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# Recent Advances in Minimal Access Surgery-3

## Robotic & Innovative Technologies

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CHAPTER 2

# Robotic Surgery: Training and Assessment

*Matthew Boal, Nader Francis*

## INTRODUCTION

Over the past three decades, there has been a rapid uptake of minimally invasive surgery (MIS), laparoscopic and robotic techniques, across different specialties. Robotic surgery is a well-established modality; since the introduction of da Vinci robotic surgical system in 2000 and has since been used in more than 8.5 million procedures, 1.25 million of which were in 2020.[1] Initially, it was developed and introduced to cardiac surgery, subsequently it was adopted in many subspecialties and nowadays urology is the specialty to truly adopt it as minimally invasive technique.[2]

Perceived advantages of robotic surgery include ergonomics for the surgeon, improved depth of field vision with 3D visualization of the operative field, increased stabilization, and dexterity with instruments.[3]

There is evidence showing improved ergonomics with robotics versus laparoscopic and open, predominantly by improving posture[4] as well as arm and shoulder positions. One study using validated tools showed better scores for postural analysis in robotics versus laparoscopy.[5] Surgeons reported pain in pelvic surgery with 50% after laparotomy, 56% in laparoscopy, and 23% after robotics.[6] In a dry study, ergonomics and performance improved, as well as reduced mental stress/cognitive load in surgical novices when comparing robotic to laparoscopic tasks.[7]

When comparing 2D versus 3D in MIS, some early small studies showed reduced error rates[8] including skills-based error by 93%.[9] The European Association of Endoscopic Surgery (EAES) suggested that 3D vision reduces operative times, particularly in cases with laparoscopic suturing, as well as reduced errors in dry lab simulation.[10] The evidence in experimental labs is in favor of robotics performing better than standard laparoscopy when performing complex tasks,[4] usually suturing and knot tying tasks.

Dexterity is the ability to perform a difficult action quickly or skillfully with the hands.[11] Although there is no clinical data on the degrees of freedom to perform a task well, laparoscopy has four degrees of freedom and is backed up with clinical data as to its effectiveness. A robotic arm has an outer and inner joint so giving it six degrees of freedom, mimicking a human hand

and arm articulation. A seventh degree of freedom in a robotic arm can be considered with jaw movement. Intuitive's da Vinci system was the first laparoscopic robotic system to incorporate six degrees of freedom in 2000.[2] A study showed that the presence of wristed instrumentation, tremor abolition, and motion scaling by robotic systems enhance dexterity by nearly 50% as compared to laparoscopic surgery.[9] This may account for data suggesting a reduced learning curve for robotic technical skills when compared to laparoscopy.[12,13]

Perceived disadvantages mostly relate to lack of haptic feedback, potentially increasing the risk of iatrogenic injury, although, several new models have incorporated automated haptic feedback.[14] Cost-effectiveness is a concern in robotic surgery, many American studies comparing the cost of robotic-assisted to laparoscopic surgery showed it is more expensive, with longer operating times.[2]

It is hypothesized with the enhancement of technology that this will lead to reduced error, improved patient outcome through reduced complications and length of stay, along with increased annual throughput with improved portability of newer systems; this will offset the cost of training and purchase.[2]

As we progress in healthcare, we must expect to have increased expenditure in pharmaceuticals and medical devices, in order to remain at the forefront of surgical technology whilst maintaining competency, given the increasing public and professional scrutiny of surgical performance and patient safety.

## IMPORTANCE OF TRAINING AND VALIDATED CURRICULA IN ROBOTIC SURGERY

### Error in Surgery and Robotics

With an increasing use of robotic systems across different specialties, there is an ongoing call for standardization of training, assessment, testing and credentialing.[15] A study from the USA reported 10,624 adverse events relating to robotic procedures between 2000 and 2013.[16] Experts raised concerns over surgical curricula being random and insufficient to ensure patient safety,[17] leading to the development of EAU Robotic Urology Section Curriculum (ERUS). In addition, an independent review by the Emergency Care Research Institute (ECRI) on health technology hazards identified a lack of robotic surgical training as one of the top 10 risks to patients.[18,19] Comparisons are frequently made between the aviation industry and surgery in terms of adverse event analysis and nontechnical skills. The aviation industry, however, has mandatory, recurrent, reassessment, and requalification throughout the career pathway and an internationally agreed standard for training, which robotic surgery does not.[19,20]

Describing the "Swiss Cheese Effect" Reason in 2000 identified errors in health care with a systems-based approach rather than individual blame. Reason highlighted four main areas to reduce human error and improve patient safety.[19,21]

1. Policy writing and training
2. Standardization and simplification
3. Automation
4. Improvement of devices and architecture.

