Role of digital resources in minimally invasive colorectal surgery training

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Abstract

Laparoscopic techniques have become the standard for many benign and malignant colorectal pathologies. Recently the application of robotic-assisted technologies has been, and continues to be, explored. These new technologies require different skillsets and bring novel training challenges, and today's trainees must demonstrate competence in more techniques than ever. Compounding this is the reducing time spent operating in current training programs due to caps on working hours and service pressures.

The need for adjunctive training strategies outside the operating room has prompted development of multimedia and digital resources to build the cognitive skills crucial in both non-technical and technical aspects of surgery. Many are based on principles of cognitive task analysis, breaking down operations and key decisions into nodal points to be mentally rehearsed. Resources built on this technique have shown improvements in both operative and non-operative skills, suggesting these resources can advance trainees along the learning curve in minimally-invasive surgical techniques.

More work to fully elucidate the clinical benefits of such resources is required before their role as a substitute for lost operative training hours can be established. Despite this, alongside other developing technologies such as simulation, they are a promising addition to the armamentarium of the modern-day colorectal trainee.

Keywords: *minimally-invasive, colorectal, cognitive task analysis, digital resource*

Minimally invasive colorectal surgery

Since the first laparoscopic colectomy was described in 1991,[1] the application of minimally invasive surgery (MIS) has expanded to encompass a multitude of both benign and malignant colorectal operations; it is now an accepted and indeed expected technique in many pathologies. MIS, which has grown in recent years to include not just laparoscopic surgery but robotic techniques as well, has been shown to have comparable short- and long-term survival outcomes to open surgery in both colon and rectal cancer, with the advantages of faster recovery and shorter hospital stay.[2,3,4] Despite this, uptake of minimally invasive surgery is variable both internationally, and nationally between centres.

A recent report with specific focus on barriers to MIS uptake for colorectal cancer in the United Kingdom (UK) identified issues such as poor understanding of the current literature regarding open versus minimally invasive resection, financial constraints and pressure on operating times, and inadequate training.[5] With respect to the latter, whilst there was consensus that adequate numbers of MIS training courses were offered, participants raised issues of lack of funding to attend, as well as inability to practice and utilise newly-learnt skills in units where patient throughput is insufficient. These barriers are not unique to the UK, and a similar national Canadian survey cited lack of operative time and formal training as the main barriers to adoption of the technique amongst colorectal surgeons.[6] Whilst minimally invasive colorectal surgery has been demonstrated to be feasible in developing countries,[7] as in the Western world training in the technique remains one of the biggest hurdles to its adoption.

Current training in minimally-invasive colorectal surgery

Training in minimally invasive colorectal surgery (MICS) faces several challenges, namely adequate supervised operative training time, and access to sufficient caseload. The learning curve is steep though exact estimates of required caseload are difficult, as consensus is lacking in the measurement technique. In laparoscopic cholecystectomy, a learning curve of 50 cases based on risk of bile duct injury is quoted, (risk of injury 1.7% in first 50 cases, 0.17% subsequently);[8] in MICS no equivalent outcome exists, and instead surrogates such as operative time and conversion rates are considered, though these are not entirely reflective of competence or experience, and moreover may in fact represent good judgement in some cases. With this in mind, a wide range of learning curves has been quoted for MICS, from 5-310 cases for laparoscopic, and 15-30 cases for robotic.[9] Though studies have shown no inferior outcomes in MICS between experts and expert-supervised trainees in terms of leak rate, conversion to open, R0 resection, or local recurrence rates, trainee-led operations have been shown to have a longer operative time.[10,11,12] In the current climate of pressure for theatre utilisation and targets to reduce waiting lists, particularly for cancer which forms the bulk of MICS, this can lead to lack of training opportunity to progress along the learning curve.

