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SETTING THE SCENE
REVIEW

# The age of robotic surgery – Is laparoscopy dead?

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**KEYWORDS**

Robotic urological surgery;
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**ABBREVIATIONS**

3D, three-dimensional;
dVSS, da Vinci Surgical System;
EAU, European Association of Urology;
ICG, indocyanine green;

**Abstract** ***Introduction:*** Robot-assisted laparoscopic surgery (RALS) has become a widely used technology in urology. Urological procedures that are now being routinely performed robotically are: radical prostatectomy (RP), radical cystectomy (RC), renal procedures – mainly partial nephrectomy (PN), and pyeloplasty, as well as ureteric re-implantation and adrenalectomy.

***Methods:*** This non-systematic review of the literature examines the effectiveness of RALS compared with conventional laparoscopic surgery for the most relevant urological procedures.

***Results:*** For robot-assisted RP there seems to be an advantage in terms of continence and potency over laparoscopy. Robot-assisted RC seems equal in terms of oncological outcome but with lower complication rates; however, the effect of intracorporeal urinary diversion has hardly been examined. Robotic PN has proven safe and is most likely superior to conventional laparoscopy, whereas there does not seem to be a real advantage for the robot in radical nephrectomy. For reconstructive procedures, e.g. pyeloplasty and ureteric re-implantation, there seems to be advantages in terms of operating time.

***Conclusions:*** We found substantial, albeit mostly low-quality evidence, that robotic operations can have better outcomes than procedures performed laparoscop-

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IVC, inferior vena cava;
NSGCT, non-seminomatous germ cell tumour;
(RA)PN, (robot-assisted) partial nephrectomy;
PSM, positive surgical margin;
RAIL, robot-assisted inguinal lymphadenectomy;
RALS, robot-assisted laparoscopic surgery;
RALUR, robot-assisted laparoscopic ureteric re-implantation;
(RA)RN, (robot-assisted) radical nephrectomy;
(RA-)RPLND, (robot-assisted) retroperitoneal lymphadenectomy
(RA)RC, (robot-assisted) radical cystectomy;
(RA)RP, (robot-assisted) radical prostatectomy;
WIT, warm ischaemia time

ically. However, in light of the significant costs and because high-quality data from prospective randomised trials are still missing, conventional urological laparoscopy is certainly not 'dead' yet.



## Introduction

Robot-assisted laparoscopic surgery (RALS), initially developed by the USA forces as a tele-surgery tool in order to perform procedures in war zones without endangering the surgeon, has become a widely used technology in urological surgery. The first trials on RALS were performed by cardiac surgeons, followed very soon by other specialities like ear, nose and throat (ENT) and gynaecology. Today, RALS has been adopted by many other different specialities, such as colorectal, maxilla-facial and thoracic surgery.

The da Vinci® Surgical System (dVSS; Intuitive Surgical Inc., Sunnyvale, CA, USA) was sanctioned in 2000 by the USA Food and Drug Administration (FDA) and has until recently been the only commercially available robotic surgical system.

Urological procedures that are being performed robotically now are: radical prostatectomy (RP), radical cystectomy (RC), renal procedures – mainly partial nephrectomy (PN) and pyeloplasty, as well as ureteric re-implantation and adrenalectomy. The technical advantages of the dVSS compared to conventional laparoscopy include: the magnified three-dimensional (3D) high-definition vision, where the camera is controlled by the surgeon and not the assistant; as well as the EndoWrist® instruments (Intuitive Surgical Inc.) with seven degrees of motion, motion scaling, and tremor reduction. The lack of haptic feedback and the tremendous costs associated with the purchase of the dVSS, disposables, and maintenance are obvious disadvantages.

Healthcare providers and hospitals are faced with the question of whether the robotic approach is indeed superior and more effective than conventional laparoscopic procedures or if they are spending 'money for nothing', as recently stated by the author of a critical paper on endometrial robot-assisted operations. This non-systematic review gives a critical insight into the contemporary literature and examines the effectiveness of RALS compared with conventional laparoscopic surgery for the most relevant urological procedures.

## Methods

For this non-systematic review we identified articles in PubMed/Medline during August 2017. We used the search terms 'robotic urological surgery' 'robotic' 'laparoscopic' and 'robotic vs laparoscopic' combined with each surgical procedure analysed in this paper. Articles were excluded if they were not published in English or if they were unavailable for viewing in PubMed. Review articles, editorials, commentaries and letters to the editor were included if they contained relevant information.

