Cureus
Part of SPRINGER NATURE

Open Access Review Article

The Learning Curve: Integrating Robotic Appendectomy Into Surgical Residency

Constantinos G. Zografos [1], Panagiotis Drymousis [1], Hemant Sheth [1], Fiammetta Soggiu [1], Tushar Agarwal [2], Evangelos Menenakos [3], Dimitrios Schizas [4], Nikolaos Garmpis [5]

1. Department of General Surgery, London North West University Healthcare NHS Trust, London, GBR 2. Department of Colorectal Surgery, St Mark's Hospital, London, GBR 3. Fifth Department of Surgery, Evgenidion Hospital, School of Medicine, National and Kapodistrian University of Athens, Athens, GRC 4. First Department of Surgery, National and Kapodistrian University of Athens, Athens, GRC 5. Department of Colorectal Surgery, Guy's and St Thomas' NHS Foundation Trust, London, GBR

Corresponding author: Constantinos G. Zografos, koszogra92@hotmail.com

Review began 09/23/2026
Review ended 10/19/2026
Published 10/29/2026

© Copyright 2026
Zografos et al. This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

DOI: 10.7759/cureus.118786

Abstract

Robotic-assisted surgery is increasingly used across surgical specialties, although its adoption varies among institutions and remains limited by platform costs, availability, and the training required to achieve proficiency. This narrative review examines the potential role of robotic appendectomy (RA) as an introductory procedure in surgical residency, with particular attention to the learning curve, operative efficiency, safety, and educational feasibility in emergency general surgery. Appendectomy may provide an opportunity for junior residents to develop foundational robotic skills, including console navigation, three-dimensional visualization, instrument handling, and tissue dissection, before progressing to more complex robotic procedures. Its potential educational value derives from the familiarity of the operation to general surgeons and its comparatively limited procedural scope; however, its suitability as an initial training procedure depends on case selection, appropriate supervision, institutional resources, and the availability of a structured training program. RA should therefore be considered a potential component of surgical education rather than a universally applicable starting point. Further evaluation is needed to determine whether early exposure improves technical proficiency and trainee confidence without compromising patient safety, limiting experience in conventional laparoscopic surgery, or imposing unjustified costs.

Categories: General Surgery
Keywords: appendectomy, emergency and elective surgery, general surgery, learning curve, residency training, robotic surgery, surgical education

Introduction And Background

Acute appendicitis is one of the most common causes of emergency abdominal surgery worldwide. Laparoscopic appendectomy is an established minimally invasive approach, offering the benefits of small incisions and generally favorable postoperative recovery compared with open appendectomy [1,2]. The development of laparoscopic appendectomy represents an important milestone in minimally invasive surgery. Semm performed the first reported laparoscopic appendectomy in 1983, contributing to the broader adoption of laparoscopy in general surgery [3]. From an educational perspective, appendectomy is an important procedure in surgical residency because it allows trainees to develop fundamental operative skills and, with appropriate supervision and demonstrated competence, progress toward greater operative autonomy.

Robotic-assisted surgery (RAS) has expanded the range of available minimally invasive techniques. Platforms such as the da Vinci systems (Intuitive Surgical, Inc., Sunnyvale, CA), Hugo™ RAS (Medtronic, Minneapolis, MN), and Versius (CMR Surgical Limited, Cambridge, UK) have introduced alternative approaches to instrument manipulation and operative visualization, although their availability and clinical use vary among healthcare institutions [4]. Robotic platforms offer technical features including three-dimensional visualization, wristed instrument articulation, tremor filtration, and an ergonomic surgeon console [5]. These characteristics may be advantageous in selected operations; however, they do not in themselves establish superior clinical outcomes or cost-effectiveness for every procedure.

The role of robotic-assisted appendectomy therefore requires careful consideration. Appendectomy is generally a relatively short procedure for which conventional laparoscopy is an established and effective approach. Robotic assistance may introduce additional costs associated with platform acquisition and maintenance, instruments, operating-room time, docking, and system preparation. Other practical barriers include robot availability during emergency shifts, access to trained operating-room personnel, limited operating-room resources, and the availability of appropriately credentialed surgeons [4,6,7]. In the United States, the choice of approach may also depend on the operating surgeon's robotic privileges and clinical judgment.

These constraints may be particularly relevant when an emergency procedure must be performed without delay. Furthermore, nonoperative management with antibiotics is an alternative to appendectomy for selected patients with uncomplicated acute appendicitis, further contextualizing the role of surgery in this setting [1]. Consequently, adopting robotic appendectomy (RA) as a routine therapeutic approach cannot be justified solely by the technical capabilities of robotic platforms; its clinical and economic value must be assessed in the context of established laparoscopic practice [6,7].

Despite these limitations, RA may have educational value beyond the acquisition of basic console skills. As an operation involving the appendix and ileocecal region, it may provide an opportunity for junior residents to become familiar with robotic instrument control, tissue handling, and dissection around the caecum. In selected cases requiring mobilization of the cecum or adjacent colon, trainees may also gain exposure to dissection along the lateral peritoneal attachments, principles that are relevant to more extensive colorectal procedures. This potential progression from a relatively limited operation to increasingly complex colorectal surgery provides a rationale for investigating RA as an introductory training procedure. Nevertheless, appendectomy does not routinely require the extent of colonic mobilization undertaken during a hemicolectomy, and the transferability of skills acquired during RA to more complex colorectal operations remains to be established. Its use in training should therefore be guided by appropriate case selection, structured learning objectives, direct supervision, and competency assessment, consistent with established recommendations for robotic colorectal training [8]. Training should also complement, rather than compromise, opportunities to acquire laparoscopic and open surgical skills.

Accordingly, this narrative review examines the available evidence regarding the potential role of robotic-assisted appendectomy in surgical residency, distinguishing direct evidence on its clinical outcomes from indirect evidence on robotic learning curves and surgical training derived from other procedures.

