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Robotic colorectal surgery training: Portsmouth perspective

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This study aims to discuss the principles and pillars of robotic colorectal surgery training and share the training pathway at Portsmouth Hospitals University NHS Trust. A narrative review is presented to discuss all the relevant and critical steps in robotic surgical training. Robotic training requires a stepwise approach, including theoretical knowledge, case observation, simulation, dry lab, wet lab, tutored programs, proctoring (in person or telementoring), procedure-specific training, and follow-up. Portsmouth Colorectal has an established robotic training model with a safe stepwise approach that has been demonstrated through perioperative and oncological results. Robotic surgery training should enable a trainee to use the robotic platform safely and effectively, minimize errors, and enhance performance with improved outcomes. Portsmouth Colorectal has provided such a stepwise training program since 2015 and continues to promote and augment safe robotic training in its field. Safe and efficient training programs are essential to upholding the optimal standard of care.

Keywords: Robotics; Colorectal surgery; Education; Simulation training; Artificial intelligence

INTRODUCTION

The burgeoning interest in robotic surgery, driven by both users and industry, has resulted in a rapidly expanding market of surgical robotics, as evidenced by publications, media coverage, and discussions. Although fewer than 10% of operations were performed robotically globally in 2023, the surgical robots' market is projected to reach US $25.47 billion by 2030, at a compound annual growth rate of 15.4% from 2023 [1, 2].

There are currently 5 mainstream soft tissue robotic platforms, with hundreds more in various stages of development. This reflects the inevitable "robotic tsunami" that will soon sweep across surgical theatres globally and strongly impact the way we perform minimally invasive surgery. Although all robotic platforms are modelled on the same 3-component concept (patient cart, vision cart, and surgeon console), several pertinent differences exist among them, each with its own advantages and disadvantages. This will eventually require surgeons not only to learn how to use a single robotic platform, but also to be able to develop transferable skills to operate different platforms available in surgical theatres. A few centers have switched to a multiplatform approach, which may bring benefits in the critical adoption of robotics for

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tailored indications with the allocation of a certain platform to a specific procedure.

Robotic surgery was established to decrease human error by expanding the surgeon's abilities [3]. However, the safety of robotic surgery is intertwined with the skills and training of the surgeon in using the console [4]. This is even more relevant than with traditional surgery, since general knowledge about robotic mechanisms is required. Studies have shown that well-designed robotic surgery training significantly reduces errors [5]. However, formalized training programs are still under development, and there is a misconception that laparoscopic skills are easily transferable to robotic surgery. In addition, a lack of clear and standardized credentialing could increase the liability risk for surgeons performing robotic surgery [6]. Unfortunately, no dedicated curriculum or credentialing system for robotic surgery exists in most countries [7]. To date, most robotic surgery courses and certifications have been issued by industry, with potential conflicts of interest in trainee evaluation and the risk of product-centric training.

Moreover, despite the rapid expansion of robotics, the number of surgeons trained to use these platforms remains limited, with opportunities mainly open to well-established surgeons and limited access to younger trainees. This is also because robotic platforms are not widely available in all residency training hospitals and therefore cannot be incorporated into the general surgical training syllabus yet. Moreover, robotic platform training is still strongly under the control of industry with individualized, well-established, stepwise training programs including observership and proctored sessions.

Queen Alexandra Hospital under the Portsmouth Hospitals University NHS Trust (Portsmouth, UK) adopted robotics in a multispecialty manner in 2012, with outcomes indicative of proficiency. Alongside urology, colorectal surgery has evolved rapidly with interest in robotic surgery due to its benefits, particularly in deep pelvic dissection. This has extended the use of robotic surgery from general surgery to all other specialties.

Robotic training is a complex educational process that requires well-equipped centers, established educational programs, experienced proctors, and support from relevant societies and colleges. This narrative review reports the principles of robotic training, including theoretical training, case observation, simulation, dry lab, wet lab, tutored programs, proctoring (telementoring), procedure-specific training, and follow-up. Moreover, the Portsmouth Colorectal robotic training model is reported as a standardized, safe, and established approach.

PRINCIPLES OF THE ROBOTIC TRAINING PATHWAY

Robotic training consists of a multistep and multimodal pathway built on theoretical knowledge, case observation, simulation (virtual, dry, and wet lab), tutored programs (fellowships), and post-training proctoring with case follow-up and telementoring [8].

Theoretical training

Theoretical training is delivered through structured or unstructured pathways, ranging from lectures to video-based education. Whilst the former is still being developed under the guidance of educational societies and the Royal College, the hunger for content and the eagerness of surgeons to showcase their abilities and innovative techniques have flooded social media platforms with the risk of losing quality control. Nonsurgical video streaming channels (e.g., YouTube) and surgical video databases (e.g., AIS Channel, WebSurg, Touch Surgery, AMASI Lens, etc.) also provide a voluminous library of videos on robotic procedures and techniques.

Theoretical training should be structured and delivered in a stepwise manner, taking care to cover all topics comprehensively. Training should include 9 cardinal pillars (Table 1) and the principles of robotics, including a complete understanding of the robotic platform and the technology, ergonomics, camera and 3rd arm control, and procedural strategy. Every button, control, pedal, and touchscreen function should be fully understood and acknowledged by the trainee. The content of theoretical knowledge should underpin these 9 pillars, as these are fundamental for a complete and structured understanding of robotics and the development of a skillful practice. This basic robotic skills training has been coded into a Basic Surgical Skills Course named ROBO-CERT, which has been conducted by the Portsmouth Colorectal Team since 2015 and is endorsed by the Royal College of Surgeons of England. The training was compiled as a manual and organized as a course by the Association of Laparoscopic Surgeons of Great Britain and Ireland (ALSGBI), under the name of Robotic Driving License Course [9].