In robotic surgery, these processes described earlier are being addressed but still need more research and development.

Work is needed still to develop and validate curricula to globally standardize training and certification of robotic surgery within each specialty,[22] however, accepting that there will geographical and financial differences in the ability to provide certain elements, e.g., cadavers, dual console training. Considering these limitations, we must explore alternative ways to improve training and accessibility for all.

## Robotic Training Curricula

A proposed framework for development of curricula in any branch of medicine for learning a technical skill, five steps are recommended:[23]

1. Knowledge-based learning
2. Deconstruction of the procedures into component tasks
3. Training in a skills laboratory environment
4. Demonstration of transfer of skills to the real environment
5. Assessment of competency to enable granting of privileges for independent practice.

Initial curricula introduced include fundamentals of robotic surgery (FRS), fundamentals skills of robotic surgery (FSRS) and urology have introduced the first validated specialty curriculum, EAU Robotic Urology Section Curriculum (ERUS),[22,24] from which British Association of Urological Surgeons (BAUS) based their curriculum.[25] Other curricula exist now within specialties including thoracics,[26] gynecology[27] and general surgery, but none have been standardized.

In 2020, the Orsi Consensus Meeting on European Robotic Training (OCERT)[28], had 36 international experts identify and agree on 23 key statements, based on three themes:

- Training Standardization pathways
- Validation metrics i.e. objective assessment
- Implementation prerequisites and certification.

Other key aspects included accreditation should be awarded by the relevant professional societies and/or universities.

Fundamentals of Robotic Surgery and FSRS are both simulation-based. FRS has four modules spanning from pre- to postoperative, focusing on all aspects including didactic teaching, psychomotor skills, team training, and communication skills with the aim to teach generic robotic skills and cognitive modules to surgeons from any specialty. It has been validated in a recent RCT showing better performance of those trained following FRS compared to controls.[29] It also boasts a free app, taking the student through Intuitive systems training and with a validated, expert created, cognitive test at the end. This allows for one of the steps to be achieved set out by OCERT which there was 100% consensus on that "pre-course e-learning evaluation be completed to a sufficient standard (benchmarked) before attending a basic robotic skills training course". It should be noted that the FRS and e-learning is only relevant to da Vinci robotic systems, as such, similar methods will have to developed and evaluated for other robotic systems. FSRS is validated and assessed by the Robotic Skills Assessment Score tool. ERUS follows a more comprehensive model of didactic online teaching, simulation with dry, wet and live lab training including procedure-specific assessment. The next stage is a fellowship including observation, bedside assisting, dual console mentoring until independent in a procedure and certification with a theoretical and practical examination.[24,25] ERUS, similarly to FSRS, concludes simulation training with summative assessments, using GEARS and a theoretical examination.[25] There are some concerns, however, over the generalizability of ERUS across lower volume centers. The program was piloted in a higher volume center which is potentially why the desired training goals were achieved.[28]

Robotic procedure-specific sign off recommendations by BAUS differ per procedure but broadly focus on the total number of logbook cases and certain objective outcome measures, e.g., operative time, estimated blood loss, positive resection margins, and complication rate.[25] This misses an additional opportunity to analyze intraoperative skill and errors, rather, looking at patient outcomes as an indicator of competency.

