Peer reviewed article

The da Vinci robotic system for general surgical applications: a critical interim appraisal

Johannes Bodner[a], Florian Augustin[a], Heinz Wykypiel[a], John Fish[a], Gilbert Muehlmann[a], Gerold Wetscher[b], Thomas Schmid[a,]

[a] Department of General and Transplant Surgery, Innsbruck Medical University, Austria
[b] Schnaz County Hospital, Austria

Summary

Principles: The recently introduced robotic surgical systems were developed to overcome the limitations of conventional minimally invasive surgery. We analyse the impact of the da Vinci™ robotic system on general surgery.

Methods: The da Vinci™ operating robot is a telemanipulation system consisting of a surgical arm cart, a master console and a conventional monitor cart. Since its purchase in June 2001, 128 patients have undergone surgery using the da Vinci™ robot in our department. The mean age of the 78 female and 50 male patients was 52 (range 18–78) years.

Results: The procedures included 29 cholecystectomies, 16 partial fundoplications, 16 extended thymectomies, 14 colonic interventions, 10 splenectomies, 10 bariatric procedures, 7 hernioplasties, 6 oesophageal interventions, 5 adrenalectomies, 5 lower lobectomies, 4 neurinomectomies and 6 others. 122 of 128 procedures (95%) were completed successfully with the da Vinci™ robot. Open conversion proved necessary in 4 patients due to surgical problems, and two other procedures were completed by conventional laparoscopy due to robot system technical errors. 30-day mortality was 0%, one redo-operation was necessary and two lower complications not requiring surgical re-intervention occurred. The resection margins of all tumour specimens were histologically tumour free.

Conclusions: Various general surgical procedures have proved feasible and safe when performed with the da Vinci™ robot. The advantage of the system is best seen in tiny areas difficult of access and when dissecting delicate, vulnerable anatomical structures. However, in view of longer operating times, higher costs and the lack of adequate instruments, robotic surgery does not at the moment represent a general alternative to conventional minimally invasive surgery.

Key words: robotics; da Vinci; laparoscopy; thoracoscopy; general surgery

Introduction

The introduction of minimally invasive surgery some 20 years ago marked a milestone in the field of operative medicine [1]. It has resulted in reduced tissue trauma and allows quicker recovery, with early reintegration into the patients' normal social and working processes. Minimally invasive surgery represents a basic advance in surgery and new horizons have been opened [2–5].

Although today minimally invasive surgery is well established in general surgery, its routine application is still restricted to technically relatively simple surgical procedures: for cholecystectomies, fundoplications, pulmonary wedge resections and all kinds of hernia repairs it has achieved gold standard status and is used all over the world. A multitude of other, more complex minimally invasive procedures are being carried out successfully in some centres but have not yet achieved general acceptance [6–10].

Further developments in the fields of computer technology, micromechanics and data transfer have recently led to the implementation of robotic surgical systems [11–13]. This has raised hopes of overcoming the limitations of conventional minimally invasive surgery and thus throwing it open to more surgeons and procedures. At Innsbruck University Hospital a da Vinci™ operating robot (Surgical Intuitive, Inc., Mountain View, CA, now occupying a monoply position in surgical robotic systems) was purchased in June 2001. To maximise utilisation and reduce maintenance costs it is jointly used by the departments of General and Transplant Surgery, Cardiac Surgery, Urology and Gynaecology/Obstetrics.

No financial support declared.

Observation material and methods

The da Vinci™ operating robot is a telemanipulation system composed of a surgical arm cart, a master console and a conventional monitor cart [14].

Figure 1

The three components of the da Vinci™ robotic system.

a

b

Figure 2a + b

The surgeon sits at the console in an ergonomic, comfortable position and handles the robotic instruments on the surgical arm cart via telemanipulation.

Figure 3

The multiarticulated robotic instruments allow for precise manoeuvring within tiny areas of difficult access.

