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REVIEW

Robotic Appendicectomy
A review of feasibility

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ABSTRACT: Acute appendicitis is one of the most common abdominal emergencies. There has been an increasing use of robotic abdominal surgery. However, it remains underutilised in emergency settings. This study aimed to systematically review robotic appendicectomy (RA) feasibility. A 20-year systematic review was performed, along with quality assessment. The research protocol was registered with PROSPERO. The search yielded 1,242 citations, including 9 articles. The mean quality score was 10.72 ± 2.56. The endpoints across the studies were rate of conversion to open surgery, length of hospital stay, blood loss and operative time. RA is a safe, feasible technique that can be performed in elective and emergency settings with minimal blood loss. The operative time and hospital stay were within acceptable limits. Robotic surgery's major drawback is its high cost and limited availability. Future studies evaluating RA with a focus on its application during emergencies and its cost-effectiveness are recommended.

Keywords: Robot Surgery; Robotic-Assisted Surgery; Robot Enhanced Surgery; Robotic Surgical Procedure; Appendectomy; Appendicectomy; Gastrointestinal Surgical Procedure.

Acute appendicitis is known to be the most common abdominal surgical emergency in the world, with approximately 50,000 acute appendicectomies performed annually in the UK.[1] Laparoscopic appendicectomy (LA) is considered the gold-standard management and is recommended over open appendectomy in all patient groups.[2,3] However, the coronavirus disease-19 (COVID-19) pandemic has brought a new challenge for surgeons undertaking laparoscopic procedures, with its safety being debated out of fear of contaminated aerosol transmission to healthcare workers.[4,5]

Over the last decade, there has been an increase in the routine use of robotic surgery in several surgical specialties, with nearly all surgical subspecialties adopting it.[6,7] Compared with traditional laparoscopic techniques, the robotic system is known to improve precision, visualisation, spatial flexibility and stability.[8,9] In particular, robotic surgery has been shown to reduce the risk of potential viral transmission to surgeons and theatre staff as it allows them to be remote from the patient and from each other.[4,10,11] Although routinely used in elective cases, robotic surgery remains generally unexplored and potentially underutilised in emergency surgeries.[9,12,13]

This study aimed to systematically review robotic appendicectomy (RA) procedures in elective and emergency settings and assess its indications and feasibility.

Methods

This study was registered with the PROSPERO register for systematic reviews (CRD42022324582). The systematic review was performed in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[14]

SEARCH STRATEGY

A 20-year literature was conducted on the PubMed, ScienceDirect and Cochrane databases for articles published between 2002 and April 2022 [Figure 1]. The used search terms were 'robotic appendectomy' and 'robotic appendicectomy' in addition to Mesh terms.

INCLUSION AND EXCLUSION CRITERIA

All citations directly related to RA were included in this study. Conference abstracts, letters to editors and non-English publications were excluded.

PROCEDURE

Two authors inspected the citations and systematically reviewed them against the inclusion and exclusion criteria. The final list of citations was compiled by consensus between the two authors. The articles retrieved were studied based on their nature, date of publication, aims and findings in relation to RA and the type of robotic system used. In cases where the type of robotic system used was not clearly stated

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in the manuscript, the corresponding author was contacted for confirmation. In one study, the type of robotic system used was not clearly mentioned, and the authors could not be reached.

QUALITY ASSESSMENT AND SYNTHESIS

The retrieved citations were read for further assessment of eligibility. The authors' method of identifying and evaluating data complied with the PRISMA checklist and has been reported in line with assessing the methodological quality of systematic reviews (AMSTAR 2).[15] There was good compliance with the Amstar 2 tool, reporting 'Yes' in 11 criteria and 'Partial yes' in two. The 'Nos' were related to meta-analysis, which was not applicable in this study.

The Medical Education Research Study Quality Instrument (MERSQI) was used to assess the quality of the included studies.[16] This instrument contains 10 items that reflect six domains of study quality including study design, sampling, type of data, validity, level of data analysis and outcomes. The score represents the mean of two independent assessors' quality estimations of each citation. MERSQI's maximum score is 18, with a potential range of 5 to 18. The maximum score for each domain is three. The mean quality score was calculated to be 10.72 ± 2.56, while the moderate quality score of citation was ~11. A score of ≥13 indicates high quality and a score of 5–9 indicates low quality.

