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A 5-Year Perspective over Robotic General Surgery: Indications, Risk Factors and Learning Curves

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Rezumat

O perspectivă de 5 ani asupra roboticii în chirurgia generală: indicații, factori de risc, curbă de învățare

Introducere: Chirurgia robotică a inaugurat o nouă era în mai multe specialități dar expansiunea inovației medicale este mai lentă în chirurgia digestivă decât în urologie din cauza problemelor legate de cost și cost-eficiență. Studiile deja publicate tratează implementarea programelor robotice dar și date tehnice și clinice specifice anumitor proceduri. Există puține articole care să evalueze programele robotice deja existente. Scopul studiului de față este să analizeze rezultatele unui program robotic cu o durată de 5 ani și să pună în evidență modificarea indicațiilor într-un centru experimentat într-o gamă largă de operații toracice și abdominale.
Material și metodă: Toate cazurile consecutive de chirurgie robotică realizate în centrul nostru de la debutul programului și până la 31 decembrie 2012 au fost incluse în acest studiu cu un total de 734 de cazuri rezolvate de-a lungul a 5 ani de experiență în domeniu. Variabilele demografice, clinice, chirurgicale și postoperatorii au fost analizate. Testele statistice realizate au inclus: teste comparative parametrice și non-parametrice, analiza uni și multivariată precum și analiza CUSUM.
Rezultate: Vârsta medie a fost de 50,31 ani. Lotul a inclus 60,9% femei și 39,1% bărbați. 55,3% dintre intervenții au fost indicate în tratamentul unei boli neoplazice. 36% din toate cazurile de etiologie benignă și malignă au fost boli localizate la nivelul pelvisului în timp ce 15,4% au fost boli localizate la nivelul joncțiunii esogastrice. Au fost realizate 18 conversii. Timpul operator mediu a fost de 179,4±86,06 min. Timpul mediu de docare a fost de 11,16±2,82 min iar durata medie a spitalizării a fost de 8,54 (±5,1) zile. S-au înregistrat 26,2% complicații din toate subtipurile clasificării Clavien dar complicațiile grave (Clavien III-V) au reprezentat numai 6,2%. Sexul masculin, vârsta peste 65 de ani, cazurile oncologice și suturile robotice au fost identificate ca factori de risc pentru rezultate postoperatorii nefavorabile.
Concluzii: Datele de fața susțin fezabilitatea diverselor proceduri, inclusiv a celor complexe, în chirurgia generală și redau evoluția ascendentă a unui program bine conceput de chirurgie robotică. Din gama largă de indicații posibile, considerăm că un program robotic se poate focaliza pe cazurile oncologice precum și pe patologia pelvină și gastroesofagiană ce include neoplazii cervicale, endometriale și rectale, achalazie și boli ale joncțiunii esogastrice.

Cuvinte cheie: chirurgie robotică, cancere pelvine, chirurgie gastroesofagiană, curbă de învățare, factori de risc

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Abstract

Introduction: Robotic surgery has opened a new era in several specialties but the diffusion of medical innovation is slower in digestive surgery than in urology due to considerations related to cost and cost-efficiency. Studies often discuss the launching of the robotic program as well as the technical or clinical data related to specific procedures but there are very few articles evaluating already existing robotic programs. The aims of the present study are to evaluate the results of a five-year robotic program and to assess the evolution of indications in a center with expertise in a wide range of thoracic and abdominal robotic surgery.

Material and methods: All consecutive robotic surgery cases performed in our center since the beginning of the program and prior to the 31st of December 2012 were included in this study, summing up to 734 cases throughout five years of experience in the field. Demographic, clinical, surgical and postoperative variables were recorded and analyzed. Comparative parametric and non-parametric tests, univariate and multivariate analyses and CUSUM analysis were performed.

Results: In this group, the average age was 50,31 years. There were 60,9% females and 39,1% males. 55,3% of all interventions were indicated for oncological disease. 36% of all cases of either benign or malignant etiology were pelvic conditions whilst 15,4% were esogastric conditions. Conversion was performed in 18 cases (2,45%). Mean operative time was 179,4±86,06 min. Mean docking time was 11,16±2,82 min. The mean hospital length of stay was 8,54 (±5,1) days. There were 26,2% complications of all Clavien subtypes but important complications (Clavien III-V) only represented 6,2%. Male sex, age over 65 years old, oncological cases and robotic suturing were identified as risk factors for unfavorable outcomes.