The patient side-placed surgical arm cart is a manipulator unit with two instrument arms and a central arm to guide a two-channel endoscope. At the master console the surgeon handles telemanipulators and optical controls using three-dimensional vision. His intuitive hand movements are transmitted from the handles to the tips of the laparoscopic instruments on the surgical arm cart.

The range of robotic instruments is limited. A cautery hook, different forceps, scissors, needle holder, clip applicator and an ultrasound coagulation device (Endosurg™) are available. Stapler devices are not yet available. The instruments are reusable, most of them up to ten times.

The main technological advantages of this system are realistic 3-D imaging, motion-scaling and tremor filtration. Thus, it facilitates more precise and accurate endoscopic surgery.

Since its purchase and approval by the local ethics committee, 128 patients have been operated on with the da Vinci™ robotic system in our department. The mean age of the 78 female and 50 male patients was 52 (range 18–78) years. Informed consent was given by all patients. The different robotic procedures are classified into 12 operating groups (table 1). The following procedural steps were performed robotically:

– cholecystectomy: dissection and controlling of the cystic artery and the cystic duct – extirpation of the gallbladder from its hepatic bed
– partial posterior fundoplication: mobilisation of the right and left diaphragmatic crura – mobilisation of the distal oesophagus – closure of the hiatal crura – creation and fixation of the partial posterior fundic wrap (the entire procedure)
– procedures on the left hemicolon: central clipping and dissection of the colonic arteries and veins – total mobilisation of the affected colonic segments (if necessary including a total mesorectal rectal resection) – mobilisation of the left colonic flexure
– extended thymectomy: resection of the thymus en bloc with the precordial fatty tissue laterally to both phrenic nerves, caudally to the diaphragm and cranially along the upper thymic horns up to far cervically – dissection and controlling of the thymic veins at the innominate vein with clips (the entire procedure)
– splenectomy: division of the peritoneal attachments and the splenic ligaments – controlling of the short gastric vessels – dissection of the splenic hilum
– bariatric procedures: installation of an adjustable gastric banding – installation of a gastric pacing (the entire procedures)
– extraperitoneal inguinal hernioplasty: retraction of the hernial sack – dissection of the spermatic cord and vessels / of the rotundum liga-

Table 1

Robotic procedures: numbers and indications.

Procedure	n	Indication (n)
Cholecystectomy	29	Cholelithiasis
Partial fundoplication	16	Gastrooesophageal reflux disease
Colonic intervention	14	Diverticulosis (11)
		Sigmoid / rectal carcinoma (3)
Extended thymectomy	16	Thymoma (6)
		Myasthenia gravis (7)
		Others (3)
Splenectomy	10	Idiopathic thrombopenic purpura (5)
		Lymphoproliferative disorder (3)
		Others (2)
Bariatric procedures	10	Morbid obesity
Hernioplasty	7	Inguinal hernia
Oesophageal intervention	6	Oesophageal cancer (4)
		Benign oesophageal tumour (2)
Adrenalectomy	5	Adenoma (3)
		Phaeochromocytoma (1)
		Metastasis (1)
Lower lobectomy	5	Non small cell lung cancer (T1N0)
Neurinomectomy	4	Thoracic, paravertebral neurinoma
Others	6	Various benign tumors

ment – positioning of the mesh (the entire procedure)
- oesophageal procedures: thoracoscopic dissection of the oesophagus and lymph node dissection for oesophageal cancer; oesophagomyotomy – resection of a submucosal tumor – suture of the oesophagomyotomy
- adrenalectomy: dissection of the adrenal gland – controlling of the adrenal veins with clips (the entire procedure)
- lower pulmonary lobectomy: dissection of the pulmonary ligament – dissection of the lower pulmonary vein – dissection, ligation and division of the lower apical and lower mainstem arteries – dissection of the lower lobe bronchus – lymph node dissection
- resection of a thoracic paravertebral neurinoma: incision of the parietal pleura – resection of the tumour, controlling of its vessels (the entire procedure)
- others: resection of an ectopic parathyroid from the aortopulmonary window (the entire procedure); resection of a mediastinal goitre (the entire procedure)

The interventions were performed by six different surgeons who were experienced laparoscopists. Before starting the institutional robotic programme, three surgeons received prior training on the robot at the company's laboratory in Utrecht, Netherlands. The other three surgeons completed special training at the department with defined manoeuvres (knot tying, grasping of various objects etc).