RISK OF BIAS WITHIN AND ACROSS STUDIES

The risk of bias was assessed in a blind manner; the mean score between the two raters was calculated if the scores did not match. The authors also controlled for accumulated risk of bias by grading the body of evidence of the findings according to the MERSQI score.

Results

CITATION SELECTION AND CHARACTERISTICS

The 20-year systematic search yielded 1346 citations. After scanning the titles and abstracts, relevant citations were extracted. The inclusion and exclusion criteria were applied, and duplicated and irrelevant citations were excluded. A final list of nine citations were considered suitable for the research rationale [Figure 1].

The full texts of the articles were read by two authors for further evaluation. The tabular analysis of the citations on RA procedures, which comprises details about the studies such as the journal in which they were published, aims and findings of the studies, robotic system used, quality scores and evidence grades [Table 1].[17–25]

RISK OF BIAS WITHIN AND ACROSS STUDIES

The authors applied MERSQI scores in the current systematic review since it has been demonstrated to be a reliable and valid instrument for measuring methodological quality in research.[16] Additionally, to decrease the risk of bias within the studies included in the current systematic review, the authors excluded recommendations, letters to editors, abstracts and commentaries. The full texts of the retrieved citations were read for further assessment of eligibility. There

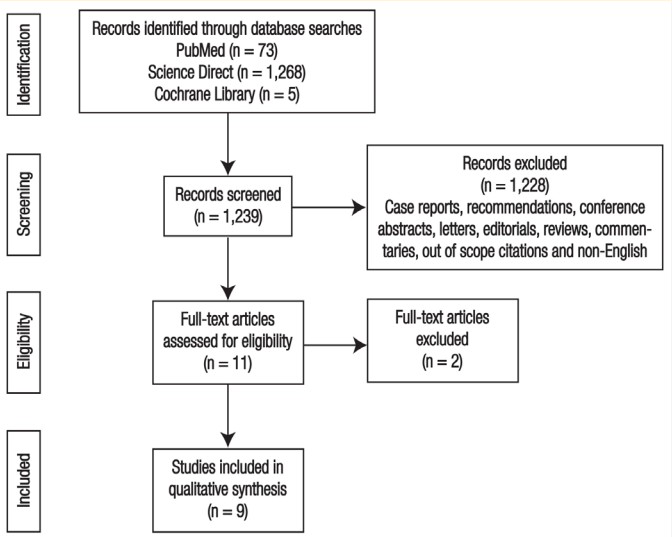

Figure 1: Flow diagram of the systematic search.