Conclusions: The present data support the feasibility of different and complex procedures in a general surgery department as well as the ascending evolution of a well-designed and well-conducted robotic program. From the large variety of surgical interventions, we think that a robotic program could be focused on solving oncologic cases and different types of pelvic and gastroesophageal junction conditions, especially rectal, cervical and endometrial cancer, achalasia and complicated or redo hiatal hernia.

Key words: robotic surgery, pelvic cancers, gastro-esophageal surgery, learning curve, risk factors

Introduction

Robotic assisted surgery has opened a new era as it has been proved by the continuously growing number of articles in the field since its early approval by the FDA in 2005 and until now (1). Several specialties adopted robotic surgery: urology, gynecology, digestive surgery, thoracic and cardiovascular surgery as well as ENT.

The diffusion of medical innovation consists of several waves: the first 2,5% are the innovators, the following 13,5% are considered early adopters, the early majority consists of the following 34%, the late majority is formed of another 34% wilst the last 16% are considered as the laggards (2). Due to acquisition and maintenance costs it is difficult to estimate whether the diffusion of robotics is still in the early majority phase or if it has approached the late majority wave. It is well known that in the urologic departments within the USA, diffusion has largely reached the late majority phase with more than 85% of radical prostatectomies being performed robotically (3). The situation is less clear in general and digestive surgery although for most of the procedures regularly performed in this field a robotic technique has already been described and published.

The innovators focused their papers on the protocol of establishing a robotic program (4-6) and on the general feasibility of the operations. A more specific feasibility and cost-effective analysis was approached by the early adopters as it was differentiated on types of procedures (7-14). Five to eight years after the adoption of the technology several medium term and survival results are being published (15-23) and more complex procedure are being described (24-32). Several reviews, meta-analyses or systematic reviews have been recently published on the subject (18,33-42). However there are very few long term evaluations of the robotic programs (43).

Our initial planning followed the guidelines of the innovators. We tried to be among the early adopters (14,32,44-50) as we approached a wide range of operations, some of which we had already performed laparoscopically, others of which we approached directly robotically. As we reached five year experience in the field we asked ourselves what has been achieved during this period, how experience changed our perception on the technology as well as our operative performance and how it modified our indications. Furthermore we tried to establish a learning curve for the general manipulations of the robot and to investigate some general risk factors.

Therefore, the aims of the present study are to evaluate the results of a five-year robotic program and to assess the evolution of indications in a center with expertise in a wide range of thoracic and abdominal surgery.

Material and Methods

In the department of surgery of Fundeni Clinical Institute, the first DaVinci system was acquired in December 2007 and robotic surgery was first performed on the 5th of January 2008. We initially used the DaVinci S system and, since 2010, we replaced it with the DaVinci Si model. While the initial robot was acquired with funding for research, all robotic procedures were part of a Robotic Surgery National Program that assured maintenance of the system and disposable materials. Case-related standard costs were covered by the national health insurance system at regular-procedure bases. However a cost analysis could not be performed due to the unavailability of the exact data.

All consecutive robotic surgery cases performed in our center since the beginning of the program and prior to the 31st of December 2012 were included in this study, summing up to 734 cases throughout five years of experience in the field. Patients were informed about the disease, the different treatments and surgical approaches, about the potential benefits and complications. The research was approved by the Fundeni Clinical Institute Ethics Committee in accord with the ethical standards of the Helsinki Declaration of 1975.

Ever since the first case, data was continuously collected into a local Robotic Surgery Registry that included demographic variables (age, sex, ASA classification), disease-related variables (diagnostic leading to operation, comorbidity, characteristics of the lesion – targeted organ, diameter of the lesion, TNM where appropriate, previous radio- and/or chemotherapy), surgical variables (type of intervention, approach, concomitant operations, main operator, assistant surgeons, anesthesiologist, operative time, R0 status, intraoperative incidents, intraoperative robotic suturing where appropriate, conversions to laparoscopy or to open technique), postoperative variables (hospital stay, complications, reinterventions, ICU stay). Survival data was not available for the present paper. Completeness of the data was 96%. The statistical analysis was based on intention-to-treat.