Results

122 of 128 procedures (95%) were successfully completed with the da Vinci™ robot. Open conversion was necessary in four cases posing surgical problems: in the very first pulmonary lobectomy procedure dissection of the lower stem pulmonary artery led to major bleeding, and in another lobectomy procedure problems arose due to an anatomical anomaly of the pulmonary artery. In one thymectomy procedure a lesion of the mammary artery occurred due to collateral tissue damage by a robotic instrument. The fourth open conversion concerned a patient with a 17×8 cm large paravertebral thoracic neurinoma. Conversion to the conventional laparoscopic approach was necessary in two cases due to technical robotic problems which, however, did not compromise patient safety (sudden total breakdowns of the system which could not be booted up again). Besides the above mentioned two bleedings with a blood loss of 300 ml and 90 ml in the pulmonary lobectomy and thymectomy procedures respectively, there was no relevant (>50 ml) blood loss in any other procedure. 30-day mortality in all 128 patients was 0%. One redo-operation was necessary in a patient after oesophageal dissection (a persistent lymph fistula was clipped thoracoscopically). Lower complications without surgical re-intervention (n = 2, 2%) included transient recurrent nerve palsy after resection of an ectopic parathyroid from the aortopulmonary window and a haematoma after splenectomy. A wound infection of a port side was observed in four patients (3%). The resection margins of all tumour specimens were histologically tumour free.

The operating times for the different procedural groups are shown in table 2. Times for robotic procedures are divided into set-up time, console time and total operating time. The set-up time includes connection of the components, booting

Table 2

Times for each procedure (median in minutes).

Procedure	Set-up	Console	Total
Cholecystectomy	35	52	98
Partial fundoplication	35	154	198
Colonic intervention	45	178	310
Extended thymectomy	40	130	150
Splenectomy	35	107	147
Bariatric procedures	45	137	167
Hernioplasty	40	67	118
Oesophageal intervention	40	117	147
Adrenalectomy	40	128	181
Lower lobectomy	70	270	318
Neurinomectomy	30	51	65

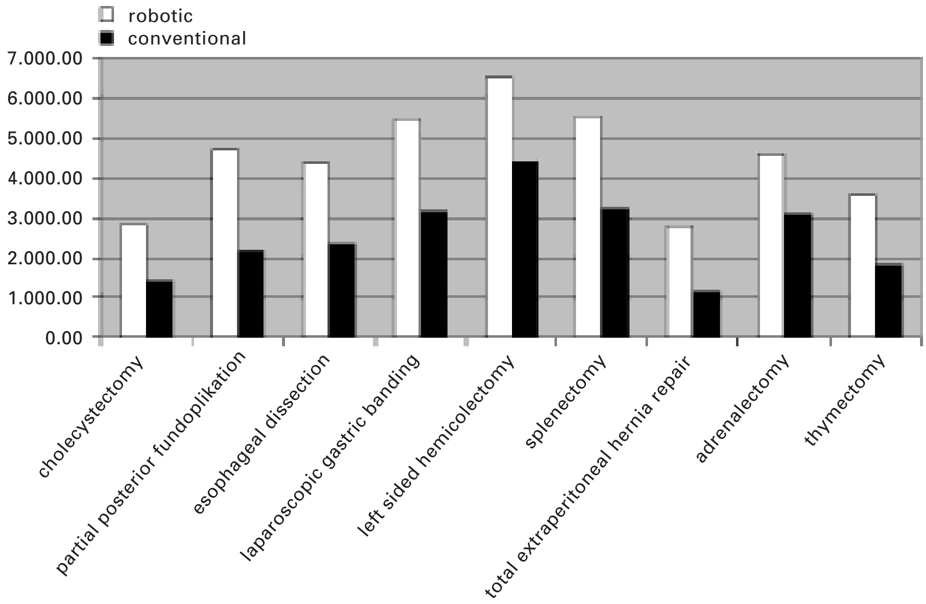


Figure 4

Procedural costs (median per patient, in €): robotic versus conventional minimally invasive surgery.

