capturing these insights at a fundamental level is key from a learning perspective, and consequently from a training design perspective. However, the CTA also unraveled the inherent complexity of the procedure, arising from dynamic intersections between the various categories of task variables, such as instruments, lesion type, tissue type (vascular/fibrotic etc.), technique and so on. While the aim of the CTA was not to achieve 100% replication of complexity and detail (of anatomical features, techniques, interactions etc.), it illuminated the progression of nuanced skills in the journey from novice to expertise. More importantly, the CTA identified ways in which the basic concepts and rules are *actually* instantiated in practice, considering the complexity of the procedure. For instance, when dissecting through the submucosa, a key precaution is to avoid bleeding. Knowing that blood vessels are wider and less branched at deeper levels than more superficial levels, it is advisable to keep the plane of dissection as close to the muscularis as possible. However, this increases the chance of perforating the muscularis, and also losing orientation of the knife position relative to the lesion boundaries. Therefore, a safe practice, especially for beginners, is to cut 2mm at a time, then withdrawing the scope to get a better view of the field and ensure that the dissection is proceeding in the correct direction. Incorporating such insights in guided instruction is crucial in bridging the gap between conceptual knowledge and procedural and other concrete details [31].

The CTA helped identify various tacit cognitive processes of ESD practitioners, especially of experts, including insights that are not usually explicitly taught to learners. These included nuances related to various skills and maneuvers, such as the use of subtle proprioceptive cues through the endoscope control to determine whether the knife tip has breached the submucosal boundary into the muscularis. While this may be more of a tacit cue utilized in addition to the more explicit visual cues, the participant who recalled this cue only did so upon specific probing by the interviewer about proprioceptive cues. Another tacit cue that the knife is in the optimal plane of dissection, i.e. deep in the submucosa, just above the muscularis, is the presence of thicker and fewer blood vessels (as mentioned above). Conversely, encountering thinner and more branched out vessels provides an indication that the cutting plane is not as low as it should be. Making these tacit or implicit cues explicit is helpful in translating them into teachable insights. This effect is consistent with the findings of several studies which have employed CTA in developing teaching programs for various types of surgery [19, 24].

Although the hierarchical taxonomy-like representation of the ESD procedure provides a convenient template to organize the CTA findings, the CTA also revealed that this sequence is not always strictly linear or hierarchical. The adaptive nature of the procedure implies that there is often some back-and-forth between certain steps, such as starting with partial circumferential incision, then partly through the dissection deciding to switch to a tunneling or pocket-creation approach. This needs to be kept in mind when informing the design of any didactic for ESD. That being said, however, we found that the ESD procedure, largely follows the sequence of tasks listed through the HTA [28]. Therefore, we found the level of granularity and detail in the HTA-based representation to be useful in terms of guiding the CTA questions and organizing the themes.

Participants represented a continuum of expertise, ranging from novice to super-expert. Therefore, the information presented in this paper represents the perspectives of learners at different stages of the learning curve. That said, the intermediate category of GI-expert/ESD-novice comprised just one participant. Therefore, future work should involve eliciting perspectives from additional participants in this category in order to validate findings, and address the specific learning needs of this subset of practitioners in the surgical endoscopy community. Overall, however, the study demonstrates the CTA framework’s potential to develop specific training and design insights for varying levels of skill and expertise. In other words, the framework can be used to provide adaptive training according to the trainee’s progress along the learning curve. For instance, novices may be trained to dissect with a short-tip knife (e.g. Dual knife) and a coagulating current in order to minimize the risk of perforation and bleeding; intermediate-level trainees could advance to the use of more aggressive knives, e.g. Hook knife, in tissues with low vasculature and high fibrosity, as these knives cut more efficiently, but with higher chance of causing bleeding in highly vascular tissue; and experts could practice the use of aggressive knives in a wider range of vasculature, as they are adept at avoiding/managing bleeding with less aggressive knives. This use of CTA for differential training insights for different competency levels is unique in the surgical training literature.

Future work:

The value of the findings presented in this paper can only be validated when applied to the design and development of training systems, such as simulators. Future work related to the current findings involves the design of a virtual reality based training simulator for colorectal ESD. Table 3 shows an example of translation of CTA findings to specific design insights for the simulator. A comprehensive list of insights for the various facets of a training simulator, including virtual tissue image rendering, instrument modeling, and tissue response based on instrument control, will be generated based on the CTA. The ultimate aim of the simulator would be to support the learning goals for each stage of the procedure by incorporating the cognitive aspects of each task into its design elements.