Case observation: live or virtual

Harji et al. [8] pointed out that prior live case observation was integrated into training pathways in 53.8% of retrieved training programs in a systematic literature review. Case observation is often performed before formal training to familiarize the trainee with the procedures; however, watching high-quality live surgery is safer and more beneficial when performed under guidance. The risk is that the observer may not recognize small but significant ac-

Table 1. Robotic training pillars with a description of each and the corresponding level of complexity

Pillar	Description	Complexity
Robotic platform modules	Knowledge of the components of the platform	Low
Robotic platform user guide	Knowledge of the complete usage of the system	Medium
Ergonomics	Full understanding of the principles of ergonomics	Low
Camera control	Strategic use of the camera to identify and follow the points of interest during surgery	Medium
Third arm control	Strategic and continuous control of the third arm use for optimization of visualization and dissection	Expert
Dissection control	Mastering the recognition of visual cues in the absence of haptic feedback	Expert
Procedural strategy	Knowledge of the surgical steps for a surgical procedure	Medium/expert
Emergency undocking	Knowledge and practice related to emergency undocking	Medium
Robotic team communication/nontechnical skills	Practice in clear and concise communication between surgeon, bedside assistants, and nursing staff	Medium

tions or may not fully weigh each action performed by the master surgeon, leading to the risk of mimicking a complex or risky surgical action without correctly weighing the risks and possible complications. This can be fully understood when observing bowel grasping by expert surgeons. It is performed skillfully by applying gentle traction on the viscera through wide gripping to avoid serosal tears or perforation. This is often not acknowledged by the trainee, and failure to use the appropriate technique may put the patient at risk even while performing simple actions. Having the surgeon provide a running commentary while performing the surgery, highlighting the key steps taken to ensure safety, or alternatively having a second consultant or trainer in the operating room explaining the steps and emphasizing how certain actions are performed can enhance the learning experience of the trainee without distracting the focus of the console surgeon.

An innovative immersive vision tool was developed to provide advanced robotic training where the trainee can follow the surgical field, the hand movements in the surgeon's console, and the intraoperative view all together in a virtual reality 360° visor [10]. The validity of this innovative tool was confirmed by a user survey with positive feedback regarding engagement for training opportunities [10].

The advent of telementoring technology may also provide further benefits for training. Teaching trainees how to evaluate visual cues as a substitute for the absence of haptic feedback is an essential and complex task.

Simulation

Hands-on robotic training starts with simulation curricula through virtual reality (VR) simulations, as well as dry and wet lab training. VR simulations are industry-provided and include the simulators from Mimic Technologies Inc, the da Vinci Skills Simulator (which is built as a "backpack" module for the surgeon console), and the Sim-Now da Vinci Si and Xi Simulators (Intuitive Surgical Inc) [8]. CMR Surgical has introduced not only the Versius Trainer Simulator, but also the Versius Trainer in Virtual Reality [11]. The former allows the trainee to complete the training at a convenient time and place without the need for the surgeon console (available only out of ours). This could potentially shorten the learning curve and help surgeons to reach proficiency faster.

Medtronic provides the Hugo task simulator (Medtronic Ltd), which turns the surgeon console into a 3-dimensional (3D) high-definition simulated environment, enabling surgeons to learn and practice with instrument and camera control, electrosurgery application, needle driving and suturing, and movement and efficiency [12].

Harji et al. [8] described published combinations of exercises adopted in training programs. The reported simulation training exercises involved combinations of non-anatomical tasks and simple surgical tasks (i.e., suturing) without any procedure-specific, task-based simulation exercises. The approach was different among training programs, with 30.7% describing a time-based approach [13–16], 23.1% using a competency-based approach [17–19], and 7.6% using a combination of both [20]. Time requirements ranged between 8 and 50 hours of simulation time, whilst the National Colon and Rectal Surgery Robotic Training Program required scores of >90% for several key exercises based on the simulator type [17, 19]. Training programs included dry and wet lab courses, with porcine wet lab training being the most adopted [8].

Dry lab

Dry lab is the next step in training. This ensures the transfer of muscle memory established during simulations into the platform. The dry lab should provide exercises in a stepwise manner ac-

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cording to the following scheme: (1) camera control and targeting; (2) use of 2 graspers; (3) articulation of the EndoWrist (Intuitive Surgical Inc; i.e., sea spike and ring and rail exercises); (4) use of the scissors (cold cut); (5) force control (i.e., holding and stacking sugar cubes one on the other without losing the hold); (6) 3rd arm control (i.e., use of a synthetic model); (7) suturing on a suture pad (single and continuous stitches); (8) use of clip appliers around vessels (i.e., on a synthetic model); (9) use of a robotic stapler (i.e., on a synthetic model); and (10) use of monopolar and bipolar energy devices (i.e., use of a synthetic model).

The Versatile Training Tissue (VTT; Kotobuki Medical Inc) is a newly developed synthetic tissue made of food-grade materials that perfectly mimics human tissue in terms of consistency, elasticity, moistness, and energy resistance. The VTT model can be used for training on electrocautery and high-frequency electrosurgical devices in specific platforms. The VTT organ models are well-designed synthetic models that can be used as intermediate training platforms for robotic surgery.

Wet lab

Generally, wet lab training can be further subclassified into animal cadaveric tissue, live animal tissue, and human cadaveric training. The use of animal cadaveric tissue is the simplest of the 3 and can easily be organized with minimal cost. For example, bovine or porcine intestines placed within a robotic endotrainer are commonly used to train surgeons to perform bowel anastomosis. Although this *ex vivo* tissue is less realistic due to being nonvascularized and more flaccid than live tissue, it is more akin to live tissue than synthetic models and is useful for exercises such as bowel and soft tissue handling, mesenteric division, suturing, and stapling.