## Learning Curve

The learning or proficiency gain curve is defined in surgery as the start point, the slope and then the plateau of that individual,[29] i.e., the number of procedures a surgeon needs to perform to reach a plateau in relation to specified outcomes such as operating time, conversion rates, complication and mortality.[30]

When implementing a technique or a new intervention, the learning curve must be considered and ways to shorten it effectively should be taken into account. The move to proficiency-based training, rather than traditional time-based curricula is based upon clearly defined training endpoints for the trainee. It allows an opportunity for performance review and setting new targets as they progress along the learning curve. Feedback on performance is provided and leads to enhanced skill acquisition.[31]

The definition of competency is usually based on a summative assessment and case numbers usually quoted at around 15–25 per case type. However, total case number alone is a crude tool to assess competence. A meta-analysis showed the mean number of procedures to become "expert" across various specialties was 39.[20,32] The environment in which learning is taking place must also be considered. An "institutional" learning curve was demonstrated in one study showing that case numbers to become competent were 74 when a new robotic service was set up, reducing to 25–30 once it was well established.[20,33] This shortened learning curve could be due to improved team training and supervisor knowledge. Additionally, the concept of interspecialty proctors could be used to enhance learning of generic robotic skills.[20]

One theme identified in the learning curve by ERUS, while developing the curriculum was identifying the needs of the trainees who often have exposure to minimally invasive surgery. However, there seems to be no difference in the learning curve for robotic skills in those who are laparoscopically trained with those who perform mostly open.[29,34] One study found that there was no negative impact on the learning curve of a novice with no previous laparoscopic or even open urological experience.[35]

ERUS curriculum discusses that case load alone is not enough to assess proficiency in robotic skills and procedures. The ERUS curriculum basic layout is seen in **Figure 1**.

## E-Learning

There is growing evidence supporting the effectiveness of e-learning on clinician performance and patient outcomes.[36] It can enhance access to learning including standardization and accessibility globally. It will undoubtedly help with initial knowledge acquisition and can incorporate non-technical skills key to robotic, or any, surgery.

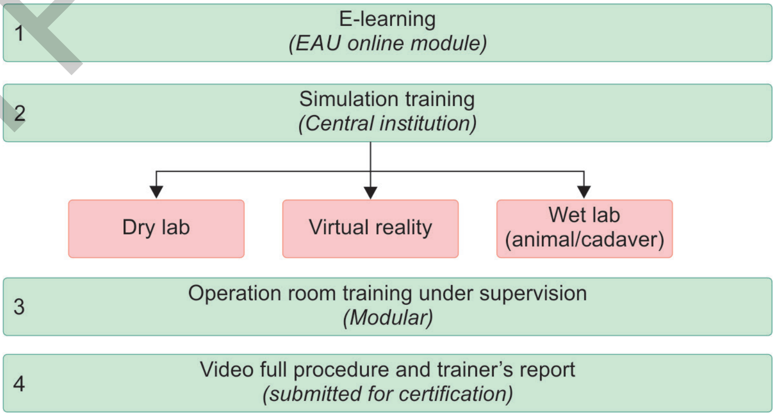


**Fig. 1:** ERUS proposed curriculum.[17]

E-learning can provide effective task demonstration; comprehensive, standardized instruction and demonstration to understand and acquire skills or procedures.[37] Normally task demonstration is unstructured through verbal feedback intraoperatively, however, this misses an opportunity pre-operatively to enhance learning through video-based tutorials.

## Simulation-based Training

Training in robotics is difficult due to the time constraints of working hours, availability, and financial constraints.[38] Simulation is, therefore, a key element to shorten the learning curve before and during observership/mentorship programs.[39] Validated virtual reality simulation platforms exist including Mimic dV-trainer, ProMIS, Sim Surgery Educational Platform (SEM) and Intuitive Systems showing construct, face and content validity[38] with level 2 and 3 evidence,[40] while the Robotic Surgical Simulator system demonstrates face and content validity.[17] There is a lack of evidence for the predictive validity of most VR simulators,[41] however, a meta-analysis in 2021 demonstrated skill and predictive validity of da Vinci Skills Simulator (dvS) and Mimic dV-Trainer.[42] Additionally, one study in laparoscopy showed improved operative performance in laparoscopic cholecystectomy after VR simulation.[43]

Simulation training in the dry and wet lab allows progression through the learning curve without compromise to patient safety and is shown to be transferable to clinical practice.[44] Although in some regions geographically there may be cost and ethical issues for wet lab use (cadaver or animal),[45] however, VR and dry lab simulation are both validated and widely available tools for training and assessment. Additionally, simulation-based training is proven to be an invaluable teaching method for non-technical skills outside of robotics in medical and aviation training. Within postgraduate medicine, it is a useful tool for clinical and performance based formative assessment[46] containing feedback sessions which are key to bridgeing knowledge gaps.