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Appendix 1 –: Decision Tables

Factors affecting knife choice:

Lesion type	**Organ wall**	**Fibrosity**	**Vascularity**	**Expertise**
Mucosal	**Thick wall**	**More**	More	**High**
Sub-mucosal	*Thin wall*	*Less*	Less	*Low*

Key: Choice of knife

Aggressive knife (E.g. Hook) - more precise, cutting, long tip

Non-aggressive knife (E.g. Dual, IT/IT2/IT-Nano) - less precise, burning, short tip

Positioning the patient - Gravity:

Useful for	**Not useful for**
Small to mid-size lesions	Too small (weight does nothing), and too large and bulky

Direction of Cut/Dissection:

Rectal	**Colonic**	**If gravity can be used to pull lesion down**
Start distal	Start proximal	Bottom first, then top and come down

Circumferential cutting or Tunneling Method:

Adequate traction + Good fluid retention	Inadequate traction / Poor fluid retention
Circumferential	Tunneling

Currents: Cut and Coag:

Vascular/ Bleeding	No-bleeding	Fibrotic
High Coag (Force coag, Swift etc.)	Blended cut (Endo-cut) - adjustable coag and cut	Dry-cut

Knife-Cut or Coag:

Artery or big vein	Small venules (narrower than knife tip)
Skeletonize using coag-graspers or forceps	Cut through - knife tip should coagulate the vessel

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Questions - General Categories:

What are the main goals and priorities at this stage?

What factors determine the choice of equipment?

What skills are involved in terms of endoscopic control, tissue manipulation, electrocautery etc.?

What are the main challenges and concerns at this stage?

What precautions or preventive measures do you use to overcome the risk?

What alternative strategies can be used?

What decisions are involved?

Exemplar Questions Specific to Various Stages of ESD:

Stage 1.0: Prepare for the Procedure

What type of knife and electrocautery setting do you start with? What factors determine this choice?

Stage 2.0: Demarcate the area for dissection:

How do you decide whether or not to proceed with ESD, based on your inspection of the lesion?

Stage 3.0: Inject solution into submucosa:

If the injectate has low holding strength, e.g. saline, what compensatory strategies do you use to maintain sufficient lift of the tissue above the knife tip?

Stage 4.0: Make the marginal incision into the area of dissection:

Does it matter where along the circumference, you make the initial incision – proximally vs. distally?

Stage 5.0: Dissect the submucosa beneath the lesion/tumor:

How do ensure that you are maintaining the optimal plane of dissection as you are cutting? What are the criteria for choosing the depth of the dissection plane?

How do you prevent or avoid bleeding in highly vascular tissue? How do you prevent perforating the muscularis when the deep margins obscured due to fibrosis of the tissue?

Stage 6.0: Remove/retrieve the lesion:

What precautions and strategies are involved in ensuring that the entire lesion is removed without any tear or damage (after the dissection is completed)?

Stage 7.0: Evaluate the lesion bed for bleeding/perforation:

What visual cues are used in recognizing potential bleeders? / How do you decide which vessels to coagulate and which ones to leave alone, in order to prevent delayed bleeding?

Stage 8.0: Send the lesion for histopathology: What are the standards for specimen preparation, and what precautions and techniques are involved in preparing the lesion specimen for histopathology?

Figure 1.

Sample CTA interview questions by stage of ESD procedure

Table 1:

A: Findings from CTA – Cognitive elements of ESD procedure, from Preparation to Demarcation stage

B: Findings from CTA – Cognitive elements for ESD procedure, from Marginal Incision to Dissection of Submucosa stage

C: Findings from CTA – Cognitive elements for ESD procedure, Dissection of Submucosa stage

D: Findings from CTA – Cognitive elements for ESD procedure, from Removal of Lesion to Sending the Lesion to Histopathology stage