The Halstedian principle of ‘see one, do one, teach one’ is no longer relevant to the current landscape of surgical training, in which the apprenticeship model of surgical training has given way to shift systems, frequent rotation, and loss of firm structure. In the UK, streamlining of the pathway from newly-qualified doctor to consultant, alongside caps on hours from the European Working Time Directive, has resulted in the number of training hours prior to consultancy decreasing from around 30,000 to 6000;[13,14] similar trends have followed in the United States with Accreditation Council for Graduate Medical Education duty hour restrictions, reducing the number of clinical hours surgical trainees spend in the operating room. Furthermore, whilst laparoscopic equipment and expertise is present and standard in the majority of teaching hospitals in the Western world, this is not true of robotics, and exposure to this is at present limited largely to fellowships in a small number of programs and geographical locations.

Currently training in minimally-invasive colorectal surgery is not standardised, and a trainee's experience is highly subject to region or centre of training. In the UK, trials have demonstrated the ability of trainees to achieve MICS competence within a general surgery training program,[15] but this level of procedural experience is not uniformly replicable outside of trials and across different centres. Moreover, competence is measured by case experience, but this may not reflect proficiency, the aim as an independently practicing surgeon. The American Board of Colon and Rectal Surgery requires 50 MICS procedures for board certification;[16] studies have shown that during residency these numbers can be achieved,[17] yet subjectively almost a third of graduating residents do not feel ready to perform these procedures,[18] suggesting the experience being gained is not sufficient for proficiency.

Non-operative training in minimally-invasive colorectal surgery

In an attempt to address the limitations of, and gaps in, current minimally-invasive colorectal training, the focus in recent years has been on non-operative training adjunctive methods of building proficiency. By transporting the trainee along the learning curve prior to or alongside operating room experience, issues of lack of case throughput, reduced operative hours, and time to develop non-technical decision-making skills can be attenuated.

Much work has focussed on the role of simulation for this, ranging from basic box trainers, which build generic laparoscopic skills, to animal and cadaveric models, which offer the greatest anatomical similarity to patient operating. More recently, virtual and augmented reality simulation has evolved, and has been validated for training in certain operations.[19,20,21] Despite the many recognised benefits of simulation training, including shortened operative time, enhanced trainee confidence, and improved accuracy,[22,23] simulation has not been widely integrated into surgical curricula. Reasons for this include high financial cost of simulation equipment, lack of evidence or understanding of translational benefits, and problems with access.[24] Moreover, surgical simulators focus primarily on attainment of motor skills; increasing research is shedding light on the crucial role of non-technical and in particular cognitive skills in the attainment of operative proficiency,[25] and these are thought to be especially important during the early part of the learning curve.

Cognitive training

Traditional training in surgery has focussed on cultivation of motor skills to achieve procedural competence in terms of operative time and accuracy. Spencer *et al* reported a skilfully performed operation is 75% decision-making and 25% dexterity,[26] and multiple subsequent authors have reported the importance of cognitive skills in becoming the expert surgeon.[25,27] Whilst laparoscopic and robotic surgery may require advanced dexterity compared to some open procedures, the large burden of cognitive skill remains, and is an attractive target for training outside the operating room.

Fitts and Posner proposed a three-stage model of skill acquisition.[28] In the cognitive stage, task goals are established alongside a relevant sequence of steps required to achieve these. The associative stage involves practicing the executive programme developed in the cognitive phase and refining the steps, and the autonomous phase is characterised by automation of movements, with focus on improving speed, accuracy, and utilisation of acquired skills in novel settings. This well-recognised model highlights the importance of cognitive training, not only for development of valuable non-technical skills, but also as underpinning development of motor skills required to become a proficient surgeon. The role of cognitive skills training is well-established in other fields such as high-level sport and aviation; cognitive training has been shown to improve a variety of motor skills in sport, as well as improving overall performance via specific mental processes such as reaction and movement planning.[29] Its scientific basis is rooted in the simulation theory described by Jeannerod, in which it was proposed that covert action (imagining or mentally rehearsing the action) activates the same neural pathways as overt action (performing it).[30] This has been explored through the use of functional neuroimaging, which has confirmed that similar neural pathways are activated during cognitive training and actual task performance,[31] and that the functional plasticity that occurs in mental practice closely mimics that seen with practice of a motor skill.[32]