Table 1: Tabular analysis of the included citations

Author and year of publication	Journal	Type of study	Objective	Patients (n)	Indications	Robotic system	Findings/outcomes	MERSQI scores* (Quality)
Akl *et al.*[17] (2008)	The International Journal of Medical Robotics and Computer Assisted Surgery	Cohort study	To assess the feasibility, safety and pathological findings of incidental RA in patients undergoing robotic gynaecological surgeries.	Altogether Elective RA 107 patients.	Chronic pelvic pain and gynaecological malignancies.	Da Vinci robotic system	Incidental RA was performed safely and effectively in conjunction with other robotic gynaecological procedures with no perioperative complications related to appendicectomy.	13 (high)
Yi *et al.*[18] (2016)	Surgical Endoscopy	Case report	To develop and validate one low-cost and easy-use minimally invasive surgical robot system "Micro Hand S" that surgeons can use to resolve the complicated surgeries challenge.	Altogether, 10 patients (Emergency RA = 3)	Acute appendicitis	Micro Hand S robotic surgery	No intraoperative complications or technical problems were encountered with the use of the domestic produced "Micro Hand S" All patients recovered and were discharged from hospital without complications.	8 (low)
Yi *et al.*[19] (2017)	Surgical Endoscopy	Case series	To assess the safety and feasibility of the Chinese minimally invasive surgical robot system "Micro Hand S" in its first clinical use	Altogether, three patients (Emergency RA = 2)	Acute appendicitis	Micro Hand S robotic surgery	The robot system "Micro Hand S" was safe and effective with no intraoperative complications or technical problems being encountered with its use. At three-month follow up, patients had no adverse reactions.	8 (low)
Bütter *et al.*[20] (2017)	Journal of Robotic Surgery	Cohort study	To present the results of the first paediatric robotic surgery program in Canada.	Altogether, 41 children Interval RA = 1	Interval appendicectomy.	Da Vinci robotic system	All robotic procedures were completed without conversion, with no technical failures due to the robotic system.	13 (high)
Orcutt *et al.*[21] (2017)	International journal of surgery case reports	Case series	To present cases with appendiceal mucoceles that were successfully treated with minimally invasive approaches.	Altogether, two patients Elective RA = 1	Mucocele of appendix	Unclear	The robotic approach allowed meticulous dissection and intact removal of appendiceal mucocele with no intra- or post-operative complications.	6.5 (low)
Hüttenbrink *et al.*[22] (2018)	Langenbeck's Archives of Surgery	Cohort study	To investigate the safety and patients benefit of incidental appendicectomy during RALRP.	Altogether, 53 patients Elective RA = 53 Histopathology: inconspicuous = 33, post inflammatory changes = 11,chronic appendicitis = 4, appendicitis = 3 and neoplasia = 2	RALRP with incidental appendicectomy	Da Vinci robotic system	Incidental appendicectomy during RALRP is a feasible and safe procedure and could be considered for patients scheduled for robot-assisted prostate surgery.	13.5 (high)

RA = robotic appendicectomy; AA = acute appendicitis; RALRP = robot-assisted radical prostatectomy.

**MERSQI: Low quality 5–9 ; Moderate quality 10–12 ; High quality ≥13.*

Table 1 (cont'd.): Tabular analysis of the included citations

Author and year of publication	Journal	Type of study	Objective	Patients (n)	Indications	Robotic system	Findings/outcomes	MERSQI scores* (Quality)
Yao *et al.*[23] (2020)	International Journal of Surgery	Cohort study	To evaluate the feasibility and safety of the Micro Hand S surgical robot in general surgery.	Altogether, 81 patients (Emergency RA = 3)	Acute appendicitis	Micro Hand S robotic surgery	RA was successfully performed in all three patients.The operative time (min) 130.0,blood loss (ml) 40.0 and hospital stay (day) 6.3	11 (moderate)
Kelkar *et al.*[24] (2020)	Surgical Endoscopy	Cohort study	To provide an initial safety analysis of the first 30 surgical procedures performed using the Versius Surgical System.	Altogether, 30 patients (Emergency RA = 4)	Acute appendicitis	Versius Surgical System	RA was successfully performed in all four patients.The operation time ranged between 80-135 minutes and estimated intraoperative blood loss was negligible.	10 (moderate)
Quilici *et al.*[25] (2021)	Surgical Endoscopy	Cohort study	To define the value, cost and fiscal impact of robotic-assisted procedures in abdominal surgery and provide clinical guidance for its routine use.	Altogether, 34,984 patients (few unspecified number RA)	Abdominal surgery including AA	Da Vinci surgical system	RA were performed at a higher cost vs laparoscopic appendicectomy, with an average total cost per case $13,210 vs $7,709. Robotic technology for gastrointestinal procedures is significantly more expensive than other surgical techniques.	13.5 (high)

RA = robotic appendicectomy; AA = acute appendicitis; RALRP = robot-assisted radical prostatectomy.

**MERSQI: Low quality 5–9; Moderate quality 10–12; High quality ≥13.*

was risk of bias within studies, especially due to the small number of papers on RA procedures; however, there was a good number of RA procedures mentioned in the included cohort studies.

RESULTS OF QUALITY AND EVIDENCE-GRADE ASSESSMENTS

For the included citations, the mean quality score was calculated to be 10.72 ± 2.56, with the scores ranging from 6.5 to 13.5; there were four high-quality, two moderate-quality and three low-quality studies.