Review

Methods

A literature search was conducted using PubMed/MEDLINE and Google Scholar to identify publications relevant to the potential role of robotic-assisted appendectomy in surgical training, with particular emphasis on learning curves, robotic skill acquisition, and educational implications for surgical residents. The search covered publications from January 2000 to December 2025. The seminal historical publication by Semm, published in 1983, was also included to provide context on the development of laparoscopic appendectomy. Search terms included “robotic appendectomy”, “robotic appendicectomy”, “learning curve of robotic appendectomy”, “learning curve of robotic colectomy”, “robotic surgery”, “surgical training”, “surgical education”, and “learning curve of laparoscopic appendectomy”. Boolean operators (AND and OR) were used to combine relevant terms.

Eligible publications included peer-reviewed clinical trials, observational studies, and relevant review articles, including systematic reviews or meta-analyses, addressing RA, surgical education, or the learning curve of RAS. Studies investigating laparoscopic appendectomy and robotic colorectal procedures were also considered when they provided relevant information on technical skill acquisition, trainee participation, or the potential transferability of surgical skills. Studies of robotic procedures in other surgical specialties were considered when they provided relevant evidence regarding robotic learning curves or the acquisition of robotic surgical skills. Publications were excluded if they were not peer-reviewed, were unrelated to the objectives of the review, or were case reports that provided insufficient relevant clinical or educational information. Only publications available in English were considered.

The initial search identified 136 records. Following the removal of 66 duplicate records, 70 records remained for screening. Of these, 47 were excluded because they were insufficiently relevant to the learning curve, surgical training, or educational implications of RA. A total of 23 articles were included in the final narrative synthesis.

The findings were synthesized descriptively, focusing on the evidence directly relating to RA and the indirect evidence derived from other robotic or laparoscopic procedures. Particular attention was given to learning-curve measures, acquisition of robotic surgical skills, trainee participation, patient safety, and the potential educational, logistical, and economic limitations of robotic-assisted appendectomy. The study-selection process is summarized in Figure *1*, while the publications included in the narrative review and their relevance to surgical training are summarized in Table *1*. This review was designed as a narrative review, and no review protocol was prospectively or retrospectively registered.

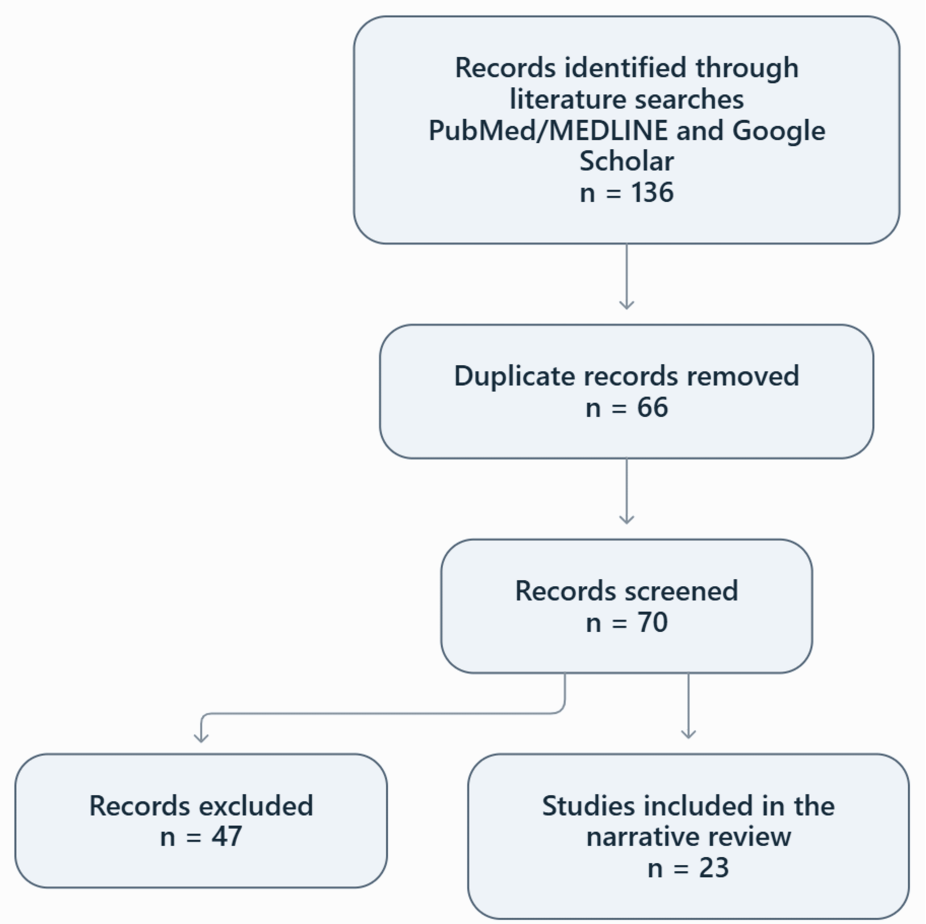


FIGURE 1: Study-selection flow diagram showing the identification, screening, exclusion, and inclusion of records in the narrative review of the potential role of robotic appendectomy in surgical training