## Results

### *Robot-assisted RP (RARP)*

Most reviews on RARP describe the low level of evidence for this procedure and a lack of properly conducted prospective randomised trials. Another problem lies within the long learning curve regarding oncological aspects, mainly positive surgical margins (PSMs), as well as functional results. A recent paper calculated that 100–180 operations are required to obtain better results compared to an open procedure [1].

The only prospective randomised trial comparing 151 open RPs to 157 RARPs yielded similar functional outcomes at 12-weeks follow-up [1]. Other authors found no difference between open RP and RARP, even in patients with locally advanced and aggressive tumours on functional outcomes, comparable rates of PSMs, and no difference in the number of lymph nodes retrieved and complications of limited and extended lymphadenectomy [2–4]. A retrospective comparison of 1377 laparoscopic extraperitoneal RPs to 1009 extraperitoneal RARPs showed better results for the robotic approach in terms of operative time, blood loss, hospital stay, and potency recovery [5]. Another review found only two prospective randomised trials comparing the laparoscopic with the robotic approach, both with advantages in terms of continence and potency for the robot [6]. Porpiglia et al. [7] published 5-year outcomes of their prospective randomised study comparing laparoscopic RP and RARP in 2016 and confirmed a two-times greater probability of achieving continence and potency over time for RARP.

In 2012, an international collaborative group published four meta-analyses comparing RARP with open and laparoscopic procedures. They found a statistically significant advantage regarding potency and continence for RARP compared to the open and laparoscopic approaches, lesser transfusion rates compared to laparoscopy, and similar complication rates in all three techniques [8–11]. Pelvic lymphadenectomy can easily be performed using the robot, and a number of reviews showed no difference between robotically performed procedures and other techniques, including complication rates and the number of lymph nodes retrieved [4,12,13].

### *Robot-assisted RC (RARC)*

A recent controversy in the urological community concerned the pattern of recurrence after RARC. Two working groups of the European Association of Urology (EAU) found different recurrence patterns after RARC: whereas the EAU Robotic Urology Section (ERUS) found only 0.7% peritoneal carcinomatosis and 0.3% port-site metastasis after 717 RARC operations, the EAU Section of Uro-Technology (ESUT) described almost 5% disease progression and abnormal metastases, including peritoneal carcinomatosis, in 311 patients with favourable pathological characteristics ($\leq$pT2N0RO) [14].

However, the most recent meta-analysis, including 24 articles, found no differences regarding oncological outcomes between RARC and open RC but a lower 90-day complication rate, lower transfusion rate, shorter time to flatus, and greater lymph node yield in patients who underwent RARC [15,16]. One three-arm trial compared RARC with laparoscopic and open RC, and found no significant differences between the three groups for complications, length of hospital stay, and blood loss. However, operative time was significantly shorter in the conventional laparoscopic RC group [17].

Many centres are still performing an extracorporeal urinary diversion through an abdominal mini-incision, whereas only intracorporeal urinary diversion seems to fully unlock the potential of RARC. Interestingly, despite already being performed in some expert centres worldwide, this approach is still considered as experimental by the EAU-guidelines [18].

### *Robot-assisted radical nephrectomy (RARN)*

Laparoscopic RN is recommended by the EAU for patients with $\geq$T2 renal tumours and localised renal masses not treatable by nephron-sparing surgery [19]. RARN is rarely mentioned in the literature, mainly because of the higher costs and the lack of real advantages compared to the laparoscopic approach. Consequently, there are no reliable comparative data with regard to RARN vs the conventional laparoscopic approach [20]. However, over the last decade the robot has been used in high-volume centres to operate on patients with advanced RCC including tumour thrombus into the inferior vena cava (IVC). Gill et al. [21] recently presented their series of 16 patients with level II and III IVC thrombus. The median operative time was 4.9 h, median (range) blood loss was 375 (200–7000) mL, and there were no conversions to open surgery.