	Steps of Procedure	Goals/Principles/Criteria	Challenges/Concerns/Barriers	Strategies	Decision-Making
1.0	**PREPARE FOR PROCEDURE**				
	Prepare equipment	N/A	N/A	N/A	N/A
	Ensure using the appropriate electrocautery knife tip for lesion	Consider various lesion and tissue parameters, along with anticipated operative technique	Match the instrument choice with the experience and skill of the practitioner	For beginners, it is advisable to use less aggressive knives with shorter tips, e.g. the Olympus Dual knife, in order to avoid the risk of perforation and bleeding	Choose knife according to: (i) lesion parameters, (ii) tissue parameters (fibrosis, vascularity, mucosal/sub- mucosal thickness), (iii) familiarity and comfort, (iv) skill-level
	Set appropriate CUT and COAG energy settings for electrocautery knife	Similar to above	N/A	N/A	Similar to above
	Ensure appropriate injection solution for procedure	Choosing an injectate that holds up well and maintains ‘lift’	N/A	N/A	N/A
	Position the patient	Using gravity for traction/counter-traction	Not always possible, esp if blocking patient airway	General anesthesia => can rotate the patient any which way	Depending on: a) Lesion size, b) Visibility - pooling of fluids/blood can obscure
	Insert scope and tools into natural oriface (anus)	N/A	N/A	N/A	N/A
2.0	**DEMARCATE AREA FOR DISSECTION**				
	Locate the lesion	Basic endoscopy skills; knowing to check in places where it’s easy to miss, e.g. behind folds	Scarring/yellow mucous from previous procedures/biopsy Flatness (e.g. Paris IIb) Behind Folds Turns/flexures/tortuosity (e.g. at diverticulum)	Make sure to check behind folds and around flexures	N/A
	Identify the type and size of lesion	Awareness of classification schemes, e.g. NICE, Paris Identify the lesion i) location, (ii) type, (iii) size Anticipate challenges, approach, strategies and decisions depending on above factors	Difficult to determine if lesion is fit for ESD until the procedure actually starts	If lesion size estimation is critical prior to resection, measurments may be estimated by placing an appropriate sized snare over the lesion to use as a “ruler” Measurment is generally more accurate when performed prior to submucosal lifting. Near focus or magnification endoscopy may be helpful to better characterize pit-pattern and/or vessel pattern.	To do ESD or not Size: bigger the lesion, longer the duration of procedure. Also large bulky lesions prolapse; back and forth during bowel movements leads to fibrosis

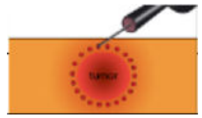
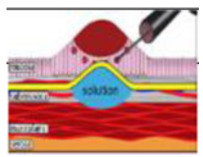
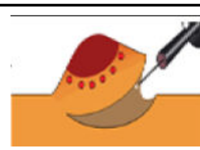
	Steps of Procedure	Goals/Principles/Criteria	Challenges/Concerns/Barriers	Strategies	Decision-Making
					Type: Smaller, flatter lesions are easiest Plan for alternate procedures
	Detect the margins of the lesion	Important to visualize and capture all margins	Boundary definition not very clear in some lesions, e.g. granular, serrated, flat, Paris2A lesions	The following could be used to better visualize the boundary of the lesion: Magnifying scope; Staining; UV light	N/A
	Mark area around lesion with dye or cautery	Keeping a 'negative margin'; ensuring margin encompasses ENTIRE lesion with some clearance Set yourself up to maintain orientation and guidance during incision	Coag current causes contracture of tissue as it shrinks and burns, so you could end up at the specimen site before you know it	Use cautery to mark dots at optimal distances to guide cutting direction (for circumferential incision), and maintaining orientation (for tunnelling) Leave sufficient margin around the lesion boundary (5mm outside boundary)	N/A
3.0	**INJECT SOLUTION INTO SUBMUCOSA**				
	Using the boundary of coag marks as a guide, inject solution into the submucosa under the lesion	Injectate should be delivered into the submucosal layer Injection should provide sufficient 'lifting' of the upper layers	Knowing that the needle tip is in the submucosa and not outside of it	Injection in the following locations: Distal, proximal, lateral 1, lateral 2	N/A
4.0	**MAKE MARGINAL INCISION INTO THE AREA OF DISSECTION**				
	Choose type of knife (i.e., type of tip) -- presumably already prepared in Step 1	N/A	N/A	N/A	N/A
	Choose setting on the electrocautery unit	Using the optimal cut-coag mix in the current setting given the tissue and lesion parameters	Mucous/fluid layer may make marking difficult. Therefore, need a relatively dry (mucous-free) surface. This can sometimes create uncertainty about appropriate coag setting to use	Soft Coag; If not sufficient because of mucous layer, use force coag; and/or extend knife tip further beyond cap. To ascertain what coag setting is needed, could test mark away from the lesion area	N/A
	Place the knife into the working channel	N/A	N/A		N/A
	Make an initial incision at one of the boundary marks by applying electrosurgical current	Setting up for dissection based on location, orientation and features of lesion, dissection technique	Anticipating potential flapping around of mucosal flap during dissection	Start at the most 'difficult' end If possible, use gravity: initial cut at bottom, then start from top so lesion begins to fall as you're coming down	Circumferential or partial incision
			Rectal ESD: fluid retention is poor in human rectum. So high chance of leakage	Pocket creation on distal (anal) side, followed by tunneling	
	Continue to make the marginal incision along the boundary marks until the incision is complete	Determining if circumferential or tunneling method is appropriate depending on fluid retention and traction Circumfrential incision: goal is to make incision about 5mm outside of the marking dots to ensure negative	Bleeding from the marginal incision can be tricky to treat. Often vessel is underneath the "lip" of the incision.	May be helpful to extend incision and/or perform some localized submucosal dissection to expose the bleeding vessel.	Circumferential or partial incision