Table 3

Procedural costs per patient (median in €).

Procedure	Material	Personnel	Overall
Cholecystectomy	2308	518	2826
Partial fundoplication	3732	990	4722
Extended thymectomy	2857	704	3561
Splenectomy	4815	747	5562

up of the robotic system, and sterile draping of the surgical arm cart. The console time is that part of the total operating time (first cut to skin closure) during which the surgeon operates on the console, the time of the effective robotic act.

In 2001 the purchase cost for the da Vinci™ robotic system accounted for € 1,000,000, while the cost of maintenance per year is approx. € 100,000. The robotic approach is significantly more expensive than conventional minimally invasive surgery. Figure 4 shows the institutional procedural costs for the various procedures in comparison with the corresponding laparoscopic (thoracoscopic) costs. This extra cost is due to longer operating times, as well as the high per-minute cost of the robot itself and higher costs for the robotic instruments, which are re-usable ten times only. Table 3 gives the material costs, personnel costs and overall costs for the robotic procedures cholecystectomy, fundoplication, the gastric banding procedure and splenectomy.

Discussion

Robotic surgery was originally developed to render possible a kind of telesurgery bridging thousands of kilometers or even continents. Although the feasibility of this aspect was proven and gained some media attention, it is not the future of robotic surgery. More probable opportunities for robots in general surgery are those interventions for which only the robot renders possible or noticeably simplifies a minimally invasive approach, i.e. procedures in which precise dissection and reconstruction of delicate, vulnerable anatomic structures take place in tiny areas difficult of access [15–17]. In the light of our present experience, we regard extended thymectomies and other mediastinal interventions, adrenalectomies, oesophageal procedures and total mesorectal excision deep in the pelvis minor as appropriate for a robotic approach. The steric vision and the manoeuvrability of the instruments are of great assistance in pulmonary lobectomies, although the lack of robotic stapler devices and flexible instruments hampers full robotic performance. For the other interventions evaluated the robot either does not offer relevant advantages over conventional laparoscopy to justify its extra cost (cholecystectomy, fundoplication, bariatric procedures, extraperitoneal inguinal hernioplasty) or the robot's current level of development is inadequate (colonic procedures, splenectomy). In our department the programme has been momentarily confined to adrenalectomies and thoracic and oesophageal procedures.

The patients' satisfaction following a robotic approach is high. In a recent follow-up study 33 (30–35) months after robotic cholecystectomy the robotic approach was favourably viewed by all 23 patients and 22 (96%) reported that they would opt for a robot-assisted procedure again if offered [18]. This ready acceptance of the robotic approach may result from the satisfactory cosmetic and symptomatic results, but also from the patients' impression that they had taken part in the dawn of a new surgical era.

On the other hand, robotic surgery is significantly more expensive than conventional minimally invasive procedures (figure 4). This difference results from the use of specific robotic instruments, higher costs for disposables and the longer total operating time [19]. The time delay may be explained by the learning curve. However, with increasing experience on the part of the entire team (surgeons, scrub nurse, theatre attendant), the set-up time has been markedly reduced in our department from approx. 90 minutes in the first robotic cases to the present 35–40 minutes, and no longer involves any time loss.

Future perspectives

"Hybrid operations" could offer a future field for robotic applications: most parts of a surgical procedure would be done as conventional minimally invasive surgery, and the robot would be used only for the technically most challenging parts of the operation, such as vascular or intestinal anastomoses.