Simulation with animal, fresh frozen or Thiel embalmed cadavers are considered the highest fidelity. Live animal replicates intraoperative physiological conditions and human cadavers represent accurate anatomy.

The next step in for high fidelity, simulation training is 3D printing, with existing validated and cost-effective compared to animal and cadaver, mostly within urology.[40] Novel 3D printed models using hydrogel casting methods have created a surgical rehearsal platform and a reasonable alternative to cadaver or animal tissues. Results have shown similar mechanical and functional properties of hydrogel polyvinyl alcohol (PVA) kidneys compared to those of a live kidney.[47] In addition, objective metrics can be simulated for assessment including blood loss, tissue tension through tensiometers and tumor resection margins through UV light examination. This novel non-biohazardous simulation excludes ethical/religious issues, infection and safety risks, as well as reducing financial costs.[48]

## PROCTORING/PRECEPTORING, MENTORING, FELLOWSHIPS AND ASSESSMENT

Proctoring/preceptoring is the observation of a surgeon by a trainer during the initial phase of the proficiency gain curve, i.e., a trainee observed by someone experienced, in order to assess their knowledge and skills of the new procedure/technique. In robotics, this is the key to accreditation of surgeons but also of institutions who are proctoring, to ensure safe acquisition of skills before going on to independent practice.[49]

Mentoring is training when an experienced surgeon in a technique supervises with the intention to guide acquisition of a new skill, e.g., robotics, in the steep part of the proficiency gain curve, therefore, ideally be independent of performance review. Mentoring can point out strengths and help overcome difficulties experienced by the trainee through "tips and tricks".[49]

In the UK, the National Institute for Health and Care Excellence (NICE) in 2006 suggested laparoscopic surgery be offered to all appropriate colorectal cancer patients. However, it had to be waived initially as it was recognized only a minority of surgeons could provide training. This resulted in the National Training Programme for Laparoscopic Colorectal Surgery (LAPCO) being set up by the Department of Health, England.[20,50] The LAPCO scheme thought that 20 cases would be enough to become competent but recognized that there would be variation. This competency-based training program involved a sign off process by which surgeons in training had to submit two videos of complete, unedited, laparoscopic colorectal procedures which were independently assessed as a summative assessment using the validated competency assessment tool (CAT). Additionally, LAPCO used *global assessment scale (GAS)* forms as a formative tool to assess proficiency-gain and guide when learners are ready for summative assessment. The trainee and trainer could then monitor which areas of the operation or skill they needed to focus on and shorten the learning curve. These assessment tools showed predictive validity. This program is still to be replicated on this scale in other emerging technologies, such as robotic surgery.

Other areas for support to enhance learning include real time feedback and support through telementoring/telestration likened to air traffic controllers in the aviation industry, where a remote surgeon can be supported by a mentor through a procedure.[51,52]

The BAUS curriculum explains that a mentorship program needs to be structured for effective feedback. The mentor must enhance learning through exchange of knowledge, practical learning, and continuous feedback.[25]

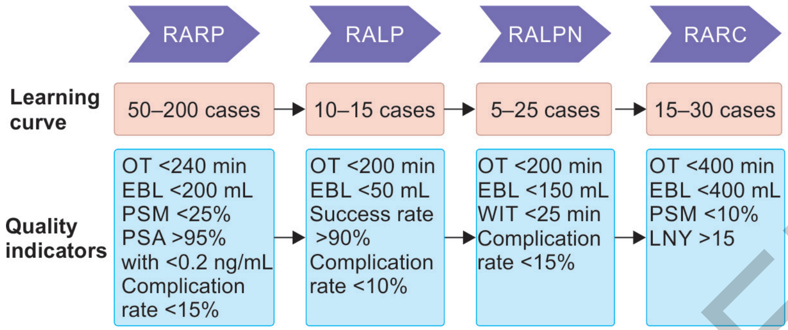


**Fig. 2:** BAUS "sign-off" recommendations based on current evidence.[25,35] (RARP: robotic-assisted radical prostatectomy; RALP: robot-assisted laparoscopic pyeloplasty; RALPN: robotic-assisted laparoscopic partial nephrectomy; RARC: robotic-assisted radical cystectomy)

This is important to note as effective feedback should be continuous, objective and validated. Currently, most objective tools for robotic surgery skills assessment are summative.