Using live animals under anesthesia for this purpose, in contrast, is more realistic but is costly and requires a suitable lab with ventilators, monitoring devices, and veterinary anesthetists. This modality is not available in the United Kingdom due to how animal welfare and ethics committees interpret the 1876 Cruelty to Animals Act. Live animal training offers the advantage of intact blood circulation, which allows bleeding and maintains tissue perfusion, retaining its integrity and color and allowing tissue planes to be appreciated better than in cadaveric models. This set-up is specifically beneficial for tissue dissection; vascular dissection, control, and repair; and lymph node harvest, as well as for performing a complete procedure, although the anatomy is not the same as in humans. In view of ethical restrictions, innovations such as the Pulsating Organ Perfusion (Optimist Ltd) device have been created to preserve this experience while reducing animal experiments. These devices use isolated animal organs or organ complexes perfused with colored fluid by a pressure-controlled pump, enabling the simulation of hemorrhagic complications [21].

Human cadaveric training is possibly the closest to operating on live patients, with advances from age-old phenol and formalin–preserved cadavers to fresh frozen and soft cadavers, which have significantly less tissue rigidity and joint stiffness than the former. Even perfused and ventilated cadavers have been introduced to simulate breathing movements and the bleeding and pulsatility of vessels, as well as to maintain tissue color and turgor like in a real patient [22]. Albeit expensive, human cadaveric training is a complete training solution, more so with perfused cadavers, as trainees may perform a complete procedure from patient positioning and setup to dissection and anastomosis as if they were performing surgery on a real patient. Various institutions around the world provide human cadaveric training for robotic colorectal surgery, amongst which are as follows: (1) IRCAD Institute (Strasbourg, France) with 7 other IRCAD centers worldwide; (2) Newcastle Surgical Training Centre at Freeman Hospital (Newcastle upon Tyne, UK); (3) School of Global Health at King Chulalongkorn Memorial Hospital (Bangkok, Thailand); (4) Clinical Training and Evaluation Centre at University of Western Australia (Perth, WA, Australia); and (5) Silent Mentor Centre at University Malaya Medical Centre (Kuala Lumpur, Malaysia).

Tutored programs (fellowships)

Observerships and fellowships are tutored programs where the advanced trainee joins expert centers for robotic surgical training. These programs can be hands-on or hands-off and can provide the trainee with comprehensive insights into the daily busy activity of a robotic theatre and an advanced surgical team. These programs can be self-funded or provided through surgical society support (i.e., ColoRobotica Program of the European Society of Coloproctology, Royal College of Surgeons, ALSGBI as a few examples). These programs are an essential step for the trainee to establish a solid base of clinical, research, and surgical knowledge for starting a robotic surgical service in a safe and efficient way without needing to "learn on the patient". These programs should last 6 to 12 months to provide sufficient training.

Proctoring

Proctoring requires the adoption of skilled mentors with advanced experience in robotic surgery and competence in teaching and training. Despite being a critical step in robotic training, proctoring has been mostly industry-driven, with no clear indications for expert selection and training programs. Proctoring requires the availability of skilled surgeons who have mastered the robotic platform and relevant procedures and have the necessary time to travel and offer proctoring sessions. Moreover, the number of proctored per supervised cases ranges between 5 and 30, reflecting a clear lack of standardization amongst programs [8]. Finally, some training programs mandate training as bedside assistant before progressing to supervised console cases [23], which is also adopted for surgical residents through the National Colon and Rectal Surgery Robotic Training Program [19].

Proctoring is an enjoyable experience in a dual console setting. This setup allows both the trainee and the trainer to share the same 3D high-definition view of the surgical field in a safe way. Piozzi and Khan [24] discussed the benefits of a dual console setting that enables proctoring, guiding/supervising, surgical stress control, remote proctoring, and a multispecialty strategy. The dual console allows the proctor to swap the control of the robotic instruments at any time through a "give and take" and "swap all" functions. This allows the trainee to operate in a tutored fashion using 1 or 2 operating arms while the proctor has control of the camera and the 3rd arm, allowing the trainee to build up confidence and skills in the use of the EndoWrist technology in a safe way. Moreover, the dual console allows the proctor to use visual pointers to show specific anatomical structures and planes, as well as to concentrate on a specific point in a 3D way for directed training.

Teleproctoring

With advancements in robotic surgery and telecommunication technology, milestones such as "Operation Lindbergh" have proven the power of telesurgery in overcoming geographical barriers. The advancement of high-quality and stable connections through 5G technology has enabled remote *in console* proctoring without requiring the proctor to join the surgery physically and without the need for a dual console on site [25]. Besides increasing access to surgery in regions that lack expertise, these technologies also play an important role in providing training and education without borders. Teleproctoring software used for laparoscopic training [26] is currently being improvised and extrapolated for use in robotic training. Generally, these software programs are designed for trainers to teach and guide the novice surgeon by communicating via audio, video and graphical (intraoperative annotation on the surgeon's display) input, without being physically present. For such training to take place, the expertise to perform open surgery in the unfortunate event of an emergency must be readily available at the trainee's facility. Other hurdles facing this modality are connectivity issues like increased latency periods, misinterpretation of instructions, unavailability of hands-on interaction or non-verbal human cues, limitations in bi-directional audio and visual communication, and the ethical issues surrounding adequate supervision in patient care [27]. Contrary to training in laparoscopy, if the trainer has access to a compatible surgeon console connected to the patient cart of the apprentice in a different location, the proctor can take control of some or all robotic arms to assist or facilitate training or to resolve a difficulty in a surgical step [28].

Procedure-specific training

After training on the principles and basics of robotic surgery, when robotic surgery begins to be adopted in elective practice, advanced procedure-specific training programs are recommended. These courses utilize lectures, cadaveric labs, and proctoring sessions, and are essential to help the robotic novice surgeon acquire expertise in advanced robotic procedures. These programs are characterized by progression-based training where a complex procedure is broken down into a series of key steps of growing complexity [29]. This enables the mastery of each step prior to the overall completion of the procedure. These programs can be employed as a final component of robotic training for residents/fellows or as programs for established surgeons.