It has been shown that important cognitive elements are poorly delineated and transferred from experts to trainees in surgical procedures; by definition, experts practice in the autonomous phase of skill acquisition, performing routine actions intuitively. For example, a study of expert trauma surgeons teaching open cricothyrotomy to surgical residents found that on average, experts omitted 71% of clinical knowledge steps, 51% of action steps, and 73% of decision steps,[33] whilst a similar study in colonoscopy training found experts omitted 50% of the key steps and 57% of critical decisions.[34] This suggests that irrespective of the level of exposure to training cases in theatre, strategies must be employed outside of the traditional trainer-trainee apprenticeship model to address these skills, and indeed multiple studies exploring laparoscopic skills curriculum development have identified the importance of inclusion of cognitive skills training.[16,35]

Cognitive task analysis

Cognitive task analysis (CTA) is the process of generating a comprehensive breakdown of the steps and key decisions required of a task. The usual method is a series of structured interviews by a cognitive task analyst with a small number of subject matter experts, in which the experts describe the steps of a specific task and answer questions to assess their actions, critical cues, potential error identification, and cognitive decision points. Following this, the procedural steps and decision points are summated into a document to form the basis of cognitive training.[33] It has been shown to be more effective in capturing intuitive knowledge and thought processes derived from experts than standard didactic teaching alone.[36] Its role in other industries is well-established, such as the use of cognitive simulators in aviation training, which have been shown to significantly improve overall flight performance.[29] Increasingly CTA is being explored in the healthcare field, where it is effective in capturing surgical expertise.[33] CTA itself is not an educational tool, but rather provides the basis upon which educational and training resources can be developed.

In line with other industries, use of cognitive task analysis in medicine has demonstrated success in improving overall procedural ability. Following a CTA-based course, Velmahos *et al* found interns demonstrated significantly superior procedural knowledge and practical skill in central venous catheter insertion compared to the control group (traditional didactic teaching), and were more confident and required less senior input than their control counterparts.[37] Similarly, Campbell *et al* found superior procedural performance of medical students and surgical residents in open cricothyrotomy in those taught with a CTA-based curriculum rather than the standard power-point presentation technique.[38] Those in the CTA intervention group reported significantly higher self-efficacy scores than control.

Cognitive task analysis-based digital resources in surgery

With the advent of the internet, surgical education has been transported away from didactic lectures and textbook learning towards online resources and digital applications, enabling education and training anytime, anywhere, for anyone. The benefits of multimedia and digital resources in medical education have been shown,[39,40] and current generations of trainees are well versed in the use of these technologies. It is unsurprising, therefore, that the benefits of cognitive task analysis are being harnessed by technology companies and educational institutions via integration into digital resources to supplement and complement operative surgical training.

Early digital resources for surgical training consisted of computer-generated multimedia programs. Multimedia resources have been shown to significantly decrease the learning curve and increase retention when compared to traditional didactic training in other industries such as business and military, as a result of interactive engagement of multiple senses.[41] Though not always explicitly designed using what we would recognise today as CTA techniques, many follow the principles, and thus the effect of this type of cognitive training in surgery can be elucidated. As technology has advanced and interest in development of CTA for training has increased, digital resources in the form of mobile phone and tablet applications have been produced.