BAUS and NICE note that mentor-/fellowships need to be in high volume centers that are "off" their institutional learning curve.[25] Access to these centers needs to be considered with individual learning curves and standardizing curricula globally, taking into account that there will be geographical variation. **Figure 2** is an example from the BAUS curriculum where there is an opportunity to enhance training through validated formative assessment tools to shorten the learning curve, due to the large volume of caseload considered necessary before sign-off.

**Figure 2** shows the expected progression through these procedures, each one from left to right becoming more complex. The lower numbers indicate that once proficient in RARP they would be expected to have a shorter learning curve for the next procedures. Quality indicators seen in **Figure 2** could also have other objective measures related to patient outcome added in formative and summative assessments, including intraoperative error analysis, shown to be directly related to patient outcome in one study looking at rectal cancer surgery.[53]

Global assessment scale forms have been adopted in laparoscopic surgery which could be modified and validated for robotic surgery. Feedback to trainee surgeons could be broken down into a modular pathway **(Fig. 3)** with a CUSUM curve for each part, to highlight which areas of need are greatest, once the proficiency gain curve is at a satisfactory level, already existing summative assessment tools could be used for "sign-off" and accreditation.

## Assessment Tools

Assessment is defined as the process of collecting and evaluating information to measure progress. It is established that assessment shapes the experience

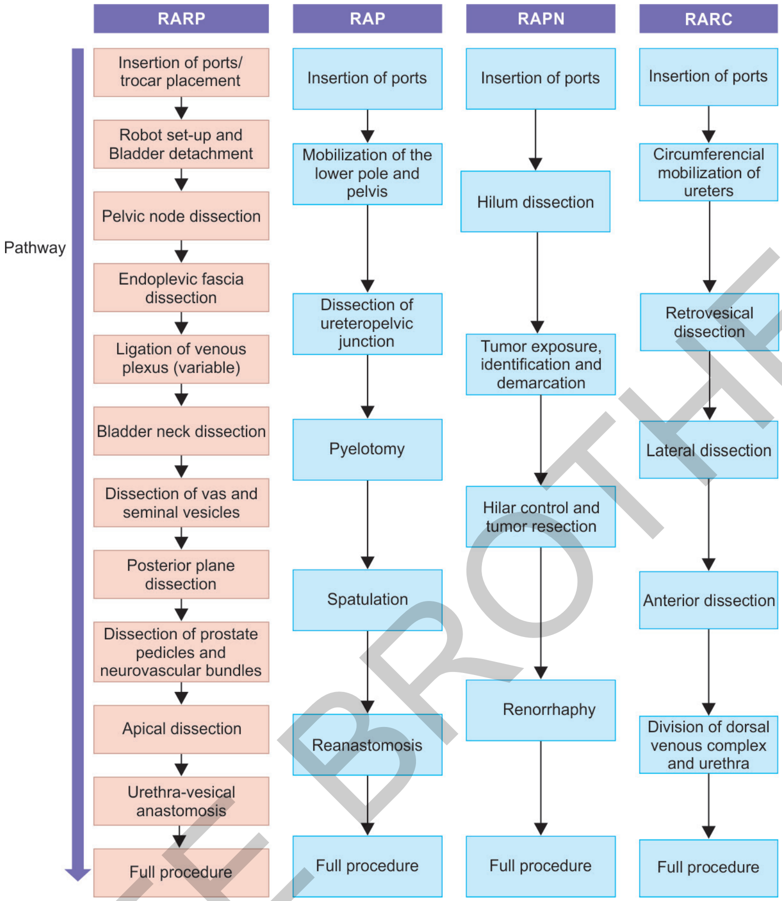


**Fig. 3:** BAUS modular pathways.[25]

of students and influences their behavior more than any other element of their education.[46] Broad categories of assessment include formative and summative.

## *Formative Assessment Tools*

Formative assessment (FA) is a tool to monitor progress and provide feedback to a student to inform training and education. In other words, it is an assessment for learning. Feedback is shown to raise student achievement; however, quality of feedback is the key.[54] Feedback needs to identify the gap in skills or knowledge, but also advise how to narrow this gap.