Robotic training competency assessment tools

The assessment of robotic surgery training needs to be comprehensive, using objective checklists that are procedure-specific and validated [30]. Several tools have been developed and validated for this purpose, each having its own advantages. Amongst the commonly used tools are the Competency-Based Assessment of Robotic Surgical Skills (CARS), Global Evaluative Assessment of Robotic Skills (GEARS), Robotic Objective Structured Assessment of Technical Skills (R-OSATS), Assessment of Robotic Console Skills (ARCS), Proficiency-Based Progression (PBP) metrics, and GRADE (Grading of Recommendations, Assessment, Development, and Evaluations). GEARS evaluates proficiency in using the platform in terms of depth control, dexterity, efficiency, force control, autonomy, and robot control [31], whereas R-OSATS and ARCS evaluate a surgeon's independent console skills [32, 33]. ARCS, in contrast, was designed to purely evaluate a surgeon's independent console skills via 6 skill domains.

CARS is a unique competency-based scoring system for general surgery residents, including 10 robotic surgery competencies: tissue dissection, tissue handling and retraction, robotic stapler use, arm exchange, camera use, intracorporeal suturing and tying, wristed articulation, port placement, docking, and intangibles such as console ergonomics and control [34]. CARS has been successfully used with a series of surgical residents in the United States [34].

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PBP is unique as it is more procedure-specific and assesses trainees as part of a modular training model, in which a procedure is broken down into key parts, with evaluations of the trainee's proficiency in each part. Progression to the next step is only allowed when a pre-set benchmark of proficiency is achieved in each step [35]. Similarly, a specialty-specific, validated, competency assessment tool for colorectal resections is used in the national training program for laparoscopic colorectal surgery in England and can be adopted for use in robotic colorectal training assessment with some adjustments [36]. The GRADE recommendation instead places a greater emphasis on operative and postoperative outcome parameters, with less weightage of trainee performance, behavior, skill, and knowledge in its assessment. With the advent of mainstream robotic platforms providing feedback to the user by extracting information from each session, training assessments can be made more objective by including these data, particularly parameters such as economy of movement and frequency of instruments being out of the visual field. Newer platforms, such as the da Vinci 5 (Intuitive Surgical Inc), even allow measurement of the amount of force applied on tissues, and this can be used to improve tissue handling skills [28]. Overall, an ideal method for a holistic assessment of robotic training would be the combined use of the abovementioned tools as they complement each other's deficiencies. This should be coupled with blinded video assessments to eliminate bias.

The MASTERY (Measuring the Quality of Surgical Care and Setting Benchmarks for Training using Intuitive Data Recorder Technology) trial (ClinicalTrials.gov identifier: NCT04647188) is a multicenter prospective cohort study involving patients undergoing robotic-assisted multispecialty surgery, where automated digital point of care data relating to the surgeons' performance are collected via the Intuitive Data Recorder device (Intuitive Surgical Inc). This study collects data on surgeon characteristics, patient characteristics, and 30-day surgical outcomes including complications, reoperation, length of stay, hospital readmission, and patient-reported outcomes. The recorder will provide objective metrics such as instrument positions and button presses, referred to as objective performance indicators, which are then correlated with the clinical outcomes [37].

The 3 steps of robotic competency assessment

Despite the presence of a few robotic centers worldwide (e.g., the IRCAD institute or Orsi academy), robotic training is heavily industry-funded and controlled. This generates a relevant conflict of interest. A 3-step approach could resolve this, including platform competency, robotic certification, and governance.

Platform competency should be industry based. Surgeons should be trained by industry instructors in well-equipped dry labs. The aim is full proficiency in the use of the platform.

Robotic certification should instead be provided by surgical societies or colleges that should work globally to introduce a shared training pathway, courses, and final certification to evaluate competency. This should be a sort of a robotic license to perform robotic surgery. This certification should be, to the extent possible, system-agnostic and multiplatform.

Governance should be provided by hospital surgical teams, including external elements from surgical societies and other experienced hospitals, to monitor the robotic surgery performance and evaluate possible weaknesses and areas for improvement. This should be performed on a regular basis for all surgeons and would require a constant prospective audit of their surgical practice.

PORTSMOUTH TRAINING PROTOCOL

To address the exponential need for robotic surgery training, educational institutions, surgical associations, and single hospitals have launched numerous different training programs without a critical and shared outline of a robotic training route.

The training pathway is characterized by all the steps previously discussed and is executed in a stepwise fashion through an established PBP setup from basic literacy to robotic expertise (Table 2).

ROBO-CERT course

The training starts with the Basic Robotic Surgical Skills course "ROBO-CERT," which is accredited by the Royal College of Surgeons of England. This course is held 6 times a year and is managed by an experienced team of expert trainers with vast clinical and training experience with various robotic platforms. This course is composed of a virtual component where the robotic platform is dissected and discussed in detail. These succinct videos describe the 3 main components of a da Vinci Surgical System (Intuitive Surgical Inc; surgeon console, vision cart, and patient cart), and cover other essential topics such as principles of port placement, docking, emergency undocking, and differences between the X and Xi systems. Participants are also familiarized with the structure of the exercises that will be performed during the hands-on component.