Computer-based

CTA resources have shown training benefits across multiple surgical procedures and disciplines. Ramshaw *et al* explored the effect of a CTA-based multimedia interactive computer-based training program covering five commonly performed laparoscopic general surgical procedures on general surgery residents.[42] The residents reported significantly improved knowledge levels and comfort in assisting in or performing each procedure, and rated the resource as more valuable than alternatives used such as text, lectures, videos, and animal labs. Though subjective, this demonstrates good acceptability as a training resource, and the finding that these benefits were universal irrespective of level of resident or prior laparoscopic experience is important in consideration of their application. Similarly, Luker *et al* found that a CTA-based multimedia resource for tendon repair improved knowledge and decision making around flexor tendon repair of plastic surgery residents, assessed objectively by expert questioning.[43] To assess the value of such resources, it is helpful to compare them to existing training techniques. A randomized controlled trial by Bhattacharyya *et al* showed improved knowledge of femoral nail procedure on a validated assessment tool following interaction with a

CTA-based multimedia tool; the CTA resource group showed greater improvement than the control group who used a standard operative training manual.[44] Importantly, some groups have demonstrated translation of the cognitive benefits of similar computer-based multimedia resources to improved surgical skill. Bhattacharyya *et al* demonstrated enhanced performance in diagnostic knee arthroscopy of orthopaedic trainees following training with a CTA interactive multimedia resource (Imperial Knee Arthroscopy Cognitive Task Analysis, IKACTA) compared to experience-matched controls.[45] Similar resources have been shown to not only be effective over controls, but superior to some traditional training methods in enhancing motor surgical skills. In a randomized controlled trial, Pape-Koehler *et al* demonstrated significant improvements in simulator performance of laparoscopic cholecystectomy following multimedia-based training over control (no training); the benefits in practical performance were superior to those offered by an equivalent period of practical training on the simulator.[46]

App-based

Building on the increasing evidence base of CTA in surgical training, technology companies and academic healthcare institutions have begun to develop mobile or tablet applications (apps). These harness the benefits of digital resources over instructor-led CTA training, which can be expensive to facilitate and geographically limiting, and address the ever-changing landscape of surgical knowledge and techniques by enabling regular updates to available content. In addition, they circumvent the requirement of some multimedia resources to be accessed within a particular institution. One of the most comprehensive and widely used such app is Touch Surgery™. This app is a CTA-based interactive mobile platform designed for the self-teaching and assessment of operative procedures across surgical specialties. Each procedure is divided into sequential key steps and surgical decisions which the user works through via touch-screen interaction. Assessment of learning is then available, with the facility to repeat this to improve accuracy. Touch Surgery (TS) has been validated and identified as a useful tool in improving surgical performance by several groups across multiple surgical disciplines. In orthopaedics and plastic surgery, the TS modules for intramedullary femoral nailing and carpal tunnel release, respectively, have shown face, content, and construct validity.[47,48] In general surgery, Kowalewski *et al* validated the Touch Surgery laparoscopic cholecystectomy modules amongst both medical students and general surgeons.[49] Importantly this has been shown at randomized controlled trial to correspond to improved technical performance over the control group (provided with written procedural information rather than Touch Surgery modules) on a cadaveric porcine laparoscopic cholecystectomy model.[50] That the information provided to the control group included an itemised breakdown of operative steps covering the same content as the TS modules (and hence was also CTA-based) suggests that there is an additional benefit conferred by TS and similar interactive platforms over the CTA principle alone. Similar observations of benefits over traditional formats of learning have been made in other modules of TS, such as carpel tunnel release.[51]

In recent years, iLappSurgery Foundation has released apps for several general surgical procedures and subspecialties which harness CTA principles combined with relevant literature and events, providing valuable educational adjuncts for surgeons that are free to download and globally accessible. Each app is structured around three main themes: firstly, it contains a wealth of practical course content including three-dimensional animations, medical illustrations, and teaching videos with real-time voiceovers to highlight key steps, identify correct planes, and emphasize critical landmarks for the procedure. Secondly, the app contains a publication and video library. Finally, it directs users to relevant educational events, conferences and workshops. One such app from iLappSurgery is the 'taTME app' (transanal total mesorectal excision), the value and accessibility of which is reflected with its high download numbers and reported app engagement. [52]