RESULTS OF INDIVIDUAL STUDIES

A total of 174 procedures were included in this review, including 161 elective, 12 emergency and one interval RA. Four citations were considered to be high quality based on their MERSQI score. Only one study failed to specify the exact number of included RA procedures.

In a retrospective analysis by Akl *et al.*, 107 patients underwent elective RA in conjunction with other robotic gynaecological procedures between 2004 and 2007. The study's main objective was to evaluate the feasibility and safety of RA. The patients had a postoperative follow-up period of at least six weeks, and the researchers encountered no perioperative complications related to the concomitant gynaecological procedures. Further, none of the patients required conversion to open or laparoscopic surgery. Additionally, the researchers found that RA could be performed effectively without significantly prolonging the operative time.

A study by Bütter *et al.* aimed to measure the outcome of the first paediatric da Vinci surgery programme in Canada among 41 children. All procedures were completed without the need for conversion to open or laparoscopic surgery. The researchers found that the use of the robotic system offered them a significant advantage compared to laparoscopic surgery. These advantages included a markedly enhanced magnification and three-dimensional visualisation, increased instrument dexterity and improved precision and ease of suturing.

Hüttenbrink *et al.*'s study aimed to investigate the safety and benefit of performing incidental RA during robotic-assisted laparoscopic radical prostatectomy (RALRP) among 53 patients between 2012 and 2014. The findings supported the decision to perform the incidental RA as no intraoperative or postoperative complications were encountered. Additionally, the median hospital stay was five days, which was similar to the length of stay following other RALRP procedures performed during the same period.

Quilici *et al.*'s citation included a cohort study of 34,984 patients in which the value, cost and fiscal

impact of robotic abdominal surgeries were compared to those of open and laparoscopic surgeries. The cost of RA was significantly higher than that of the laparoscopic technique, with an average total cost per case of $13,210 versus $7,709 for RA and laparoscopic appendicectomy, respectively. In addition, the mean duration of robotic surgery was longer than that of the laparoscopic technique in abdominal surgery. However, this study contained few RA procedures, which made it difficult to obtain a valid comparison between the different surgical approaches. Furthermore, the use of robotic technology for abdominal surgeries provided no significant difference in clinical outcomes when compared with the other surgical techniques.

SYNTHESIS OF THE STUDIES

There was a difference in endpoints across the studies, with the endpoints including rate of conversion to open surgery, length of postoperative hospital stay, intraoperative blood loss and operative time. The mean length of hospital stay was 5.2 days and the estimated mean blood loss was 22.5 mL.

CONVERSION RATE AND INTRA-OPERATIVE COMPLICATIONS

Akl *et al*. evaluated the safety and feasibility of elective RA during gynaecologic robotic surgery.[17] In this study of 107 patients, none required conversion to laparoscopic or open surgery. Hüttenbrink *et al*. studied 53 patients who underwent elective RA during RALRP and found no intraoperative or postoperative complications related to the incidental RA; they encouraged its consideration for patients scheduled for RALRP.[22]

LENGTH OF HOSPITAL STAY

Kelkar *et al*. aimed to analyse the safety and effectiveness of the Versius surgical system in its first in-human use on 30 patients undergoing gynaecological or general surgical procedures.[24] Four patients with acute appendicitis underwent emergency RA and had an average length of hospital stay of four days (2–7 days).

Yao *et al*. evaluated the feasibility and safety of the surgical robot, Micro Hand S. Of 81 patients who underwent robotic surgery, three underwent emergency RA for acute appendicitis and had an average postoperative hospital stay of 6.3 days.[23]

Hüttenbrink *et al*. reported an average postoperative hospital stay of five days for elective RA during RALRP versus six days for all other RALRP performed in the same period.[22]

ESTIMATED BLOOD LOSS

Kelkar *et al*. reported that the estimated blood loss was negligible (<5 mL) in all four patients who underwent an emergency RA for acute appendicitis.[24] Yao *et al*. reported an intraoperative blood loss of 40.0 mL amongst all three patients who underwent emergency RA.[23]

OPERATIVE TIME

Kelkar *et al*. reported a median operative time of 105 min (80–135 min) among four patients who underwent emergency RA, while Yao *et al*. reported a similar operative time of 130.0 min between emergency RA cases.[23,24]

Akl *et al*. measured the operative time of 10 consecutive robotic cases and reported an average operative time of 3.4 min (range 2–6 min).[17] The authors concluded that RA can be performed effectively without any significant difference in the operative time.