Study	Study design/topic	Main contribution	Relevance to this review
Baird et al. [1]	Clinical review of acute appendicitis	Reviews the management of acute appendicitis, including operative and nonoperative treatment options	Provides clinical context for appendectomy and the role of antibiotics in selected patients
Guller et al. [2]	Comparative analysis using a large administrative database	Compares outcomes following laparoscopic and open appendectomy	Establishes the clinical context for conventional laparoscopic appendectomy
Semm [3]	Historical report of endoscopic appendectomy	Describes an early milestone in the development of laparoscopic appendectomy	Provides historical context for the evolution of minimally invasive appendectomy
Oleynikov [4]	Review of robotic surgery	Discusses robotic surgery and its development in clinical practice	Provides background on robotic platforms and considerations affecting their adoption
Anderson et al. [5]	Technical comparison of a mechanical analog and the da Vinci interface	Examines suturing performance at challenging angles using different instrument interfaces	Provides indirect context for the technical demands of robotic instrument manipulation
Rifai et al. [6]	Retrospective comparison of robotic and laparoscopic approaches to appendectomy and cholecystectomy	Examines operative time and time to discharge across robotic and laparoscopic procedures	Informs discussion of procedural efficiency and resource implications
Reinisch et al. [7]	Systematic review of robotic operations in urgent general	Reviews the use of robotic surgery in urgent general surgical settings	Provides context for the logistical feasibility of robotic surgery in emergency practice

	surgery		
Tou et al. [8]	European Society of Coloproctology guideline on robotic colorectal training	Provides recommendations for training and competency development in robotic colorectal surgery	Supports structured training, supervision, and competency assessment; the guidance is not specific to appendectomy
Thomas et al. [9]	Multihospital retrospective cohort study comparing robotic and laparoscopic appendectomy	Compares clinical outcomes between robotic and laparoscopic appendectomy	Provides direct comparative clinical evidence on robotic appendectomy, but does not by itself establish an educational benefit
Akl et al. [10]	Robotic appendectomy in gynecological surgery	Describes robotic appendectomy performed in the context of gynecological surgery and reports pathological findings	Illustrates a setting in which appendectomy may be performed alongside another robotic procedure
Hüttenbrink et al. [11]	Incidental appendectomy during robotic-assisted prostatectomy	Examines incidental appendectomy performed during robotic laparoscopic prostatectomy	Provides context for appendectomy performed during an already established robotic operation
Bokhari et al. [12]	Learning-curve study of robotic-assisted laparoscopic colorectal surgery	Investigates the learning curve associated with robotic colorectal surgery	Provides indirect evidence on robotic skill acquisition and operative proficiency
Chen et al. [13]	Bibliometric analysis of simulation-based robotic surgery education	Maps research trends in simulation-based training in robotic surgery	Supports discussion of simulation, structured education, and skills assessment
Hirschburger et al. [14]	Single-center experience transitioning from open to robotic right colectomy	Examines a transition to robotic right colectomy and associated functional outcomes in a learning-curve setting	Provides indirect context for learning curves and the acquisition of skills in more complex robotic colorectal procedures
Kim et al. [15]	Learning-curve study of laparoscopic appendectomy performed by a surgical trainee	Evaluates the learning curve of a trainee performing laparoscopic appendectomy	Provides a comparator for trainee learning in an established minimally invasive procedure
Kim et al. [16]	Study of the resident learning curve for laparoscopic appendectomy according to seniority	Examines the relationship between resident seniority and learning-curve performance	Informs discussion of trainee experience and the progression towards operative proficiency
Wong et al. [17]	Review of the learning curve for robotic colorectal surgery	Reviews evidence relating to learning curves in robotic colorectal procedures	Provides indirect evidence on robotic proficiency and the limitations of extrapolating learning-curve findings between procedures
Bibi et al. [18]	Review of the development of single-site robotic cholecystectomy	Describes the evolution of single-site robotic cholecystectomy	Provides broader context on the development of robotic approaches to common abdominal procedures
Jang et al. [19]	Propensity score-matched comparison of robotic single-site and laparoscopic cholecystectomy	Compares outcomes between robotic single-site and laparoscopic cholecystectomy	Provides indirect comparative evidence on robotic and laparoscopic approaches to a common abdominal operation
Karim et al. [20]	Systematic review comparing learning curves in robotic and laparoscopic cholecystectomy	Synthesizes evidence on learning curves for robotic and laparoscopic cholecystectomy	Provides indirect evidence for discussing differences in skill acquisition between surgical platforms
Shaw et al. [21]	Study of the robotic colorectal surgery learning curve and case complexity	Examines the relationship between learning-curve progression and procedural complexity in robotic colorectal surgery	Supports discussion of how procedure complexity may influence robotic proficiency
Reddy et al. [22]	Review comparing robotic-assisted and laparoscopic appendectomy	Reviews comparative evidence on robotic and laparoscopic appendectomy	Summarizes direct clinical literature while highlighting the distinction between clinical outcomes and educational effectiveness
Becker et al. [23]	Comparative outcomes study using ACS-NSQIP hospital data	Compares outcomes of laparoscopic and robotic appendectomy across participating hospitals	Provides direct comparative clinical evidence on robotic appendectomy, rather than proof of training effectiveness

TABLE 1: Summary of publications included in the narrative review and their relevance to

surgical training

ACS-NSQIP: American College of Surgeons National Surgical Quality Improvement Program

Current literature and barriers to adoption

Evidence specifically addressing the learning curve of RA remains limited [9]. Several factors may contribute to its limited adoption, including the acquisition and maintenance costs of robotic platforms, operating-room logistics, and the need for appropriately trained surgical and theatre staff [4]. Given the generally straightforward nature of appendectomy, the additional costs and setup requirements may limit the economic justification for its routine performance using a robotic platform, particularly within publicly funded healthcare systems such as the National Health Service.

RA has also been described in conjunction with other robotic procedures, including gynecological surgery and robot-assisted radical prostatectomy [10,11]. Performing appendectomy during an already established robotic procedure may avoid some of the additional setup requirements associated with a standalone operation. However, this approach should be distinguished from the routine use of robotic surgery as the primary treatment for acute appendicitis. The additional time required for system preparation, docking, and coordination among operating-room personnel may also restrict the availability of RA in emergency settings, particularly during out-of-hours operations when appropriately trained staff may not be available.