CTA digital resources in minimally-invasive colorectal surgery

In response to the recognised difficulties in training for complex minimally invasive colorectal techniques within the constraints of general surgery training programs, the role of CTA in colorectal surgery is starting to be explored. Shariff *et al* designed and validated a CTA-based multimedia educational tool for laparoscopic anterior resection, an index colorectal operation.[53] They found non-inferiority in test scores relating to anterior resection surgery when compared to a control group (study day of didactic lectures covering the same material). The finding that the intervention group did not outperform the control is at odds with previously discussed studies showing superiority of digital CTA resources over conventional learning resources. This may be explained by the relative freedom of participants in the intervention group, who had unsupervised access to the online resource for 30 days and no absolute requirement to use it, unlike those in the control group who had to attend study day lectures. In addition, the resource lacked interactive elements, and thus any independent additional benefit from interactivity above that conferred by CTA, which have been suggested in studies using interactive resources such as Touch Surgery, would not have been present. Nevertheless, this study suggests at least equivalence of the multimedia resource compared with didactic teaching, and overcomes some of the issues of accessibility and time constraints.

Crawshaw *et al* evaluated the effect of a CTA-based training video in laparoscopic right hemicolectomy on surgical performance in US general surgery residents.[23] Both the randomly-assigned video, and the control (residents' usual pre-operative preparation) groups, were scored on performance in an attending-supervised laparoscopic right hemicolectomy by blinded expert assessors. Residents in the video group scored significantly higher than controls in total global assessment scores, as well as in secondary measures of individual key procedural steps including vascular control and mobilization.

Extrapolating from studies in other procedures and surgical disciplines, ongoing development of CTA-driven digital resources for minimally invasive colorectal surgery is likely to produce a bank of training tools which could complement current training and compensate for reduction in operative opportunities in today's surgical training landscape. With increasing transparency and scrutiny of outcomes alongside reduced operative training opportunities, additional training tools will become increasingly a part of the repertoire for general surgical and colorectal trainees. Cognitive task analysis-based resources appear to provide cognitive training which translates to improved motor surgical ability. Importantly this has been shown to be beneficial across a multitude of training grades, from medical student to senior resident and fellow, when much of the practical experience in minimally invasive colorectal surgery is likely to be obtained. The benefits of CTA-based resources are retained when the modality is switched from instructor-led to self-directed digital, which overcomes issues of both trainer and trainee time out of the work place, and geographical limitations on courses.

The process of CTA is very time-consuming, and capturing one hour of focussed expertise requires approximately 30 hours of effort from a dedicated CTA designer;[34] the development of digital resources which can be shared across institutions and countries minimises duplications of work by multiple institutions, and is a benefit of the digital medium. In addition, the geographical reach of mobile digital resources, particularly those free-of-charge such as Touch Surgery, is global, and can address the issue of inadequate training opportunities that have been identified in developed and developing countries alike for minimally-invasive colorectal surgery. Of note, digital modalities which harness interactive elements may confer advantages above those of CTA alone.

Despite this promising trajectory, development of CTA-based digital resources to aid minimal access colorectal surgery training is in its infancy, and large-scale, randomised controlled trials to not only validate but establish clear benefit in improving operative cognitive and motor performance of new resources will be required before they are accepted as a substitute for lost operative hours. That said, the untethered, freely available nature of some of these resources means that trainees do not have to wait for their institutions or training programs to invest in this technology, and this has been borne out by the great numbers of subscribers to apps such as Touch Surgery. This is an advantage over other training adjuncts such as simulation, the access to which is far more dependent on robustly proven benefit and institutional financial considerations.

Other digital resources in colorectal surgery

The focus on cognitive task analysis in surgical training was largely triggered by its success in other industries with similar requirements for performance of complex procedural tasks, such as music, sport, and aviation. Prior to this however, surgeons have for many years recognised the utility of operative videos to complement surgical textbooks in preparing for surgical procedures. The utility and reach of surgical teaching videos rapidly expanded in the late nineties with the advent of the internet, and since then surgical videos have become the subjects of large, internationally-run websites and virtual surgical communities. These offer not only operative recordings but also step-by-step clips, online forums for exchanging ideas, and access to live-linked sessions with experts in different fields.