Image fusion is another future domain for the robot. At this stage the superposition of different radiologic imaging systems permits more precise and detailed surgical planning. The da Vinci system will implement this technique in the operating room itself by flashing a patient's scan images into the virtual three-dimensional view on the console. This will enable the surgeon to more easily detect and identify hidden anatomical structures, and in this way robotic surgery will help to make minimally invasive surgery safer.

The greatest potential for the da Vinci robot probably lies in its impact on surgical training. It will be possible to carry out a particular patient's complete surgical procedure using his CT scans and robotic virtual-reality training programmes. Thus, similar to a pilot on a flight simulator, surgeons in training will perform new operations only after performing them successfully in virtual reality.

Conclusion

With the da Vinci surgical robot surgery regains everything it lost with the introduction of the minimally invasive technique: intuitive control over the surgical instruments and steric perception of the operative field. However, the disadvantages are still great and a series of unsolved problems continue to hamper its broader and routine application: the lack of haptics is only partially compensated by the three-dimensional view, the system is cumbersome and its dimensions and rigidity hamper rapid change of the patient's position, as well as direct access for the patient-side assistant. A breakthrough for the da Vinci system in the field of general surgery presupposes further system development as well as a drastic reduction of costs. The challenge for today's robotic surgeons is to advance the system through clinical research in such a way that it becomes suitable and indispensable for routine general surgery.

Correspondence:
Johannes Bodner, MD
Department of General and Transplant Surgery
Innsbruck University Hospital
Anichstrasse 35
A-6020 Innsbruck
johannes.bodner@uibk.ac.at

References

1 Spaner SJ, Warnock GL. A brief history of endoscopy, laparoscopy, and laparoscopic surgery. J Laparoendosc Adv Surg Tech A 1997;7:369–73.
2 Korolija D, Sauerland S, Wood-Dauphinee S, Abbou CC, Eypasch E, Caballero MG, et al. Evaluation of quality of life after laparoscopic surgery: evidence-based guidelines of the European Association for Endoscopic Surgery. Surg Endosc 2004;18:879–97.
3 Robinson TN, Stiegmann GV. Minimally invasive surgery. Endoscopy 2004;36:48–51.
4 Hunerbein M, Gretschel S, Rau B, Schlag PM. Reducing trauma with minimally invasive surgery. Evidence and new strategies. Chirurg 2003;74:282–9.
5 Efron DT, Bender JS. Laparoscopic surgery in older adults. J Am Geriatr Soc 2001;49:658–63.
6 Davies MM, Larson DW. Laparoscopic surgery for colorectal cancer: the state of the art. Surg Oncol 2004;13:111–8.
7 Gagner M, Rogula T, Selzer D. Laparoscopic liver resection: benefits and controversies. Surg Clin North Am 2004;84:451–62.
8 Edwin B, Mala T, Mathisen O, Gladhaug I, Buanes T, Lunde OC, et al. Laparoscopic resection of the pancreas: a feasibility study of the short-term outcome. Surg Endosc 2004;18:407–11.
9 Ali MR, Bhaskerrao B, Wolfe BM. Robot-assisted laparoscopic Roux-en-Y gastric bypass. Surg Endosc 2004; Dec 30.
10 Pierre AF, Luketich JD. Technique and role of minimally invasive esophagectomy for premalignant and malignant diseases of the esophagus. Surg Oncol Clin N Am 2002;11:337–5.
11 Garcia-Ruiz A, Smedira NG, Loop FD, Hahn JF, Miller JH, Steiner CP, Gagner M. Robotic surgical instruments for dexterity enhancement in thoracoscopic coronary artery bypass graft. J Laparoendosc Adv Surg Tech A 1997;7:277–83.
12 Cadiere GB, Himpens J, Vertruyen M, Bruyns J, Fourtanier G. Nissen fundoplication done by remotely controlled robotic technique. Ann Chir 1999;53:137–41.
13 Shennib H, Bastawisy A, McLoughlin J, Moll F. Robotic computer-assisted telemanipulation enhances coronary artery bypass. J Thorac Cardiovasc Surg 1999;117:310–3.
14 Schmid T. Robotic Surgery Eur Surg 2002;3:155–7.
15 Bodner J, Wykypiel H, Wetscher G, Schmid T. First experiences with the da Vinci operating robot in thoracic surgery. Eur J Cardiothorac Surg 2004;25:844–51.
16 Bodner J, Wykypiel H, Greiner A, Kirchmayr W, Freund MC, Margreiter R, Schmid T. Early experience with robot-assisted surgery for mediastinal masses. Ann Thorac Surg 2004;78:259–66.
17 Giulianotti PC, Coratti A, Angelini M, Sbrana F, Cecconi S, Balestracci T, Caravaglios G. Robotics in general surgery: personal experience in a large community hospital. Arch Surg 2003;138:777–84.
18 Bodner J, Hoeller E, Wykypiel H, Klingler P, Schmid T. Long-term follow-up after robotic cholecystectomy. Am Surg 2005; 71:281–5.
19 Bodner J, Kafka-Ritsch R, Lucciarini P, Fish J H III, Schmid T. A critical comparison between robotic and laparoscopic splenectomies. Worl J Surg 2005, in press.