Despite these limitations, comparative studies have examined the clinical outcomes of robotic and laparoscopic appendectomy [9]. These investigations contribute to the assessment of RA as a potential surgical option. Nevertheless, evidence of comparable outcomes in selected populations should not be interpreted as proof of formal noninferiority or as justification for routine robotic use in all cases. Further research is required to establish the clinical and economic circumstances under which RA may offer meaningful advantages over conventional laparoscopy.

The pedagogical value of emergency robotics

Despite the economic and logistical barriers, RA may provide educational opportunities for surgical trainees. The robotic platform enables trainees to develop familiarity with three-dimensional visualization, console-based instrument control, and tissue dissection. However, the educational value of RA must be distinguished from its established clinical effectiveness, as direct evidence demonstrating that it improves training outcomes remains limited.

The learning curve reported in robotic colorectal surgery highlights the importance of structured training and operating-room experience [12]. For example, Bokhari et al. examined the learning curve associated with robotic-assisted colorectal surgery, demonstrating the relevance of operative experience when evaluating procedural efficiency [12]. Although findings from colorectal surgery cannot be directly extrapolated to appendectomy, they provide a useful framework for understanding the acquisition of robotic surgical skills and the potential influence of team familiarity on operative performance.

The high volume of appendectomies performed in emergency general surgery may provide opportunities for supervised robotic training in appropriately selected cases, provided patient safety, clinical urgency, and local resources remain the primary considerations. RA should not be adopted solely as a training exercise when conventional laparoscopy or another approach is more appropriate for the patient. Instead, its educational role should be considered within a structured training program that progresses from simulation to supervised clinical practice.

A structured pathway for robotic surgical training may include introductory theoretical education, simulator-based exercises, objective assessment of basic console skills, supervised participation in robotic procedures, and progressive demonstration of competency. Institutional credentialing and operating privileges should follow local requirements and should not be assumed to be uniform across countries or surgical specialties. The European Society of Coloproctology guidelines on robotic colorectal surgery provide relevant guidance on structured training and competency development [8]. Although these recommendations are not specific to appendectomy, their principles may inform the development of training pathways for robotic emergency surgery.

Simulation-based training may allow junior surgeons to acquire foundational console skills in a controlled environment before participating in clinical procedures. Chen et al. examined research trends in simulation-based robotic surgery education, highlighting the growing interest in structured simulation and skills assessment [13]. Dual-console systems may further facilitate supervised learning by allowing an experienced surgeon to guide a trainee and intervene when necessary. Nevertheless, the availability of such systems and their integration into emergency surgical training vary between institutions.

Overall, RA may represent a potential component of a broader robotic surgical training program. However,

its value as a training procedure, the extent to which skills acquired during appendectomy transfer to more complex operations, and its effect on the clinical learning curve require further investigation. Prospective studies incorporating objective competency measures, trainee outcomes, operative performance, and patient safety endpoints are needed to determine whether the educational benefits justify the additional resources required.

Extrapolating the learning curve

Because specific literature addressing the learning curve of RA remains relatively limited [9], its acquisition and proficiency curve must be considered within the broader context of minimally invasive and robotic surgery. In particular, evidence from robotic colorectal procedures [12,14] and laparoscopic appendectomy [15,16] can provide useful comparative benchmarks. Although these procedures differ in complexity, they share several fundamental technical and cognitive requirements associated with minimally invasive and robotic surgery. Accordingly, extrapolating learning-curve data from established procedures, while acknowledging the limitations of such comparisons, provides a framework for understanding how RA may function as a potential introductory procedure for surgeons entering RAS.

According to Bokhari et al., mastering robotic technology involves three distinctive and interrelated competencies that differentiate robotic surgery from conventional laparoscopy [12]. First, the surgeon must learn to compensate for the absence of conventional tactile feedback by relying predominantly on visual information to assess tissue tension, resistance, and the effects of instrument manipulation. This represents a substantial cognitive adaptation because laparoscopic surgeons traditionally integrate visual information with indirect tactile feedback transmitted through the instruments. In robotic surgery, this feedback is considerably reduced or absent, requiring the surgeon to develop a heightened ability to interpret subtle visual changes in tissue deformation and instrument movement. Second, the surgeon must maintain a continuous cognitive map of the position and trajectory of the robotic instruments, including those that may not remain directly within the surgeon's field of vision. This spatial awareness is essential to prevent inadvertent tissue injury and coordinate multiple robotic arms within a confined operative field. Finally, because the surgeon operates from a remote console and is physically separated from the patient and robotic cart, they must mentally visualize the movements of the robotic arms and the external components of the system. This ability is necessary to prevent external arm collisions, optimize instrument positioning, and maintain efficient maneuverability within the operating theatre [12].

These unique cognitive and technical requirements raise an important question regarding the most appropriate pathway through which surgeons should acquire robotic competence. Developing a strong foundation in laparoscopic surgery may provide an important advantage before adopting the robotic platform, particularly within conventional surgical training programs [12,17]. Laparoscopic proficiency provides surgeons with fundamental competencies in minimally invasive surgery, including camera navigation, spatial orientation, triangulation, tissue handling, dissection, hemostasis, and an understanding of the ergonomic limitations of minimally invasive surgery. These skills remain relevant when transitioning to robotic surgery, even though the robotic platform modifies many of the technical limitations associated with conventional laparoscopy. In this context, laparoscopic appendectomy is particularly valuable because it is one of the most frequently performed laparoscopic procedures in general surgery. Its relatively standardized anatomy and reproducible operative sequence provide repeated exposure to intra-abdominal anatomy and minimally invasive tissue handling. Consequently, experience with laparoscopic appendectomy may provide a practical foundation from which surgeons can subsequently develop the additional cognitive and technical competencies required for robotic surgery.