	Steps of Procedure	Goals/Principles/Criteria	Challenges/Concerns/Barriers	Strategies	Decision-Making
		margins. (Ideally, all marking dots would be visible on the resected specimen)			
5.0	**DISSECTION SUBMUCOSA BENEATH LESION/TUMOR**				
	Inject additional solution into the submucosa to lift the lesion and expose the submucosal layer	Maintain ‘lift’ and plane of dissection	Some injectates (e.g. saline) do not have sufficient holding strength and flow out too easily. The surgeon therefore has to inject more frequently to maintain lift. However, the excessive fluid obscures the field, leading to other risks like perforation.	Inject heavily to maintain lift Use injectate that holds longer Use color (e.g. meth blue) to distinguish between submucosal (stained) and muscle (brown) layers	
	Cut the submucosa below the lesion with the knife trying to avoid perforations until lesion is completely dissected	Adapting between coag and cutting currents according to field dynamics Cutting without charring Avoiding perforation Avoiding damage to specimen Maintaining clear visualization of field Maintaining orientation of lesion boundaries through the cutting process	Bleeding Fibrosis (usually only discovered when you’re in the tunnel) Perforation Damaging the specimen Charring	Use gravity: position patient to minimize pooling and flopping of tissue Use more coag current (e.g. Swift coag) to avoid bleeding; when more cutting required, say, with fibrosis, use less cutting current (e.g. dry cut) to avoid cutting a vessel Less aggressive knife (e.g. IT) to avoid bleeds Irrigate the area to maintain visibility Find optimal plane of dissection: going down closer to muscularis, away from lesion; where there are fewer (bigger) vessels than more branched (smaller) vessels towards top Use narrow-band imaging/scope with magnification (near-focus)/dyeing when fibrosis is encountered	To start distally or proximally Choice of knife Cutting current of Coag current
		Maintaing tension/counter-traction	Losing tension/integrity/holding strength In tunneling, orientation is lost. Can’t be sure if you’re gone far enough laterally	Tunneling/pocket creation Using gravity Traction techniques (e.g. clip and suture) Use of scope for tension	Circumferential Cutting or Tunneling
		Consider tissue retraction after cutting/coagulating the area (with blended and coag settings, this is always a consideration) Predicting how tissue will retract and how lesion will look as it pulls away	Where the lumen gets narrow, there’s less space to do the dissection	Start with the narrow part (don’t save for last). Tissue pulls away (retracts) from narrow part, then work in the bigger space. Avoid putting too much air/CO2 (makes it worse)	Which part to start dissection if there is narrowing of lumen
	Perform hemostasis as needed to stop bleeding of minor vessels	Avoiding bleeds. Dealing with bleeders during the process is crucial to avoiding delayed bleeding and a key advantage of ESD Recognizing type of vessels and choosing current settings accordingly	Coag current causes contracture of tissue as it shrinks and burns, so you could end up at the specimen site before you know it	COAG: Large vessels - remove knife, use forceps or coag-graspers; Small vessels (narrower than knife tip) - use knife Identify and coagulate vessels BEFORE they bleed	Cutting current of Coag current; too much thermal energy can cause perforation Knife-cut or Coag
6.0	**REMOVE/RETRIEVE LESION**				
	Once the lesion is dissected, retrieve the lesion	Ensure specimen is removed without further damage / en bloc / all margins	Folds/turns	Roth net RAP tool	N/A

	Steps of Procedure	Goals/Principles/Criteria	Challenges/Concerns/Barriers	Strategies	Decision-Making
7.0	**EVALUATE LESION BED FOR BLEEDING/PERFORATION**				
	Perform hemostasis as needed on minor vessels to prevent post-operative bleeding	Prevent delayed bleeding	N/A	Avoid excessive thermal injury by lifting vessel with goag-grasper before cauterization Close any remaining or potential bleeders	Instrument based on size of vessel (small: hot forceps, big: coag graspers)
	If a perforation through the colon wall is detected:	Close any remaining through and through perforations	Escape of air/CO2 into peritoneal couch (necessitates venting)	N/A	To close or not to close perforation (that's not through the wall)
8.0	**SEND LESION FOR HISTOPATHOLOGY**				
	Check the lesion to ensure a complete dissection aroung the lesion boundary	Ensure all margins lateral and deep - have been captured	N/A	Inspect the resected specimen to see if all marking dots are included. If dots were not used, inspection of the specimen margin should be done, followed by measurement and photography of the specimen.	N/A
	Send the lesion to Pathology for study	N/A	N/A	N/A	N/A