For trends in surgery, the volume of cases performed in our center during each year was retrieved from our department database. It should be noted that, during 2010 and 2011, the operating theatre was available only 9 out of 12 months due to works of maintenance.

The working database was imported and analyzed with Statistical Package for Social Science version 16.0 (SPSS Inc., Chicago IL, USA) for Windows. Throughout the paper, raw data is presented in numbers and percentages with a single rounded decimal. Means and standard deviations are provided for continuous data. Non parametric tests such as Mann Whitney U test and Chi square as well as ANOVA were performed for the comparison of the data. Regression analysis was performed to predict the outcome. The CUSUM analysis was performed for describing the learning curves. Univariate and multivariate analysis were used for determining risk factors and it was associated with several post hoc tests (LSD, Bonferroni, Scheffe). P-value is presented with at least three decimals and a p-value< 0,05 is considered statistically significant.

Results

The final group consisted of 734 consecutive patients who underwent robotic surgery during five years, between the 5th of January 2008 and the 31st of December 2012. The demographic data of the group is presented in *Table 1* showing an average age of 50,31 years and a higher rate of females (60,9%).

All surgeons involved including the leading surgeons and the assistant surgeons in the initial teams were certified for robotic surgery. The first case was a cholecystectomy performed by the proctor (Dr. K. Konstantinidis). The first case performed entirely by a surgeon from our department was a robotic left lateral liver segmentectomy (I.P). All main surgeons had extensive previous experience in both laparoscopic and oncologic surgery. They selected their cases for robotic surgery relying on the standard preoperative evaluation for each type of condition as reimbursed by the national health insurance system. Each surgeon showed a preference for several conditions and, depending on the results, their choice evolved over time.

Table 1. *Patients' demographic characteristics (*past conditions or concomitant morbidities other than the cause leading to surgery)*

Sex	Female	447 (60,9%)
	Male	287 (39,1%)
Age	Average (range)	50,31 (6-84)
	Standard deviation	16,65
ASA	I/II	616 (83,9%)
	III/IV	118 (16,1%)
Comorbidities	Total number of patients	263 (35,8%)
	Single co morbidity	67 (9,1%)
	Arterial hypertension	47 (6,4%)
	Diabetes mellitus	22 (3%)
	Hepatic cirrhosis	46 (6,3%)
	Obesity	15 (2%)
	Arrhythmias	8 (1,1%)
	Neoplasms*	16 (2,2%)
	Pulmonary disease	5 (0,7%)
	Other	35 (4,7%)
Previous abdominal operations		51 (6,9%)

A wide range of indications belonging to different organs were addressed robotically (*Table 2, 3* and *4*). Oncological cases represented 55,3% of all cases (*Table 2*). Pelvic surgery of both benign and malignant etiology represented 36% of all cases whilst esogastric surgery was performed in 15,4% of all patients. The proportion of cases was increasing for both oncologic indications (chi-square=27,6; p<0,00001) and for pelvic surgery (chi-square=29,1; p<0,00001) but not in a statistically significant manner for esogastric surgery (chi-square=1,4; p=0,84).

During 2012, 25,3% of all cases were performed. Whilst the raw number of cases varied over time, the proportion of robotic cases out of the total number of operations performed in our department was in an almost constant growth as showed in *Table 5* (chi-square=11,09; p-value=0,025).

The docking time decreased after the initial year and had an overall average of 11,16 minutes (±2,82) with statistically significant variations throughout the years as presented in *Table 6* (ANOVA p-value<0,0001). A CUSUM learning curve for the docking time of all cases is presented in *Fig. 1*. An initial phase of 100 cases was needed in order to establish a docking protocol for the most frequent procedures. A close to average docking time was observed during the following years with the exception of newly introduced procedures. A new decrease of the average docking time was noted in the fifth year.