At the same time, an alternative educational pathway warrants consideration. Rather than viewing extensive laparoscopic experience as an absolute prerequisite for robotic surgery, selected robotic procedures might potentially serve as introductory training opportunities within appropriately supervised programs. Hirschburger et al. described implementing robotic right colectomy in an institutional setting that progressed from open surgery to robotic-assisted extracorporeal anastomosis to a fully robotic approach with intracorporeal anastomosis [14]. Although this experience illustrates an alternative pathway for adopting robotic techniques, it did not evaluate surgical residents or directly compare laparoscopic-first and robotic-first training. It therefore does not establish that extensive previous laparoscopic experience is unnecessary or that a robot-first educational pathway produces equivalent outcomes. Nevertheless, it provides context for investigating whether selected, relatively standardized procedures, such as RA, could be incorporated into structured robotic training. The educational effectiveness and safety of this approach remain to be demonstrated.

The conventional laparoscopic appendectomy learning curve provides another useful reference point. Kim et al. retrospectively reviewed 103 patients undergoing either open appendectomy (n = 53) or laparoscopic appendectomy (n = 50) and reported that residents required approximately 30 cases to achieve independence in laparoscopic appendectomy [15]. Similarly, Kim et al., in an evaluation of three junior residents ranging from postgraduate year (PGY) 1 to PGY 3, identified a learning curve ranging from 11 to 35 cases for laparoscopic appendectomy [16]. Although these figures cannot be directly transferred to RA, they demonstrate that appendectomy is sufficiently standardized to permit measurable progression in operative independence. Importantly, the populations studied in these investigations consisted primarily of junior

trainees. Robotic surgery, by contrast, may be introduced at a later stage of surgical training, when residents already possess greater experience with intra-abdominal anatomy, operative decision-making, tissue handling, and minimally invasive surgery. Therefore, the number of cases required to achieve RA proficiency may not necessarily mirror the learning curve observed among junior trainees learning laparoscopic appendectomy.

Evidence from more complex robotic procedures further illustrates how previous surgical experience may influence the acquisition of robotic competence. Bokhari et al. reported a learning-curve phase of approximately 15 to 25 cases in robotic colorectal surgery [12]. Although colorectal resections are substantially more complex than appendectomy, their learning curves are informative because they demonstrate that robotic proficiency can be assessed according to operative efficiency and other measures of performance. Importantly, overcoming this learning curve requires not only repetition of operative steps but also mastery of visual cues and the internal and external spatial relationships unique to the robotic platform [12]. A simpler procedure such as RA may therefore allow these platform-specific skills to be practiced before a surgeon progresses to complex multiquadrant or oncological operations. Nevertheless, whether this approach actually accelerates the acquisition of competence in more complex robotic procedures remains uncertain.

More recent evidence reinforces the importance of structured training and previous minimally invasive experience. Wong et al., in their review of robotic colorectal surgery, highlighted the relationship between surgical experience, operative performance, and the acquisition of proficiency [17]. Their discussion also emphasized the potential value of structured training and proctorship. These findings highlight an important distinction between simply accumulating operative cases and participating in a structured educational pathway. Robotic proficiency is unlikely to depend solely on case volume; rather, it may be influenced by the surgeon's baseline experience, the complexity of the procedures undertaken, the availability of supervision, the quality of the training program, and the progressive acquisition of console autonomy. Consequently, the development of a successful robotic program should be viewed as a multifaceted institutional process rather than simply an individual surgeon's transition from one operative technique to another [17].

Emergency robotic procedures may provide an additional model for understanding how RA could be incorporated into surgical education. Robotic cholecystectomy, in particular, may offer a useful comparator because it is another commonly performed general surgical procedure involving a relatively well-defined anatomical region and a standardized operative sequence [18,19]. However, robotic cholecystectomy is not necessarily performed as an emergency procedure in every setting, and its learning curve cannot be assumed to apply directly to RA. The systematic review by Karim et al. reported substantial variation in the number of cases required to achieve proficiency in robotic cholecystectomy [20]. This variation illustrates that learning curves are not fixed numerical thresholds but are influenced by differences in surgeon experience, definitions of proficiency, institutional volume, operative complexity, training methodology, and the outcome measures selected. Nevertheless, these findings provide further context for considering how common general surgical procedures might be incorporated into structured robotic training.

Shaw et al. examined the learning curve in robotic colorectal surgery in relation to case complexity, providing further context for the role of procedural difficulty in the acquisition of robotic proficiency [21]. In addition, comparative studies have examined outcomes following robotic and laparoscopic appendectomy [22,23], contributing to the limited evidence base regarding the clinical role of RA.

Importantly, the potential educational role of RA should not automatically translate into an increased total number of cases required for surgical training or graduation. Robotic training should complement, rather than replace, adequate exposure to open and laparoscopic surgery. Its implementation should be guided by defined educational objectives, appropriate supervision, patient safety, and demonstrated competency, while ensuring that trainees continue to acquire the essential skills required for conventional surgical approaches. Further prospective studies are needed to determine whether RA improves the acquisition and transfer of robotic skills and whether these potential benefits can be achieved without compromising other components of surgical training.

Discussion

The Paradigm Shift in Surgical Education

Integrating RAS into emergency general surgery is more than a technological modification of existing operative techniques. It has the potential to influence the structure and philosophy of surgical education itself. Historically, complex robotic procedures, particularly robotic colorectal operations, have frequently been concentrated among experienced consultants who have already completed substantial training in open and laparoscopic surgery [21]. This traditional model reflects a logical concern regarding patient safety: trainees must first acquire fundamental operative skills before being exposed to a technologically complex platform. However, the progressive expansion of robotic surgery raises the possibility that the traditional sequential model-open surgery followed by extensive laparoscopic experience and only subsequently robotic surgery-may not be the only viable educational pathway.