To assess and train surgeons to improve; validated, reliable and objective formative assessment tools should be used. Patient outcomes such as morbidity and mortality are often used to assess a surgeon's learning curve. Issues arise here as this does not provide a detailed analysis of operative areas that need improvement,[55] missing a key learning opportunity immediately after the operation.

The UK's LAPCO successfully used and validated GAS forms. These are designed as a type of formative assessment, outlining main operative steps in several procedures. They can be used to see trends and reflect on the degree of independence or competence at each step.[55,56] The main benefits of the form being that it is highly practical and reliable, allowing trainers and trainees to focus on operative steps that need improvement during feedback.

For assessment to be meaningful, therefore, a combination of regular formative assessment with summative assessment at intervals is required.

## *Global Assessment Scale Tools*

In the LAPCO national training program, the GAS forms were found to have construct validity, inter-rater reliability, and internal consistency.[50] They were an integral part of the training pathways, providing a description of individualized proficiency gain curves (CUSUM charts) in terms of the level of support from trainer to trainee required. Using a Juster scale (1–6) at each of the task steps, 5 stating competency, immediate and informative feedback can be given to enhance learning and training, i.e., which area needs the greatest work.

CUSUM charts showed there was a measurable difference between trainees and different steps of the procedure, i.e., the hepatic flexure was the most difficult and theater set up the easiest. The point of upward inflection shows the point at which the trainee scores competency **(Fig. 4)**.

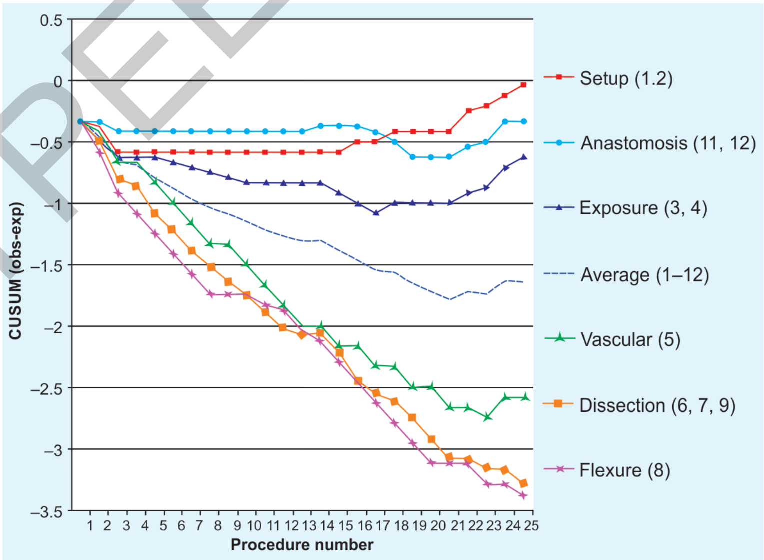


**Fig. 4:** CUSUM chart for average and specific scores.[55]

Global assessment scale forms are practical, reliable, and valid tools which can be applied to any area of surgery including robotics.

### *Robotic Summative Assessment Tools*

A summative assessment (SA) is an examination or an assessment of learning, i.e., to test a person against a standard or benchmark as to whether they are competent. SA can miss an opportunity to further aid student learning.[44] Types of summative assessment in medical training include multiple choice questions (MCQ), extended matching questions (EMQ) and objective structured clinical examinations (OSCE).

## Manual Assessment Tools in Robotic Surgery

A systematic review looked at objective assessment tools of robotic surgery technical skills, all of which are summative assessments, splits in to "manual" and "automatic" assessment. There are several validated, tools have been developed to assess generic skills, including the following:[56]

- *Global Evaluation Assessment of Robotic Skills (GEARS):* Developed from Global Operative Assessment of Laparoscopic Skills (GOALS), it can be used as a formative and summative tool for generic skills.
- *Robotic-Objective Structured Assessment of Technical Skills (R-OSATS):* Developed from OSATS for open and laparoscopic skills.
- *Assessment of Robotic Console Skills (ARCS):* Noted that GEARS did not fully assess independent console skills.