Table 2. Data about the surgical interventions
*(legend : * only 9 months of activity; ** all gynecological, rectal and pelvic conditions; *** abdominal esophagus and gastroesophageal junction cases and one GIST of the fornix, **** major hepatectomies, pelvectomies, duodenopancreatectomy, spleno(gastro)pancreatectomy*

Time of operation	2008	151 (20,6%)
	2009	152 (20,7%)
	2010*	132 (18%)
	2011*	113 (15,4%)
	2012	186 (25,3%)
Oncological cases	2008	66 (43,7%)
	2009	72 (47,4%)
	2010	70 (53%)
	2011	71 (62,8%)
	2012	127 (68,3%)
	Total	406 (55,3%)
Pelvic surgery cases**	2008	28 (18,5%)
	2009	52 (34,2%)
	2010	53 (40,2%)
	2011	49 (43,4%)
	2012	82 (44%)
	Total	264 (36%)
Esogastric surgery cases***	2008	20 (13,2%)
	2009	25 (16,4%)
	2010	18 (13,6%)
	2011	19 (16,8%)
	2012	31 (16,7%)
	Total	113 (15,4%)
Combined interventions	93 (12,7%)	
Complex interventions ****	22 (3%)	
Total number of cases	734	

Several surgical variables were studied (*Table* 6): there were 18 conversions to laparotomy out of which two belonged to the major surgery group. Consequently, there was a significant higher rate of conversions in the major surgery subgroup where we included partial or total pelvectomies, pancreatic multivisceral resections (duodenopancreatectomy, left pancreatectomy en bloc with splenectomy), esofagectomy and major hepatectomies (right hepatectomy) with a chi-square of 5,47, p-value=0,04.

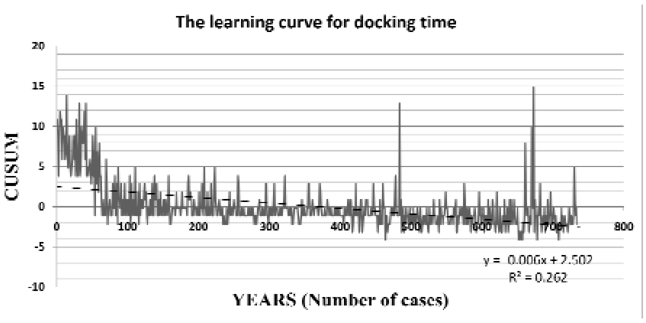

Figure 1. *The CUSUM learning curve for docking time in robotic surgery. The peaks among the later cases represent new procedures (right hepatectomy, duodenopancreatectomy etc)*

Table 3. *Targeted organ at the beginning of the operation. Secondary targets are not included (eg. concomitant hepatic biopsy or gallbladder removal)*

Targeted area	Targeted organ	Frequency (cases)	Percentage (%)
Anterior mediastinum	Thymus	71	9,7
	Thyroid	4	0,5
	Parathyroid glands	1	0,1
Thoracic cavity	Thoracic esophagus	5	0,7
Gastroesophageal junction	Abdominal esophagus and junction	111	15,1
Abdomen	Stomach	58	7,9
	Morbid obesity	4	0,5
	Duodenum	2	0,3
	Ileon	1	0,1
	Colon	48	6,5
	Gallbladder	1	0,1
	Liver	29	4
	Pancreas	12	1,7
	Spleen	89	12,1
	Surrenal glands	32	4,4
Pelvis	Rectum	129	17,6
	Cervix/uterus/ovaries	128	17 ,4
	Entire pelvis	9	1,3

Table 4. *Frequency and percentage of various types and subtypes of conditions (AHAI-autoimmune hemolytic anemia)*