The findings of Hirschburger et al. are particularly relevant in this context because they demonstrated the feasibility of transitioning from open oncologic right colectomy to a robotic approach without an intermediate period of conventional laparoscopic colectomy [14]. Although this evidence does not establish that a robotic-first approach is universally superior to a laparoscopic-first pathway, it challenges the assumption that extensive laparoscopic experience must always precede robotic training. Within surgical residency, this raises the possibility of developing a structured "robot-first" pathway for selected standardized procedures. RA could represent one such procedure because its relatively localized anatomy, reproducible operative sequence, and frequent occurrence may provide opportunities for repeated exposure to the robotic platform. Rather than introducing trainees to robotics only after they have completed a prolonged laparoscopic learning curve, selected institutions may consider incorporating robotic procedures progressively into residency training, provided appropriate supervision, patient selection, institutional credentialing, and objective assessment of competency are maintained. Trainee participation at the robotic console should also be consistent with institutional policies and applicable consent requirements, with patients appropriately informed about the trainee's role in their operation.

The educational value of RA may therefore extend beyond the technical completion of the procedure itself. Each case may provide the trainee with an opportunity to practice docking, instrument selection, camera control, clutching, wristed instrument manipulation, tissue retraction, dissection, hemostasis, and coordination of multiple robotic arms. At the same time, the trainee becomes familiar with the cognitive demands of operating from the console, including the interpretation of visual cues in the absence of direct tactile feedback and the maintenance of spatial awareness within the robotic environment. Similar skills can be acquired through other robotic procedures, and appendectomy should not be considered uniquely suitable for robotic training. Nevertheless, its relatively standardized operative sequence and potential availability in emergency general surgery may make it a useful option in appropriately selected cases. Repeated exposure may support the development of platform-specific competencies before trainees progress to more demanding robotic procedures, although this educational benefit requires further evaluation.

Addressing the "Cost-Training" Paradox

The principal argument against the widespread use of RA remains economic. Robotic procedures involve substantial equipment, maintenance, and consumable costs, which may be difficult to justify when compared with established laparoscopic alternatives [22]. From a purely procedural perspective, using a robotic platform for a relatively straightforward emergency operation may therefore be difficult to defend on immediate operative cost alone. This consideration is particularly important in healthcare systems where robotic operating time and disposable instruments are limited resources.

However, the educational implications introduce a different dimension to this economic discussion. Rather than viewing RA solely as an expensive alternative to laparoscopic appendectomy, it may be conceptualized as an opportunity to provide structured exposure to robotic technology within a high-volume clinical environment. Appendicitis is sufficiently common to generate repeated operative opportunities, meaning that trainees working in emergency general surgery may encounter the procedure frequently. However, the availability of suitable cases, trained theater personnel, appropriate supervision, and a robotic platform will determine whether these opportunities can be translated into meaningful training. In this framework, part of the expenditure associated with RA could be interpreted as an educational investment rather than solely as an operative cost. Such an interpretation does not eliminate the economic disadvantage of robotics, nor does it establish that the additional expense is necessarily offset by future savings. Rather, it suggests that cost-effectiveness assessments should consider both immediate procedural costs and the potential training value generated by appropriately selected cases.

The proposed educational benefit is particularly relevant when considering the long-term development of a robotic surgical service. A surgeon who becomes familiar with the robotic platform through repetitive, standardized procedures may subsequently be better prepared to progress toward more complex operations. If structured training reduces the number of cases required to achieve competence in more advanced robotic procedures, there may be downstream implications for operative efficiency, training capacity, and the development of a sustainable robotic program. Nevertheless, these potential benefits remain hypotheses that require prospective evaluation and should not be interpreted as evidence that RA is currently more cost-effective than conventional laparoscopy. Any educational program should also complement, rather than displace, trainees' opportunities to acquire essential open and laparoscopic skills.

The Learning Curve and Console Autonomy

The learning curve in robotic surgery is influenced by several factors, including previous surgical experience, familiarity with the robotic platform, procedural complexity, and the outcome measures used to define proficiency [12,17,20,21]. Competence extends beyond the completion of individual technical steps and includes appropriate instrument control, tissue handling, spatial awareness, operative efficiency, and clinical decision-making. However, the available evidence specifically addressing the learning curve of RA remains limited, and findings from other robotic procedures should be extrapolated cautiously.

RA may offer an opportunity for trainees to develop fundamental console skills in a relatively standardized surgical procedure. These skills include three-dimensional visualization, control of articulated instruments, and dissection around the cecum and appendix. Nevertheless, the absence of conventional tactile feedback and the need to adapt to the robotic interface introduce challenges that require structured training and appropriate supervision. Simulation-based education may help trainees develop these skills before participating in live surgery [13].

The progression toward console autonomy should be based on demonstrated competence rather than on a predetermined number of procedures alone. Simulation performance, technical assessment, the ability to recognize anatomical structures, and safe intraoperative decision-making may all contribute to evaluating readiness for greater responsibility. In selected cases, the extent of disease may require a more extensive procedure than appendectomy alone, such as ileocecal resection or right colectomy, particularly when severe inflammation or an appendiceal mass or suspected malignancy precludes safe completion of a standard appendectomy. In such circumstances, a robotic approach may facilitate complex dissection and intracorporeal anastomosis when the surgeon has appropriate colorectal robotic expertise. However, these potential advantages should not be interpreted as evidence that a robotic approach is always preferable or eliminates the need for conversion to open surgery. The choice of procedure and surgical approach should be guided by the underlying pathology, the patient's condition, the surgeon's expertise, and available resources. Such cases also illustrate the distinction between the learning curve for routine RA and the additional competencies required for more extensive robotic colorectal procedures.

An additional practical consideration is the limited intra-abdominal working space in some patients, particularly children and smaller individuals. Robotic surgery requires careful planning of trocar placement and spacing to accommodate the robotic arms and minimize instrument collision. Port size and configuration may differ from those used in conventional laparoscopy, and additional ports or adjustments to access may be required depending on the robotic platform and operative strategy. These factors can increase technical and logistical complexity and may affect operative time and the risk of access-related injury. Consequently, the potential educational benefits of RA must be balanced against the patient's anatomy and the access requirements of the robotic system. These considerations are particularly relevant in pediatric patients, for whom suitability should be assessed individually rather than assumed on the basis of potential training value alone.