The second practical component is a full day of hands-on robotic training in a dedicated dry lab facility. The course is limited to 10 participants per session, with a trainer to trainee ratio of 1:2 to ensure focused training with adequate hands-on practice. At least 2 full robotic systems (one X and one Xi), and 2 to 3 simulators are made available for use during this course. The course

Table 2. Portsmouth Training Protocol: steps, modules, and objectives

Step	Module	Objective
1	ROBO-CERT course	Virtual and hands-on basic robotic surgical skills course to train participants on the components of the robotic platform, instruments, basic of navigation, and basic task delivery (EndoWrist [Intuitive Surgical Inc] manipulation, force control, use of the 3rd arm, use of the scissors, suturing, and dissection on a synthetic model for clip applicator and robotic stapler use)
2	Case observation	Case observation of high-quality robotic colorectal operations performed by expert surgeons. Training on patient positioning and setup, port placement, docking, robotic procedure, undocking, and closure
3	Bedside assistance	Assisting at the bedside, practicing patient positioning, port placement strategy, docking, exchange of robotic instruments, intraoperative assistance, and surgeon-bedside team communication
4	Robotic hands-on fellowship	Robotic total mesorectal excision modular training program for safe and efficient training (6 mo)
5	Case selection and progression	Three-tier program: (1) Low risk/complexity (groin hernia repair, small umbilical/ventral hernia repair, and cholecystectomy; ≤ 1 hr) (2) Intermediate risk/complexity (sigmoid resection for cancer/uncomplicated diverticular disease in patients with low BMI, and right hemicolectomy for early colon cancer [not CME]; avoid male pelvises, high BMI [> 30 kg/m^2], and patients with previous abdominal surgery) (3) Advanced risk/complexity (most complex cases such as procedures involving pelvic dissection (low anterior resection, abdominoperineal resection, and lateral pelvic lymphadenectomy), and CME for colon cancer)
6	Robotic immersion courses	Short 1-wk "scrub-in" robotic experiences with a 1-on-1 relationship with the trainer to gain confidence

BMI, body mass index; CME, complete mesocolic excision.

starts with a debrief of the platform, its components, and functions and then proceeds with the hands-on exercises. The tasks are organized in increasing complexity training on the EndoWrist manipulation, force control, use of the third arm, and use of the scissors. Suturing is trained on suture pads. At last, the participant practices dissection on a synthetic model to try the clip applicator and the robotic stapler with Sureform technology (Intuitive Surgical Inc). These exercises allow the participants to test all the main functions and instruments available on the platform. The final part of the course focuses on practicing soft skills, such as clear communication between the console surgeon and the bedside team. While some trainees practice on the console, the nonactive trainees take turns being at the bedside as well as the simulator to practice communication and dry lab exercises, respectively, reinforcing the muscle memory of these skills by repetition. Upon successful completion, participants are awarded certification in Basic Robotic Surgical Skills. The ROBO-CERT course has been running successfully since 2015, with over 70 surgeons per year.

Case observation

The next step in training is observation of high-quality robotic colorectal operations performed by expert surgeons at Portsmouth University Hospitals NHS Trust. The trainee is allowed access to the surgical list throughout the day and observes the entire procedure from patient positioning and setup to port placement, docking, the robotic procedure, undocking, and closure. For an immersive experience, the dual console setup provides the trainee access to a "slave console," which allows them to have the same 3D stereoscopic magnified view as the primary surgeon. If the dual console is not available, such as during multidisciplinary procedures, the trainee uses the SCOPEYE extended reality (XR) eyes-up display (MediThinQ Co Ltd). These XR headsets provide the user with an open platform showing the same 3D stereoscopic view displayed in the surgeon console without compromising peripheral vision [38].

Bedside assistance

Bedside assistance is essential for the robotic surgeon. Once familiarized with how robotic surgery is performed via case observation, the trainee progresses to be a bedside assistant. They may be accompanied by another trained bedside assistant in the initial stages. This role requires assisting the robotic surgeon at the bedside in practicing all aspects of the robotic procedure, from patient positioning to the port placement strategy, docking, exchange of robotic instruments, intraoperative assistance via assistant port (i.e., counter traction and suction), and surgeon-bed side team communication. Being a good bedside assistant before heading to the console is essential to a trainee as it helps them better understand the needs of the person at the bedside, who has access to clear auditory input from the console surgeon but is limited to two-dimensional visuals and monocular vision of the operative field. This emphasizes the need to learn how to give clear instructions. This is another area in which the SCOPEYE headsets prove advantageous to increase the quality of the assistance pro-

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vided by improving the visual input of the bedside assistant by enabling an open platform with a 3D view without blocking the view on the patient and on the instrumentation [38]. The assistant can use/change instruments, in an ergonomic way, without ever losing view of the surgical field, which is shown in 3D (Fig. 1).

Fellowship

A robotic hands-on fellowship is an essential step to consolidate and put into practice the previous robotic training. The fellowship lasts at least 6 months and is regulated by societies or surgical colleges, aiming to provide standardized and tutored training. At Portsmouth, to access a fellowship the trainee must have the following: (1) robotic simulator proficiency (completion of 50 hours of simulator training with documented evidence of performance); (2) basic robotics exposure (prior experience with basic robotic techniques in a wet lab setting); and (3) laparoscopic colorectal surgery proficiency (demonstrated through local evaluation and a comprehensive surgical logbook). A dual console setup is available in all theatres to provide shared performance between the trainee and the trainer [24]. Video assessment of the surgical performance and feedback from the trainer is provided after each procedure to ensure a safe and steady competency progress.

Robotic total mesorectal excision (TME) is considered the pillar procedure for robotic colorectal training. A robotic TME modular training program was designed in Portsmouth for safe and efficient training [29]. Portsmouth was the 1st unit in the United Kingdom to offer a designated continuous robotic TME fellowship in 2015 for 6 to 12 months each. This structured competency-based training program has been established for trainees to progress through various modules, demonstrating mastery of each before advancing to the next level. A total of 5 modules have been defined, with increasing levels of complexity: (1) Patient Positioning and Setup; (2) Anastomosis and Closure; (3) Inferior Mesenteric Vessels and Dissection; (4) Splenic Flexure Mobilization; and (5) Rectal Dissection (Table 3). The efficacy and safety of the robotic TME modular training program in Portsmouth was assessed by comparing the perioperative and oncological outcomes of robotic TME for rectal cancer performed by expert consultants versus surgical trainees. No difference was observed between the 2 groups in terms of R0 resection rate, number of harvested lymph nodes, conversion rate, and perioperative and oncological outcomes (local recurrence, distant metastasis, and 1-, 3-, and 5-year overall and disease-free survival), with only a 25-minute difference in operating time duration for the surgical trainees.