One of the first and most subscribed of these is WeBSurg, a virtual surgical university dedicated to post-graduate education in minimally-invasive surgery, supported by the IRCAD training center. It is continuously updated, and includes information on multiple new topics per month disseminated via operative videos, experts' review, conferences, and new surgical chapters.[54] Though not explicitly underpinned by cognitive task analysis principles, subscribers can access written, diagrammatic and video information on operating room setup, laparoscopic equipment, and a stepwise description of operative procedures. The value of such online digital resources for laparoscopic training is primarily the large volume of up-to-date information; the fact that WeBSurg complies with strict ethical principles and guidelines from the Health on the Net Foundation code and receives accreditation by numerous prestigious scientific societies renders it a highly respected and reliable resource. Unlike training tools designed to improve specific skills, as is often the case with surgical skills apps and simulation, data quantifying the beneficial effects of WeBSurg are lacking and would be difficult to obtain. However, its perceived utility in minimal access surgery training can perhaps be inferred from its large number of subscribers, peaked around the age demographic likely to represent its target audience of senior trainees and practicing consultant surgeons, as well as accredited continuing medical education (CME) training obtainable via WeBSurg's virtual university.

New, similar online digital resources for surgical learning are emerging, and as with WeBSurg, their global reach is growing as internet access across all parts of the world increases. One such resource is the Advances In Surgery (AIS) Channel. This online platform for surgical learning, covering both open and minimally invasive techniques across multiple surgical specialties, was created to share advances in cutting-edge surgical expertise with current working professionals in the scientific community, and those of the future. AIS offers access to a combination of live and recorded surgical videos, forums with experts, and journal publications, alongside courses and congresses. Content is free and available on any internet-enabled device. As with WeBSurg, quantification of its benefits in specific surgical skill development are impossible, yet like WeBSurg and other similar platforms it undoubtedly represents a hugely valuable resource, reflected by its reputation and subscribership.

Limitations and future directives

Advances in technology undoubtedly bring opportunities for new tools for training in the surgical world. A challenge in developing training resources in colorectal surgery however is the rapidly changing landscape of techniques and skills required for colorectal surgeons. To prepare for practice future trainees will be required to learn a range of techniques including open, laparoscopic, robotic, and natural orifice modalities. Resources discussed in this chapter are used outside the operating room and thus the transferability of skills to real patient operating requires further clarification. Moreover, current resources, and the literature validating these, is largely focussed on laparoscopic techniques, with little available to assist with robotic training. If the role of robotics in colorectal surgery continues to expand, and we are to learn lessons and avoid the morbidity seen during the learning curve of early laparoscopic procedures such as laparoscopic cholecystectomy, today's trainees urgently require training resources in robotic surgery. These are not currently available and merit development; need for non-operative training adjuncts may be even more pronounced for robotic surgery than laparoscopic, as pressures for shorter operative times, and centralisation of robotic services, continue to limit operative training experience further.

Conclusion

The current and future landscapes of colorectal surgery warrant development of tools to address the reduced on-the-job procedural training opportunities, particularly in minimally-invasive surgery. Digital resources, with their broad accessibility and interactivity, represent a promising training adjunct to operative practice. Non-motor skills are increasingly being recognised as crucial to the development of surgical proficiency, and digital resources designed to train in cognitive aspects of surgery have shown benefits both on non-operative parameters, such as knowledge and decision-making, and on motor skills in surgery. With the advent of robotic surgery comes a new skillset to be developed by trainee surgeons and consultants alike, and generation of training tools to complement hands-on training in this technique is required. Whilst no substitute for *in vivo* surgical practice, digital resources are becoming an increasingly valuable tool in the trainee general surgeon's armamentarium.

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