Type and subtype of disease		Number of cases (%)
Abdominal malignant tumors		342 (46,6%)
Tumoral lymphoma (stomach, spleen)		27 (3,8%)
Metastases (liver, surrenal gland)		12 (1,6%)
Thymoma		24 (3,3%)
Benign tumors other then gynecological and kystic tumors		64 (8,8%)
Kystic tumors		15 (2%)
Hidatic disease		6 (0,8%)
Esogastric junction conditions other than cancers	Achalasia Hiatal hernia	73 (10%) 35 (4,8%)
Myasthenia gravis	44 (6%)	
Ectopic goitre	4 (0,5%)	
Morbid obesity	4 (0,5%)	
Hematologic indications of splenectomy other than lymphoma	AHAI Microspherocytosis Idiopathic thrombocytopenic purpura	2 (0,3%) 15 (2%) 16 (2,2%)!
	Thalassemia	1 (0,1%)
Other indications for splenectomy	Cavernoma	1 (0,1%)
	Hepatic cirrhosis with splenomegaly Splenic artery aneurysm	23 (3,1%) 1 (0,1%)
Gynecological conditions other than cancer	Uterine Fibroma Endometriosis Displasia	13 (1,8%) 3 (0,4%) 1 (0,1%)
Others		8 (1,1%)

Table 5. *The total number of procedures performed yearly in our department*

	2008	2009	2010	2011	2012
Robotic procedures	151 (3,8%)	152 (3,8%)	132 (4%)	101 (3,4%)	186 (4,9%)
Other techniques	3761 (96,2%)	3812 (96,2%)	3177 (96%)	2809 (96,6%)	3578 (95,1%)
Total	3912	3964	3309	2910	3764

Table 6. *Different operative and postoperative outcomes in our study group*

Conversion to open surgery	2008	7 (1%)
	2009	7 (1%)
	2010	2 (0,27%)
	2011	2 (0,27%)
	2012	0
	Total	18 (2,45%)
Conversion to laparoscopy as a consequence of robotic malfunctioning	2009	2 (0,27%)
	2011	1 (0,13%)
	Total	3 (0,4%)
Adhesiolysis	35 (4,8%)	
Operative time (minutes)	2008	170,70±72,04
	2009	186,97±82,11
	2010	108,3±101,9
	2011	185±82,69
	2012	163,5±86,64
	Total	179,4±86,06
Docking time (minutes)	2008	14,14±3,97
	2009	10,91±1,39
	2010	10,61±1,14
	2011	10,16±1,92
	2012	9,95±2,07
	Total	11,16 ±2,82
Intraoperative incidents	10 (1,36%)	
Robotic suturing	253 (34,4%)	
Length of stay (days)	Mean±SD	8,54 (±5,1)
Complications	Clavien I	47 (6,4%)
	Clavien II	100 (13,6%)
	Clavien III	21 (2,9%)
	Clavien IV	17 (2,3%)
	Clavien V	7 (1%)

Other than the eighteen conversions to open surgery we converted three operations to laparoscopy. All conversions were due to four cathegory of causes: tumoral extension requiring excision of vital elements, intraoperative incidents and case difficulties, anesthetic impact, and robotic malfunction. There were three cases of robotic malfunction and they were all converted to laparoscopic surgery. There was one patient with hypercapnia where the anesthesiologist suggested conversion. There were five cases of hemorrhagic robotic incidents and case difficulties: one during the right hepatectomy from the stapling line on the right suprahetic vein, one during an atypic hepatectomy of segments II, III and IVa requiring the Pringle maneuver, one in a case of splenomegaly to a patient with portal hypertension, one in a patient with a locally invasive pancreatic tumor and portal thrombosis and one perforated gastric tumor with consecutive local abscess. Unforeseen oncologic extension concerned tumors of the stomach, cervix, rectum and the surrenal gland.

There were several intraoperative incidents that were solved robotically: we performed two sutures of the pericardium and one suture of the diaphragm and we also encountered one lesion of the diaphragmatic vessels with consecutive robotic ligation, one lesion of the duodenum and one of an ileal loop, both with consecutive robotic suturing. The real benefit of the robot was proven in the difficult situations such as the suturing of a brachiocephalic truncus after a clip failure from the main thymic vein in a robotic thymectomy for nontumoral myasthenia gravis and the suturing of the left portal brunch in a left hepatectomy after stapler misfiring.

The average length of stay and the complications according to Clavien classification are provided in *Table* 6. The Clavien III cathegory of data includes all complications requiring any type of reintervention (surgical, endoscopic, radiologic) therefore no separate data on reinterventions is provided.