*Robot-assisted PN (RAPN)*

PN is considered the 'gold standard' for most renal tumours. Many studies, mostly retrospective, comparing RN with PN showed increased cardiovascular events and overall mortality, if RN was performed. Therefore, nowadays almost any kidney tumours will be assessed by the individual surgeon to determine whether it is amenable to a PN. In light of the advantages of minimally invasive renal surgery in terms of cosmesis, postoperative pain and hospital stay, and considering the technical challenges associated with conventional laparoscopy, RAPN seems to have obvious advantages.

One meta-analysis of 598 operations found no significant differences in all relevant perioperative parameters between the laparoscopic and the robotic procedure, but criticised the quality of the individual studies [22]. Another meta-analysis, with 717 patients, showed shorter warm ischaemia time (WIT) and no differences in complication rate, operative time, conversion and PSM rates [23], when comparing the robotic with the conventional laparoscopic procedure. One contemporary meta-analysis, with 4919 patients from 25 studies [24], showed decreased complications, less conversions to open surgery, reduced PSM rates and shorter WIT in the robotic group, despite larger and more complex tumours compared to the laparoscopic group. Another meta-analysis, with 2240 patients, revealed no differences in complications, but lower conversion rates, and conversion to RN, as well as shorter WIT and better postoperative renal function in the robotic group [25]. Complex tumours of $>4$ cm and with high R.E.N.A.L. (Radius; Exophytic/Endophytic; Nearness; Anterior/Posterior; Location) nephrometry scores are increasingly manageable with the robotic approach with good oncological outcomes [26]. In this regard, RAPN has proven feasible and most likely superior to conventional laparoscopy in solitary kidneys and can also be offered to patients with multifocal renal masses and even for a new or recurrent tumour in a kidney previously treated with PN [27].

*Robot-assisted pyeloplasty*

The published data regarding robot-assisted pyeloplasty show excellent results and success rates, ranging between 94% and 100%. A meta-analysis found no differences between the open and the minimally invasive approach (robotic and conventional) in terms of success and complication rates. Patients who underwent minimally invasive operations had a shorter hospital stay, less analgesics but longer operation times. The use of the dVSS showed very good results in re-do operations after failed primary procedures, with success rates of between 78% and 94%. A meta-analysis of nine published studies on 277 robotic cases and 196 laparoscopic cases showed no differences between the two techniques apart from shorter operative time for the robotic operation [28]. The chosen approach, either retroperitoneal or transperitoneal, is based on the surgeons preference and factors such as previous abdominal surgery, obesity, and crossing vessels. However, there are publications, showing shorter operative time and lower conversion rates for the transperitoneal approach [29].

*Robot-assisted laparoscopic ureteric re-implantation (RALUR)*

Ureteric re-implantation can be performed easily using the robot, especially as the open technique can be reproduced step-by-step and the published results are excellent. Nevertheless, currently no consensus exists on the role of RALUR for the surgical management of VUR, especially in children, because higher than expected complication rates and lower success rates than previously obtained with the open approach have been reported by some centres [30].

*Robot-assisted nephroureterectomy*

Nephroureterectomy is almost the ideal procedure to demonstrate the advantages of laparoscopy in terms of cosmesis and analgesic use. However, there is some debate on the oncological safety during excision of the bladder cuff and the closure of the bladder afterwards. It seems to be obvious that the use of the robot facilitates this technically demanding step, especially when the surgeon is able to perform the whole procedure without re-docking for the distal part of the operation [31].

However, a recently published review, despite showing some perioperative advantages for minimally invasive access, found no statistically significant differences between the laparoscopic and the robotic approach, and consequently asked for larger, better designed randomised controlled trials [32].

*Robot-assisted adrenalectomy*

Heger et al. [33] recently published a meta-analysis on 1710 patients who underwent either a minimally invasive (robotic or laparoscopic) or an open adrenalectomy. Blood loss was lowest in the robotic group, the retroperitoneoscopic access and robotic access led to a significant reduction in the length of stay compared with conventional laparoscopy.

*Robot-assisted inguinal lymphadenectomy (RAIL)*

Traditional open inguinal lymphadenectomy for patients with penile cancer has complication rates of between 50% and 90%. In recent years, laparoscopic inguinal lymphadenectomy has been increasingly performed mainly

because of the reduced morbidity, with comparable lymph node yield and oncological outcome. A review of the world literature from 2014 showed no lymphocoeles or lymphoedema with the robotic approach and comparable nodal yields [34]. The most recent publication also showed encouraging results with a complication rate of only 21% in 14 RAIL patients [35].