Standardization and Safety

Docking and operating-room coordination may contribute to the additional operative time associated with RA, although the extent to which these factors improve with team experience requires further study. The available comparative studies have evaluated outcomes of robotic and laparoscopic appendectomy, but their findings should be interpreted in light of study design, patient selection, and differences in operative complexity [6,9,22,23]. The safety of RA therefore cannot be assumed to be equivalent across all patient groups or clinical circumstances. Potential advantages, including three-dimensional visualization and instrument articulation, must be considered alongside the costs, access requirements, and logistical demands of the robotic system. Integration into emergency surgical training should consequently depend on appropriate case selection, structured supervision, and acceptable clinical outcomes rather than on the educational potential of the platform alone.

Standardization of the operative steps and training pathway may facilitate assessment and supervision, but the extent to which a uniform approach can be applied across different robotic platforms and clinical settings remains uncertain. Training programs should incorporate appropriate patient selection, clearly defined trainee responsibilities, and direct supervision by an experienced surgeon. Patient safety must remain the primary consideration, and the trainee's participation at the console should comply with institutional policies and applicable informed-consent requirements.

Limitations

This review is subject to several limitations. First, the available literature specifically addressing the learning curve of RA is relatively sparse compared with that concerning colorectal and other robotic procedures. Second, many of the available studies are retrospective, introducing potential selection bias and limiting the strength of causal conclusions. Third, substantial variation across robotic platforms, including da Vinci, Hugo, and Versius, along with differences in instrument availability, port configurations, training modules, and institutional protocols, makes it difficult to define a universal number of cases needed to achieve proficiency. Finally, differences in patient anatomy, disease severity, and procedural complexity further limit the generalizability of learning-curve estimates across procedures and patient populations. Consequently, conclusions regarding the educational value of RA should be regarded as preliminary and interpreted in the context of the limited procedure-specific evidence.

Future Perspectives

Future research should evaluate the learning curve of RA using prospective, multicenter studies and clearly

defined measures of technical competence, operative efficiency, and patient outcomes. Studies should distinguish between console proficiency, procedural autonomy, and clinical outcomes rather than relying on operative time alone. Comparisons across robotic platforms and training pathways may also help determine whether differences in instrument design, simulation modules, and team experience influence skill acquisition.

Simulation-based training, structured assessment, and supervised console participation may provide a framework for integrating RA into surgical education. Emerging technologies, including artificial intelligence-assisted performance assessment and telementoring, may eventually support real-time feedback on instrument movement, economy of motion, and tissue handling. However, their effectiveness in RA requires specific evaluation before routine implementation can be recommended.

Dual-console systems may facilitate supervised trainee participation by allowing an experienced surgeon to monitor performance and intervene when necessary. Nevertheless, RA should complement rather than replace training in open and conventional laparoscopic surgery. Its role within the curriculum should be determined by educational objectives, institutional resources, patient safety, and evidence of measurable training benefits. Ultimately, prospective studies are needed to establish whether RA offers a meaningful educational advantage over other procedures that provide similar opportunities to develop foundational robotic skills.

Conclusions

RAS is increasingly incorporated into surgical practice, creating a need for structured approaches to robotic training. RA may offer an opportunity for surgical residents to develop foundational robotic skills within a relatively standardized operative procedure. These skills include three-dimensional spatial orientation, control of articulated instruments, console navigation, and interpretation of visual cues in the absence of conventional haptic feedback. However, the available evidence does not establish RA as an ideal introductory procedure, demonstrate that skills acquired during the operation transfer to more complex robotic procedures, or show that its potential educational benefits outweigh the additional costs and logistical requirements.

The time required for system preparation and docking, the cost of robotic instruments and maintenance, insurance coverage and reimbursement policies, and the availability of appropriately trained operating-room personnel may limit the feasibility of RA, particularly during emergency and out-of-hours surgery. Any proposed integration into surgical residency should therefore depend on local resources, appropriate case selection, structured learning objectives, direct supervision, competency assessment, and compliance with institutional credentialing and informed-consent requirements. Robotic training should complement, rather than replace, opportunities for residents to develop open and conventional laparoscopic surgical skills. Prospective studies are needed to define the procedure-specific learning curve of RA, evaluate trainee performance and patient outcomes, and determine whether it offers meaningful educational advantages over other robotic procedures. Further research should also assess its economic implications and feasibility within different healthcare systems. Until such evidence is available, RA should be considered a potential educational option within appropriately structured training programs rather than an established standard of surgical education.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Constantinos G. Zografos, Panagiotis Drymousis, Hemant Sheth, Fiammetta Soggiu, Tushar Agarwal, Evangelos Menenakos, Dimitrios Schizas, Nikolaos Garmpis

Acquisition, analysis, or interpretation of data: Constantinos G. Zografos, Panagiotis Drymousis, Hemant Sheth, Fiammetta Soggiu, Tushar Agarwal, Evangelos Menenakos, Dimitrios Schizas, Nikolaos Garmpis

Drafting of the manuscript: Constantinos G. Zografos, Hemant Sheth, Fiammetta Soggiu, Tushar Agarwal, Evangelos Menenakos, Dimitrios Schizas, Nikolaos Garmpis

Critical review of the manuscript for important intellectual content: Constantinos G. Zografos, Panagiotis Drymousis, Hemant Sheth, Fiammetta Soggiu, Tushar Agarwal, Evangelos Menenakos, Dimitrios Schizas, Nikolaos Garmpis

Supervision: Panagiotis Drymousis, Evangelos Menenakos, Dimitrios Schizas

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

During the preparation of this manuscript, the authors used Google AI (Google LLC, Mountain View, CA) for the purpose of improving language, grammar, clarity, and academic tone. Following the use of this tool, the authors thoroughly reviewed, edited, and verified all text and content. The authors remain fully responsible for the scientific accuracy, integrity, and originality of the final manuscript.