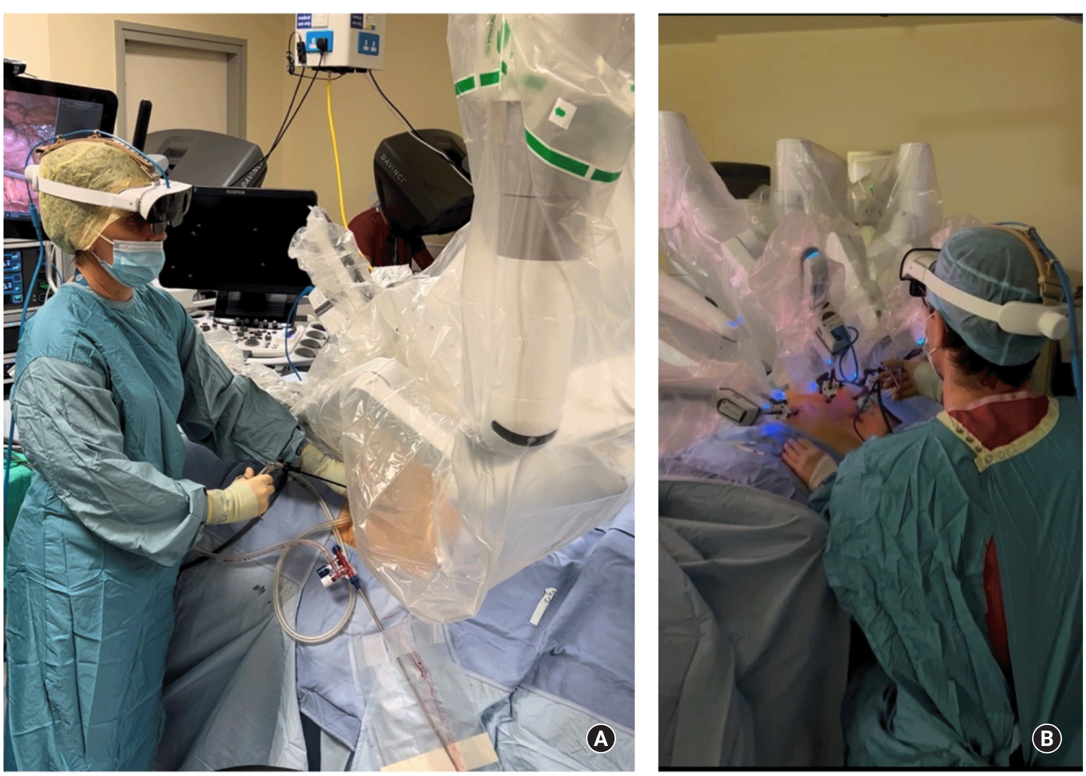

Fig. 1. Use of the SCOPEYE headset (MediThinQ Co Ltd) by the bedside assistant during (A) robotic complete mesocolic excision and (B) total mesorectal excision. The assistant can use/change instruments, in an ergonomic way, without losing view of the surgical field, which is shown in 3-dimension.

Table 3. Robotic total mesorectal excision training modules at Portsmouth Colorectal

Module	Detail
1. Patient positioning and setup	Patient and robotic cart setup
	Port placement strategy with accurate pre-incision markings
	Access, exposure, and docking techniques (modified Lloyd-Davis position)
	Port placement variations based on the robotic platform (e.g., da Vinci Si/X, Intuitive Surgical Inc)
	Patient positioning (Trendelenburg 10°, 15° right tilt)
	Bowel management (small bowel retraction, greater omentum retraction)
	Patient cart docking from the left side
	Instrument insertion under direct vision
2. Anastomosis and closure	Rectal transection using a robotic stapler (EndoWrist, Intuitive Surgical Inc) via a 12-mm trocar
	Indocyanine green fluorescence for distal rectal blood supply assessment
	Suprapubic specimen extraction
	End-to-end stapled anastomosis creation
	Anvil placement and anastomosis completion using standard techniques
3. Inferior mesenteric vessels and dissection	Dissection starting at the sacral promontory and progressing cranially
	Careful dissection alongside the IMA
	IMA division at the origin using Hem-o-Lok clips (Weck Closure Systems)
	Hypogastric nerve identification and preservation
	IMV division just below the duodenojejunal flexure
	Development of a mediolateral plane above Gerota fascia
4. Splenic flexure mobilization	Division of lateral adhesions of the left colon
	Dissection to the splenic flexure using a single-docking, infracolic, 3-step approach
	Medial dissection below the IMV
	Pancreas identification and lesser sac entry
	Pancreas tail separation from the colonic splenic flexure
	Omentum release from the transverse colon
	Full splenic flexure mobilization
5. Rectal dissection	Dissection of the posterior total mesorectal excision plane following the superior rectal artery
	Lateral and anterior extension of the dissection plane
	Distal rectal dissection out of the pelvis
	Transabdominal suture placement for improved pelvic view during dissection

IMA, inferior mesenteric artery; IMV, inferior mesenteric vein.

This modular training program shows that robotic trainees can learn to perform robotic TME safely and proficiently with a modular stepwise training program without impacting surgical and oncological outcomes and service delivery. Moreover, this program allows multiple trainees with different skills and experience to operate the same case on different modules allowing for efficient and timely service delivery for complex surgery without compromising training opportunities [29].