Table 2:

Learner competencies for different levels of experience in GI procedures and ESD (images depicting various ESD stages adapted from Ignatov et al. (2016)[30])

Task Title		Novice	Expert
Endoscopy		GI novices are also learners of endoscopy, i.e. handling the endoscope. This is an important skill for ESD	Adept even at finer scope maneuvers and orientation within and around the submucosal level
Demarcate area for dissection			
Locating the lesion		Adept at finding lesions (colonoscopy)	Adept at finding lesions (colonoscopy)
Identifying the type and size of lesion		Not usually familiar with lesion classification schemes and how to use them for ESD decisions	Most experts use classification schemes (but in US, not all use) to decide suitability of ESD
Detecting the margins of the lesion		Skill to be perfected. Some lesions, e.g. serrated or non-granular ones are harder.	Adept. Some lesions, e.g. serrated ones are harder.
Marking area around lesion with dye or cautery		Marking precision involves high-skill in endoscope control	Marking is done with high precision-control
Inject solution into the submucosa			
Using the boundary of coag marks as a guide, inject solution into the submucosa under the lesion		Difficulty lies in getting ‘underneath’ the lesion, and precisely within the submucosal space	Adept
Make marginal incision into the area for dissection (i.e., lesion)			
Type of knife (i.e., type of tip)		Less aggressive (short tip), more versatile knife used, e.g. IT or Dual knife. Less experience with multiple knives or knowing when to switch knives	May use more aggressive knife, e.g. Hook knife, with the ability to progress quickly, while also being able to control bleeding and avoiding or dealing with perforations adeptly
Dissect the submucosa beneath the lesion/ tumor			
Detecting perforations		Only basic and explicit visual cues, i.e. seeing a hole	Experts are much more adept at using visual cues, e.g. changes in the tissue deformation can indicate whether you’re in the submucosa or muscle - very nuanced skill. Some are also sensitive to subtle propioceptive cues, i.e. detecting perforation based on increased counter-resistance in the endoscopic control

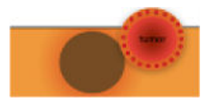
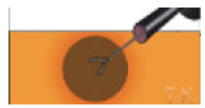
Task Title		Novice	Expert
Managing perforations		May not be comfortable with leaving any perforation open, and therefore close it as it happens	Expert may choose to leave small perforations alone if they think closing it can come in the way of dissection. Can control amount of CO_2 going in.
Perform hemostasis as needed to stop bleeding of minor vessels		Tend to cut in ways that doesn't let them see vessels, ending up with bleeds	Knows to cut in a way that allows them to see vessels and avoid bleeding
Maintaining traction as the lesion is being resected and flaps over the field		May not use traction techniques like clip-and-line. Primarily use cap and end of scope and/or gravity	May use traction techniques as necessary or experimentally
Remove/retrieve lesion		Have to learn how to capture the entire lesion with the net	Adept
Evaluate the lesion bed for bleeding and perforations			
Perform hemostasis as needed on minor vessels to prevent post-operative bleeding		Have to learn to recognize delayed bleeding - open vessels	Adept
Check the lesion to ensure a complete dissection around the lesion boundary		Have to learn to ensure that specimen is neatly and fully stretched, with all rolled edges flattened out	Adept

Table 3:

Example of translation of CTA findings for dissection task into design insight for simulator

ESD Task	CTA Findings			Design Insight
	Learning Goal	Challenge/Concern	Strategy and Decision Making	
Dissecting through tissue varying in vasculature and/or fibrosity	Adapting between coagulating and cutting currents according to tissue dynamics	Potential for excessive carbonization with coag., and perforation with cutting current	Use more coag current (e.g. Swift coag) to avoid bleeding; when more cutting required, say, with fibrosis, use less cutting current (e.g. dry cut) to avoid cutting a vessel	3 settings for the simulator using just blended current (endo-cut): 1–3 (Coag), 2–2 (cut-coag), 3–1 (Cut). Participant switches between these settings for: bleeding, normal submucosa, fibrosis, respectively