In contrast, Quilici *et al*. concluded that the mean duration of robotic surgery was significantly longer compared to that of laparoscopic surgery; however, the RAs were too few to make a valid comparison between the different surgical approaches.[25]

Discussion

To the best of the authors' knowledge, this is the first review to focus on robotic appendicectomy procedures. The current review shows that RA can be considered a feasible and safe technique, mainly in elective settings. Indications for RA included acute and chronic appendicitis, mucocele resection, as well as performing other robotic gynaecological and urological procedures.

Laparoscopic appendicectomy remains the gold standard for the management of appendicitis due to benefits such as a lower incidence of wound infections, less postoperative pain and shorter hospital stay compared with open appendicectomy.[26] Whilst the available literature on the use of robotic surgery in appendicectomy is somewhat limited, surgeons have reported more dexterity, greater precision, better visualisation and improved range of motion with its utilisation in abdominal surgery.[8,9,27] These major features have led to its widespread adoption in cases of difficult operative access and technically challenging procedures.[28]

In light of the recent COVID-19 pandemic, surgeons now consider robotic surgery to be a safe

alternative for clearing the backlog of operations whilst reducing the risk of potential viral transmission. The offered advantages of robotic surgery include operating with lower pneumoperitoneum pressures, reducing the length of hospital stay and minimising contact between the patient and healthcare workers during surgery, especially after trocars placement.[11,29,30]

Despite its advantages, robotic surgery still has many drawbacks, including limited availability and the need for additional specialised surgical robotic training. In addition, the high cost of robotic surgery compared to laparoscopic or open surgery remains one of its main limitations. Robotic surgery requires specialised training, and the cost of acquiring, operating and maintaining a surgical robotic system is significantly higher compared to other surgical techniques.[25,31,32]

The current study included three robotic systems: the da Vinci robot, the Versius and the Micro Hand S. The da Vinci robot launched in 1999 and has remained the predominant robotic surgical system for over 20 years. However, with a cost of £1.7 million per robot, £1,000 per patient for disposables and £140,000 maintenance fees per year, newer cost-effective systems have emerged to improve on the da Vinci.[33,34] The novel Micro Hand S has demonstrated significantly lower hospitalisation and operative costs in comparison to the da Vinci robotic system, (P <0.05). The surgical instruments of the Micro Hand S have unlimited use, whereas the instruments of the da Vinci surgical robot have a 10-use limit. Furthermore, the surgical instruments of the Micro hand S robot cost about 1,000 yuan per set, which is roughly equivalent to £119, an amount that is less than the 2,000 yuan (approximately £239) it costs per set for the da Vinci.[35,36] The Versius surgical system is the first UK-built surgical robot and is said to be the next major rival to the da Vinci. Although reports are limited about the specific costs of this novel system, the Versius robot offers the advantages of being smaller, more versatile and more portable, improving its cost-effectiveness.[34]

The main limitations of this review include the limited number of selected citations that studied RA and the absence of randomised trials during this 20-year period. However, there was a good number of procedures in the cohort studies included in this review. Future research is needed to further evaluate the strengths and weaknesses of each robotic surgical system in appendicectomy, with a particular focus on its application in emergency settings and its cost-effectiveness.

Conclusion

The current review included studies which considered RA to be a safe and feasible technique. RA could be performed effectively without the need for conversion and with minimal blood loss. The operative time and length of hospital stay are within acceptable limits. However, the major drawback of robotic surgery is its high cost. Future studies are needed to further evaluate the different robotic surgical systems and their use in appendicectomy, with a focus on its application during emergency procedures and its cost-effectiveness.

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