References

1. Baird DL, Simillis C, Kontovounisios C, Rasheed S, Tekkis PP: Acute appendicitis. BMJ. 2017, 357:j1703. 10.1136/bmj.j1703
2. Guller U, Hervey S, Purves H, Muhlbaier LH, Peterson ED, Eubanks S, Pietrobon R: Laparoscopic versus open appendectomy: outcomes comparison based on a large administrative database. Ann Surg. 2004, 239:43-52. 10.1097/01.sla.0000103071.35986.c1
3. Semm K: Endoscopic appendectomy. Endoscopy. 1983, 15:59-64. 10.1055/s-2007-1021466
4. Oleynikov D: Robotic surgery. Surg Clin North Am. 2008, 88:1121-30, viii. 10.1016/j.suc.2008.05.012
5. Anderson PL, Lathrop RA, Herrell SD, Webster RJ 3rd: Comparing a mechanical analogue with the da Vinci user interface: suturing at challenging angles. IEEE Robot Autom Lett. 2016, 1:1060-5. 10.1109/LRA.2016.2528302
6. Rifai AO, Rembetski EM, Stutts LC, et al.: Retrospective analysis of operative time and time to discharge for laparoscopic vs robotic approaches to appendectomy and cholecystectomy. J Robot Surg. 2023, 17:2187-93. 10.1007/s11701-023-01632-9
7. Reinisch A, Liese J, Padberg W, Ulrich F: Robotic operations in urgent general surgery: a systematic review . J Robot Surg. 2023, 17:275-90. 10.1007/s11701-022-01425-6
8. Tou S, Au S, Clancy C, et al.: European Society of Coloproctology guideline on training in robotic colorectal surgery (2024). Colorectal Dis. 2024, 26:776-801. 10.1111/codi.16904
9. Thomas EM, Orcutt G, Norris AE, Blackhurst DW, Schneider AM: Comparative analysis of laparoscopic and robotic appendectomy: a multi-hospital retrospective cohort study. Surg Endosc. 2026, 40:1362-7. 10.1007/s00464-025-12419-4
10. Akl MN, Magrina JF, Kho RM, Magtibay PM: Robotic appendectomy in gynaecological surgery: technique and pathological findings. Int J Med Robot. 2008, 4:210-3. 10.1002/rcs.198
11. Hüttenbrink C, Hatiboglu G, Simpfendörfer T, et al.: Incidental appendectomy during robotic laparoscopic prostatectomy-safe and worth to perform?. Langenbecks Arch Surg. 2018, 403:265-9. 10.1007/s00423-017-1630-5
12. Bokhari MB, Patel CB, Ramos-Valadez DI, Ragupathi M, Haas EM: Learning curve for robotic-assisted laparoscopic colorectal surgery. Surg Endosc. 2011, 25:855-60. 10.1007/s00464-010-1281-x
13. Chen S, Huang J, Zhang L, Xu Y, Zhang Z: Simulation-based training in robotic surgery education: bibliometric analysis and visualization. J Robot Surg. 2024, 18:324. 10.1007/s11701-024-02076-5
14. Hirschburger M, Schneider R, Kraenzlein S, Padberg W, Hecker A, Reichert M: Right colectomy from open to robotic - a single-center experience with functional outcomes in a learning-curve setting. Langenbecks Arch Surg. 2022, 407:2915-27. 10.1007/s00423-022-02576-8
15. Kim SY, Hong SG, Roh HR, Park SB, Kim YH, Chae GB: Learning curve for a laparoscopic appendectomy by a surgical trainee. J Korean Soc Coloproctol. 2010, 26:324-8. 10.3393/jksc.2010.26.5.324
16. Kim CW, Jeon SY, Paik B, Bong JW, Kim SH, Lee SH: Resident learning curve for laparoscopic appendectomy according to seniority. Ann Coloproctol. 2020, 36:163-71. 10.3393/ac.2019.07.20
17. Wong NW, Teo NZ, Ngu JC: Learning curve for robotic colorectal surgery. Cancers (Basel). 2024, 16:3420. 10.3390/cancers16193420
18. Bibi S, Rahnemai-Azar AA, Coralic J, Bayoumi M, Khorsand J, Farkas DT, Prasad LM: Single-site robotic cholecystectomy: the timeline of progress. World J Surg. 2015, 39:2386-91. 10.1007/s00268-015-3135-0
19. Jang EJ, Kang SH, Kim KW: Propensity score matched comparison of robotic single-site and laparoscopic cholecystectomy. JSLS. 2023, 27:e2023.00043. 10.4293/JSLS.2023.00043
20. Karim MR, Kong AE, Mohammad N, Shah RN, Patel B: Comparative analysis of learning curves in robotic versus laparoscopic cholecystectomy: a systematic review. Cureus. 2024, 16:e67468. 10.7759/cureus.67468
21. Shaw DD, Wright M, Taylor L, et al.: Robotic colorectal surgery learning curve and case complexity . J Laparoendosc Adv Surg Tech A. 2018, 28:1163-8. 10.1089/lap.2016.0411
22. Reddy S, Tote D, Zade A, Sudabattula K, Dahmiwal T, Hatewar A, Bawiskar D: Comparative analysis of robotic-assisted versus laparoscopic appendectomy: a review. Cureus. 2024, 16:e63488. 10.7759/cureus.63488
23. Quilici PJ, Wolberg H, McConnell N: Operating costs, fiscal impact, value analysis and guidance for the routine use of robotic technology in abdominal surgical procedures. Surg Endosc. 2022, 36:1433-43. 10.1007/s00464-021-08428-8