Additionally there are several procedure-specific assessment tools:

- *Observational Clinical Human Reliability Analysis (OCHRA):* It is used for error analysis can be used in conjunction with procedure-specific tools.
- *Competency Assessment Tool (CAT):* It is developed to evaluate technical surgical performance as it has concurrent validity, tested by comparing CAT scores with error analysis using OCHRA. The study developing the tool found that CAT scores were inversely proportional to OCHRA counts,[57] i.e., a better surgical skill score equated to fewer errors. The CAT can reliably assess technical performance in laparoscopic colorectal surgery, which could be adapted by other specialties. In-training GAS and CAT forms had predictive validity in surgical performance after LAPCO when assessing patient outcomes.
- Other procedure-specific tools exist within laparoscopy and robotics in different specialties, e.g., in urology PACE, RACE and CASE.

There are many different tools available and used, however, few actively outside of research and within clinical practice.

Task performance metrics assessment tools for multiple specialties have been developed through Delphi methods and validated with high inter-rater reliability when compared other tools such as GEARS. The conclusion being that they are more objective with binary answers. The tools provide a detailed step-by-step description for the operation, with definitions of errors and critical errors. These tools are promising, however, need to go undergo further evaluation including benchmarking i.e. pass/fail parameters for summative assessment or credentialing of a surgeon as competent.

In an ideal world, an agreed standardized tool would be used for formative and summative assessment, which would be modified for the skill or procedure. Using GEARS as a formative assessment for generic robotic skills and GAS tools for procedure-specific robotic skills are promising.

For summative assessment tools, again GEARS can be used as a generic tool, and CAT could be modified for robotic procedure-specific assessment in conjunction with OCHRA as video error analysis.

Currently, the shortcomings of OCHRAs are—it is manual and incredibly time consuming. The aim would be to create large, video data sets with OCHRA analysis and have machine learning with artificial intelligence to create automatic feedback after an operation to the surgeon.

### Automated Assessment Tools in Robotic Surgery

Robotic surgery can provide automatic data for assessment which in the coming years will be developed further, the aim is to have validated and reliable assessment tools which do the same as the manual assessment tools and more, only with instant results. Automated performance metrics (APMs) remove the risk of human bias and are entirely objective theoretically, improving reliability and validity.[56]

Automated performance metrics collected by the da Vinci robot include kinematic instrument tracing, system events such as camera movement, clutch use, third instrument swap and energy, finally surgical video data can be recorded for further analysis. However, they are not used by surgeons routinely or in feedback and training. Intuitive created the dVLogger, which has been likened to a black box recorder within the aviation industry. It allows recording of anonymized video and movement data recording, however, again it is not used routinely for analysis, feedback, and training.

Current APM data collected from robot systems have shown promising ability to distinguish expertise,[58] however, correlation between them and manual assessment has varied among studies.[56] Other disadvantages, currently, include making feedback meaningful from automated data and needing additional devices to record APMs, there are studies underway to analyze their relationship and further develop these tools.[59]

## ARTIFICIAL INTELLIGENCE

Further evaluation and development are needed within APMs, however, it is an exciting area of robotics particularly with the advent of artificial

# *IAGES* Recent Advances in
# Minimal Access Surgery-3

*Recent Advances in Minimal Access Surgery (RAMAS)—Vol 3* is the latest addition to the largely popular series dedicated exclusively to minimal access techniques. The recent edition of RAMAS focuses on robotic surgery and other disruptive technologies. The articles from eminent surgeons from across the globe in various fields are testimony to the fact that surgeons worldwide are steadily embracing robotic surgery for malignant as well as benign conditions.

Science is evolving, just-like humans. It is only natural that one technology gives way to better technology. Robotic surgery is what laparoscopic surgery has evolved into. Even though all the surgeries are likely to be eventually done robotically with artificial intelligence (AI) support and augmented reality in a hybrid OT one day, scientific temper asks for definite evidence for robotic assistance in surgeries. We are currently in the age of perfecting robotic techniques and gathering evidence supporting or refuting robotic assistance. To keep up with the enormous amount of evidence and rapidly changing clinical practices, RAMAS, a periodical, aims to fill up the knowledge gaps for the busy surgeon.

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