Case selection and progression during training program

Every surgeon undergoing robotic surgery training encounters 3 main challenges: (1) traction and tissue damage control caused by the lack of tactile feedback; (2) use of the 3rd arm; and (3) optimized use of the camera, which is different from laparoscopy. Case complexity, surgical risk, and operative duration should be considered when choosing cases for robotic training to progress in a safe and confident stepwise approach. A 3-tier program can be outlined: tier 1 (low risk and complexity); tier 2 (intermediate risk and complexity), and tier 3 (advanced risk and complexity).

Each surgeon, independently of previous experience with open and laparoscopic surgery, should gradually follow this surgical case selection ladder. Tier 1 includes groin hernia repair, small umbilical/ventral hernia repair, and cholecystectomy; in these procedures, the surgeon starts to gain confidence with robotic handling, 3D visualization and camera control, 3rd arm use, troubleshooting of clashing, docking practice, team communication and confidence buildup. These procedures should last less than 1 hour and are excellent for mentally preparing the surgeon and the team for more complex cases. Tier 2 includes sigmoid resection for cancer or uncomplicated diverticular disease in patients with low body mass index, and right hemicolectomy for early colon cancer (not complete mesocolic excision). The most substantial challenge for these intermediate-level procedures might be tissue and plane exposure. In this stage, the surgeon should avoid male

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pelvises, high body mass index (>30 kg/m^2), and patients with a previous history of abdominal surgery. Tier 3 includes the most complex cases, such as procedures involving pelvic dissection (low anterior resection, abdominoperineal resection, and lateral pelvic lymphadenectomy), and complete mesocolic excision for colon cancer.

There is no specific number of cases needed to progress in case selection since it depends on surgeon's commitment, practice, and skillset; however, around 10 to 15 cases would usually be needed for each tier.

Robotic immersion courses

Short 1-week "scrub-in" robotic experiences with a 1-on-1 relationship with the trainer are a suitable option for all surgeons with an established robotic practice who still require some experience to gain confidence. The rapid expansion of robotic platforms makes this fast course essential for skills.

ROBOTIC AXILLARY TECHNOLOGY

Robotic surgeons can be compared to super-athletes who constantly need to monitor their performance to obtain marginal gains from each procedure (once proficiency is obtained). Digitalization of surgery allows us to keep track of the status of training and have accessible feedback to overview strengths and weakness to optimize surgical procedures. There has been a trend in industry to provide "app-based" solutions to pursue this goal.

Intuitive Hub and My Intuitive App

Intuitive Hub (Intuitive Surgical Inc) is a visual media platform that allows surgeons to record procedures and store them for training and feedback. The Hub records, tags, and securely stores videos for efficient access, editing, and sharing. The Hub also allows livestreaming for real-time case observation and mentoring, which is essential for advanced training. Throughout surgery, the Hub can automatically tag key events, including instrument exchanges and use of the near-infrared camera view (Firefly, Intuitive Surgical Inc). The surgeon is also able to manually add bookmarks, dictate instructions, make audio notes, mark up anatomy, or pause and roll the video back to check any actions. The surgeon can create a library of surgical videos which can be navigated to analyze crucial parts of the surgery.

My Intuitive App (Intuitive Surgical Inc) makes it possible to keep all these performance information recorded and easy to access.

Touch Surgery Enterprise

Touch Surgery Enterprise (Medtronic Ltd) allows surgical teams, hospitals, and NHS Trusts to access surgical videos safely and securely for education and training, quality improvement, and transformation purposes. The system, which has been academically validated and accredited, allows the real-time anonymization of sensitive video frames and optional analytics for select procedures, enabling the surgeon to learn more from surgical practice trough an artificial intelligence (AI) system. Touch Surgery is an advanced surgical training platform that could potentially improve surgical techniques and practices through active feedback and sharing of best practices.

Surgeons for Surgeons App

The Surgeons for Surgeons (SFS) App is a social media network from surgeons to surgeons aimed at building a global surgical multispeciality community (Fig. 2) [39]. SFS makes it possible to

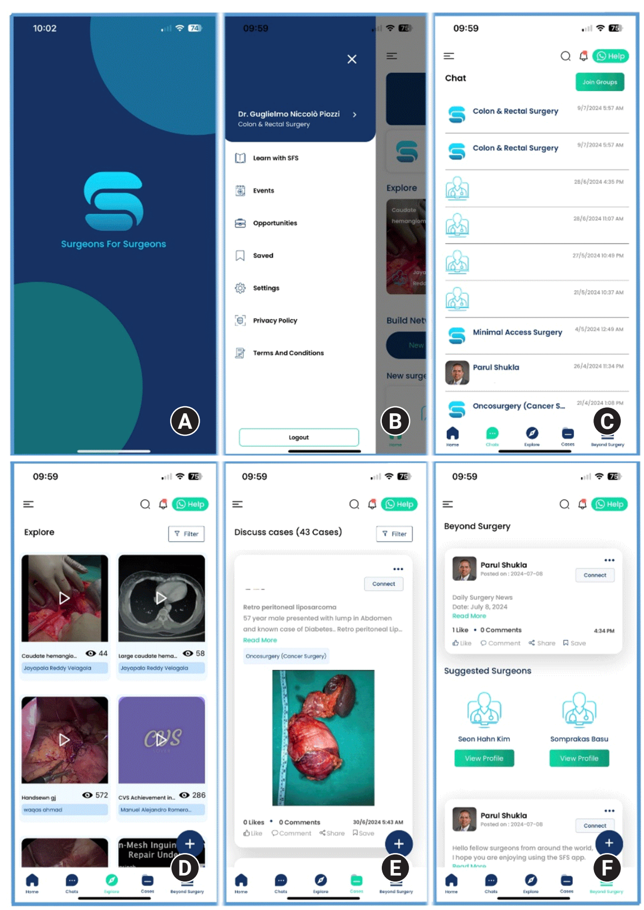

Fig. 2. Surgeons for Surgeons (SFS) App. (A) Opening screen. (B) Profile page (learning, events, and opportunities shared). (C) "Chat" page (specialty-based blog). (D) "Explore" page (video and case library). (E) "Cases" page (case description and discussion). (F) "Beyond surgery" page (open discussion to all the community).