*Robot-assisted retroperitoneal lymphadenectomy (RA-RPLND)*

In expert hands, RA-RPLND can be performed with the same standard applied to the open approach, including mobilisation of the lymph nodes up to the renal hilum, nerve sparing, and low complication rates. The robot may shorten the learning curve of the laparoscopic approach, therefore making a minimally invasive operation an attractive alternative in stage I non-seminomatous germ cell tumour (NSGCT). The largest series to date for low-risk NSGCT with 47 patients showed a 9% perioperative complication rate, preservation of antegrade ejaculation in 100% of patients, and a recurrence-free rate of 97% at 16 months [35].

A paper from the Mayo Clinic analysed 17 patients who underwent post-chemotherapy RA-RPLND. The mean operative time was 369 min and length of stay was 2.75 days. There were no retroperitoneal recurrences at 22 months and the minor complication rate (Clavien–Dindo Grade II) was 17% [36].

These results compare favourably with conventional laparoscopic post-chemotherapy series, but comparative or even prospective randomised studies are still lacking [37].

*Paediatric robotic surgery*

Theoretically, every procedure that is performed robotically in adults can be done in children as well [38]. However, in children the stakes are high and a recent editorial by Cannon and Ost [39] on minimally invasive surgery of VUR criticised the success rate of extravesical RALUR, which in most papers lies below 90%, whereas the success rate of open extravesical ureteric reimplantation lies somewhere near 98%. A recent population level analysis found a significantly higher rate of complications with the robotic approach compared to open procedures [40]. Currently, no consensus exists on the role of RALUR for the surgical management of VUR. Direct comparisons have been published for paediatric robot-assisted pyeloplasty and showed no difference [41]. A systematic review on paediatric RN and PN found no differences regarding complications, success rates or short-term outcomes between the robotic and the conventional laparoscopic approach, but higher costs and longer operative time in the robotic group [42]. Regarding paediatric robot-assisted laparoscopic pyeloplasty the differences between the robotic operation and conventional laparoscopy in most series to date were only a shorter length of stay for the robotic approach [43]. A limiting factor is body size, which makes operations in children $< 110$ cm challenging, due to increased clashing of the robotic arms.

*Robot-assisted sacrocolpopexy*

Sacrocolpopexy is used for the management of apical vaginal vault prolapse, and can be performed open and laparoscopically. The laparoscopic procedure has a long learning curve and the robot-assisted technique is believed to facilitate the difficult suturing. However, two randomised prospective trials comparing laparoscopic and robot-assisted sacrocolpopexy showed negative results, with higher costs, operative time and postoperative pain in the robotic group [44].

*Costs*

The costs of the dVSS in terms of investment, maintenance, and disposables are considerable. Bolenz et al. [45] compared costs for a RARP, with the laparoscopic and open procedure. They calculated the costs of RARP, laparoscopic RP and open RP as $9450 (USA dollars), $5687 and $4437 per operation, respectively, including maintenance and purchase of the system.

A real and significant cost benefit of the dVSS will only be obvious, if there are evidence-based data that confirm the actual benefit for the patient and the surgeon. To date, in most fields these data are not, yet, available [46,47].

*Technical innovations*

With the most recent dVSS generation, the da Vinci® Xi, the system has become much simpler and versatile: simple docking, chip-on-tip camera, autofocus, overhead instrument arm architecture that facilitates access from virtually any position, the ability to attach the endoscope to any arm, tighter port placement than with the older systems, Bluetooth connection between patient cart and surgeon console, and the ability to reposition the patient without undocking. However, the advantage of image-guided surgery has been implemented only marginally to date [48].

Already available are fluorescence-guided operations (so called Firefly® technology; Intuitive Surgical Inc.). With the injection of indocyanine green (ICG), a fluorochrome that exhibits fluorescence at a wavelength of ~800 nm (near infrared range), and using the near-infrared visualisation system of the dVSS system it is possible to differentiate the prostate from the neurovascular bundle or to visualise sentinel prostatic drainage into pelvic lymph nodes [49].

During RAPN ICG can be used to confirm ischaemia during selective clamping and save tumour-surrounding parenchyma [50].