A risk factor analysis was performed for unfavorable outcomes such as: conversion, complications, Clavien III-V complications subgroup and hospital stay. We performed univariate (*Table 7*) and multivariate analysis for factors like age, sex, ASA, type of surgery, adhesiolysis, oncological cases, robotic suturing and intraoperative incidents.

The multivariate analysis was performed for the factors that were found significant in the univariate analysis for each outcome. Both the age of more than 65 years old and the intraoperative incidents were found to be independent risk factors for conversion ($p=0,023$ and $p=0001$, respectively). Age was also found to be an independent risk factor for complications ($p=0,0001$), high grade complications ($p=0,0001$) and longer hospital stay ($p=0,020$) whilst oncological indications were found to be an independent risk factors for complications and for the Clavien III-V subgroup ($p<0,0001$ and $p=0,030$, respectively) as well as for a longer hospital stay ($p=0,0001$). Male sex was found to be an independent risk factor for a longer hospital stay ($p=0,007$). The high risk candidate for high-grade complications would be a male patient, aged over 65 years and undergoing robotic suturing whilst the typical patient with a longer hospital stay would be a male with a neoplasia undergoing robotic suturing (both $p=0,021$).

For oncologic surgery, logistic regression was used to

Table 7. *Univariate analysis of several potential risk factor for different outcomes (*=statistically significant) **Type of surgery is opposing our current favorite indications (pelvic surgery and gastroesophageal junction surgery) to the rest of localizations. Clavien III-V includes major complications attributed by Clavien classification to classes III, IV, V.*

Factors / Outcome	Conversion	Complications	Clavien III-V	Hospital stay
Sex	F=0,300 p=0,584	F=9,618 p=0,002*	F=1,462 p=0,227	F=26,399 p<0,0001*
Age >=65y	F=5,75 p=0,017*	F=18,814 p<0,0001*	F=17,702 p<0,0001*	F=48,137 p<0,0001*
ASA III and IV	F=0,33 p=0,856	F=0,359 p=0,549	F=0,098 p=0,755	F=0,725 p=0,395
Type of surgery **	F=0,332 p=0,564	F=0,011 p=0,918	F=1,118 p=0,291	F=0,435 p=0,510
Adhesiolysis	F=1,090 p=0,297	F=0,15 p=0,902	F=0,308 p=0,579	F=3,172 p=0,075
Oncological case	F=3,229 p=0,073	F=53,342 p<0,0001*	F=9,221 p=0,002*	F=125,465 p<0,0001*
Robotic suturing	F=3,457 p=0,063	F=12,905 P<0,0001*	F=0,501 p=0,479	F=26,859 p<0,0001*
Intraoperative incidents	F=29,522 p<0,0001*	F=2,988 p=0,084	F=3,536 p=0,060	F=0,282 p=0,596
Preoperative radiotherapy	F=0,022 p=0,882	F=1,790 p=0,181	F=0,619 p=0,432	F=5,472 p=0,020*

verify the outcome generated by the presence of oncologic disease as a robot indication. Although it was not significant for conversions, it turned out to be positive for all morbidity: complications in general (p<0,0001; OR=3,7) and high-grade complications in particular (p=0,004; OR=2,94).

Discussions

Since the first use of the surgical robot in our department, in January 2008, we have performed 734 cases of robotic surgery out of which we converted to open surgery only 18 cases (2,45%). The rapidly growing robotic program allowed us to perform different types of procedures (*Table 3* and *4*), to describe or assess the feasibility and the short term results of several interventions (14,23,32,44-52), to evaluate the role of the surgical assistant in robotic surgery (45), to gradually enhance the complexity of cases and to expand the range of indications.

Indications

As for the indications of choice, three directions stood out over time: an emphasizing preference for oncological cases over benign pathology and an evolving preference for pelvic and gastroesophageal junction localizations, nevermind the benign or malignant nature of the condition leading to surgery (*Fig. 2*). Both gastroesophageal and pelvic surgery require dissection in a confined place where roticulating instruments compensate the narrow space while the 3DHD camera offers a high-quality imaging with refined anatomical details and remarkable stability of the operating field.