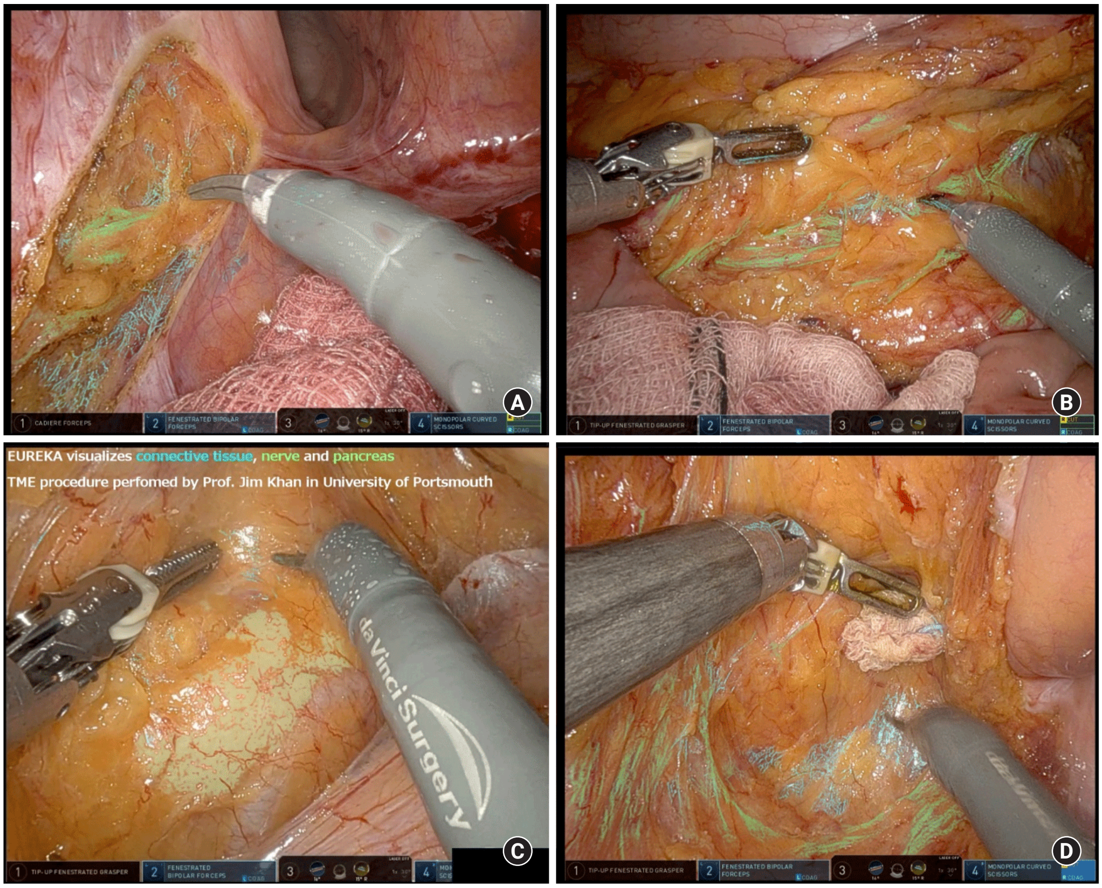

Fig. 3. The Surgical Vision Eureka (Anaut Inc) intraoperative real-time tissue and structures/organ overlay during a robotic low anterior resection. (A) Opening of the sigmoid mesentery at the sacral promontory. The blue lines show the connective tissue of the dissection planes, whilst the green lines show the hypogastric nerves descending into the pelvis. The Eureka shows 2 distinct dissection planes in blue; however, by showing the green lines, it alerts the surgeon to the correct dissection plane (above the nerves) and prevents nerve injury. (B) Mesocolic dissection caudal to the inferior mesenteric artery. The green lines show the complexity of the nerve fibers running along the planes. (C) Mediolateral dissection of the descending mesocolon. Eureka highlights the pancreas in yellow. (D) Posterior dissection plane during total mesorectal excision (TME). The blue lines show the connective tissue of the dissection plane, whilst the green lines show the hypogastric plexus nerves.

connect with expert surgeons, allowing peer to peer discussions, case presentations, sharing of clinical images and videos, and joining of webinars in a protected and professional manner.

AI navigation

Software development, especially in the application of AI, is rapidly becoming the next key step in digital surgery since the hardware of robotics is starting to plateau. One of the key aspects of AI in robotic training is intraoperative guidance through plane and organ identification and augmented reality. The Surgical Vision Eureka (Anaut Inc) is a novel AI system that can provide real-time tissue (connective tissue) and structures/organ (nerves and pancreas) identification through color superimposition (Fig. 3). This software is currently under development and is a promising tool for training and surgical assessment feedback [40].

CONCLUSION

Robotic training is complex and requires a stepwise approach where the trainee masters the use of robotic platforms through a variable pathway. Standardized training has not yet been clearly defined, but it requires a step-by-step approach, starting with theoretical training, case observation, simulation, dry lab, wet lab, bedside assistance, tutored programs, proctoring (teleproctoring), procedure-specific training, and culminating in follow-up training. This approach has been shown to be effective. Portsmouth Colorectal has an established stepwise robotic training pathway model that is safe and successful, as demonstrated by its perioperative and oncological results.

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ARTICLE INFORMATION

Conflict of interest

Jim S. Khan performs proctoring for Intuitive Surgical Inc and educational activity with Johnson & Johnson. No other potential conflict of interest relevant to this article was reported.

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