The Tile Pro feature projects intraoperative ultrasonography and preoperative imaging onto the console screen, facilitating tumour localisation. In the near future, the next steps will be virtual reality surgery, 3D navigation, and image fusion between the operative field and external 3D reconstructions [51]. It can be hoped that those innovations will further improve results of robotic surgery, as for the moment the focus lies on proving safety and feasibility.

*New systems and platforms*

The most relevant patents for the dVSS platform will expire in 2019 and new robotic systems are being introduced by other companies. An excellent review by Rassweiler et al. [52] gives an insight into these new developments. They found at least five console-based robots for laparoscopic multi- and single-port surgery, which are expected to come to market within the next 5 years. New features, amongst others, are an open console (Telelap ALF-X robot and Medtronic), haptic feedback and an eye-tracking system (Telelap ALF-X robot), 5-mm instruments with six degrees of freedom (Avatera), and robot arms attached to the operating table (Medicaroid). The first clinical experiences, robot-assisted hysterectomies, were published for the Telelap ALF-X robot (TransEnterix; Morrisville, NC, USA) and the first devices have been sold in Italy.

*Advantages for the surgeon*

The physical strain of conventional laparoscopy for the surgeon can be severe. Physical strain rates up to 88% have been described in gynaecologists performing laparoscopic surgery. Surgeons performing minimally invasive surgery have a two–three times higher relative risk of becoming unfit for work during their careers than their colleagues not performing laparoscopic procedures [53]. A survey from Stanford University of 1215 surgeons revealed that 55.4% of physical symptoms are attributed to laparoscopic surgery, whilst only 8.3% are related to robotic surgery [54]. Elhage et al. [55], using an *in vitro* simulated vesico-urethral anastomosis, showed that the laparoscopic approach took twice as long as the robotic approach, with significantly more errors and self-reported discomfort.

## Discussion

Robotic surgery was introduced into the field of minimally invasive surgery in urology >15 years ago and is now used in many departments worldwide. The advantages for the operating surgeon are obvious and have considerably contributed to the acceptance of the system. It is important to evaluate the advantage of this technology in comparison with conventional laparoscopic surgery, as the systems available today are significantly more expensive and the financial pressures on healthcare systems are high. In this non-systematic review, we found substantial evidence that RARP is superior to laparoscopy in terms of operative time, blood loss, hospital stay, and potency and continence recovery. For PN, we see fewer complications, less conversions to open surgery, reduced PSM rates and shorter WITs for robotic surgery, even with larger and more complex tumours. For those procedures laparoscopy is certainly declining at least in the developing world. For RARC there has been a controversy regarding the development of unusual recurrence patterns; however, this discussion seems to have ended now. The new 'hot' topic here is to progress from extra- to intracorporeal urinary diversion, which will probably have the biggest patient benefit, as it makes this procedure truly minimally invasive and lowers its impact. The most evident disadvantages of this new technology are the horrendous costs, which impede the distribution of the technology in many countries. There are innumerable rural areas and smaller hospitals worldwide who, for a long time, will not be willing or able, to invest in such expensive robotic technology. They will persevere to offer conventional laparoscopic procedures, and rather invest in smaller improvements, like a 3D-vision system, instead of spending millions for a robotic system.

The future of laparoscopic surgery lies in the hands of robots. The transit from conventional laparoscopic surgery to RALS is not a question of 'if' but of 'when'. New platforms coming to the market together with new features will most likely move this transition forward in time. A reduction in price, which already has started, due to the expiration of patent rights and the consecutive appearance of competitors, together with better designed clinical trials will shift the landscape of minimally invasive surgery towards the 'machine'.

## Conclusion

The dVSS is currently established in urological departments worldwide and is being used successfully for a variety of operations. The literature offers substantial, albeit frequently low-quality evidence, that robotic operations often achieve better outcomes than procedures performed laparoscopically. There is high-quality evidence that the robot has better outcomes in RP and PN and here, the robot can replace conventional laparoscopy. On the other hand, conventional laparoscopy has comparable outcomes to robotic surgery in RN, adrenalectomy, and pyeloplasty. There are also significant costs associated with robotic surgery. Therefore, conventional laparoscopy is certainly not 'dead' yet.

## Conflict of interest

There are no potential conflicts of interest for any of the authors.

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