Swiss Medical Weekly

Official journal of
the Swiss Society of Infectious disease
the Swiss Society of Internal Medicine
the Swiss Respiratory Society

The many reasons why you should choose SMW to publish your research

What Swiss Medical Weekly has to offer:

- SMW's impact factor has been steadily rising, to the current 1.537
- Open access to the publication via the Internet, therefore wide audience and impact
- Rapid listing in Medline
- LinkOut-button from PubMed with link to the full text website http://www.smw.ch (direct link from each SMW record in PubMed)

- No-nonsense submission – you submit a single copy of your manuscript by e-mail attachment
- Peer review based on a broad spectrum of international academic referees
- Assistance of our professional statistician for every article with statistical analyses

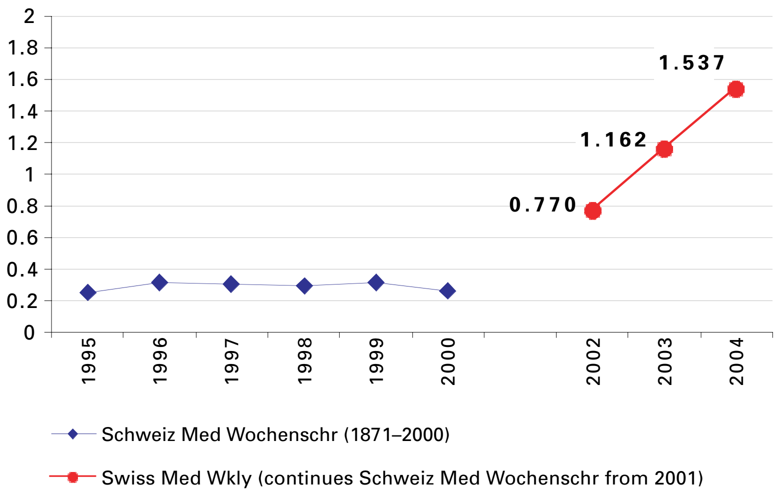
- Fast peer review, by e-mail exchange with the referees
- Prompt decisions based on weekly conferences of the Editorial Board
- Prompt notification on the status of your manuscript by e-mail
- Professional English copy editing
- No page charges and attractive colour offprints at no extra cost

We evaluate manuscripts of broad clinical interest from all specialities, including experimental medicine and clinical investigation.

We look forward to receiving your paper!

Guidelines for authors:
http://www.smw.ch/set_authors.html

Impact factor Swiss Medical Weekly



EMH
FMH Schwabe
Editores Medicorum Helveticorum

All manuscripts should be sent in electronic form, to:

EMH Swiss Medical Publishers Ltd.
SMW Editorial Secretariat
Farnsburgerstrasse 8
CH-4132 Muttenz

Manuscripts:	submission@smw.ch
Letters to the editor:	letters@smw.ch
Editorial Board:	red@smw.ch
Internet:	http://www.smw.ch