Rectal surgery

In rectal surgery it has been showed that robotic low anterior resection with total mesorectal excision (TME) produces less intraoperative blood loss and less drop in postoperative hemoglobin when compared to the open approach (15). The quality of the TME after robotic rectal resection has been taken into account by several papers among which some are multicentric or have a larger statistical power (22,51,53). The recent paper of Baik et al (51) suggests that robotic surgery may be better than conventional laparoscopic dissection in terms of local recurrence rates because of potentially better clinicopathological results of the circular resection margin (CRM). The authors

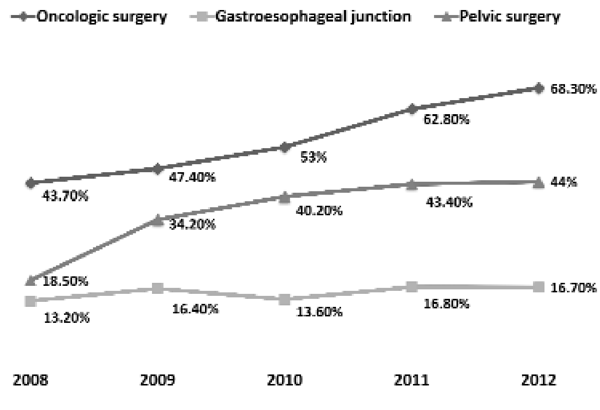

Figure 2. *Evolution of robotic surgery for oncologic cases, gastroesophageal junction localizations and pelvic localizations in our series*

opposed their results of 5,7% CRM involvement to previous reports showing a 0-16% of CRM involvement in the laparoscopic group. In their series, both local recurrence and CRM involvement were acceptable compared to previous studies but not better. An average count of 15,5 lymph nodes was reported, largely sufficient for a postoperative chemotherapy decision. A 3-year overall survival of 93,1% and a 3-year disease-free survival of 79,2% were reported (51,54). Our own series showed a 3-year survival rate of 90% (46).

A comparison of oncologic and functional outcomes between robotic and laparoscopic surgery for rectal cancer revealed better results for the robotic group at 1 year interval after the surgery (55). Other authors (56) had previously reported an earlier recovery of normal voiding and sexual function after the robotic approach compared to laparoscopy whilst reports performed during the learning curve series (21) offered comparable percentages. An analysis performed on the first 100 cases of robotic rectal surgery in our series revealed a rate of 3% of serious erectile dysfunction at an interval of 6 to 12 months from surgery and a voiding difficulty of 4% in the postoperative period out of which only 2% needed long term treatment (46). All these results concerning the completeness of the CRM, the high number of harvested lymph nodes, the promising survival curves, and the better voiding and sexual functions support the trend over time in pelvic surgery observed in our cohort.

Gynecologic surgery

Data concerning the role of robotics in gynecological surgery add more relevance to this trend. In a retrospective comparative study (57), the mean estimated blood loss was significantly lower in the robotic group as compared to the laparoscopy or open surgery groups. In the multivariate analysis, robotic surgery was independently associated with longer operative time, less blood loss, shorter hospital stay and fewer postoperative complications when compared to the group undergoing laparotomy. These findings are consistent with those concerning robotic procedures for rectal cancer. Early studies on cervical cancer show that patients may benefit from a more extensive pelvic lymphadenectomy when a robotic approach is performed by expert surgeons (17,58). A recent comparative systematic review (59) confirmed less blood loss for the robotic approach when compared to other approaches for cervical cancer. It also pointed out that robotics are associated with less postoperative infectious morbidity when compared to the open approach but similar non-infectious morbidity. However, it did not find any statistically significant increase in the number of harvested lymph nodes, or any significant reduction of the number of ureteral lesions.

Even for ovarian cancer, an indication that is not present in our current robotic surgery cohort, some authors (30) state that laparoscopy and robotics are preferable to laparotomy for patients requiring primary tumor excision alone or with one additional major procedure while laparotomy remains preferable for patients requiring two or more additional major procedures. Survival does not differ with the type of surgical approach. The same authors (31) compared robotics with other techniques even for the secondary cytoreduction for recurrent ovarian cancer and they discovered that laparotomy is necessary only in case of widespread peritoneal insemination.

The feasibility of partial and total pelvic exenterations has already been discussed in several reports (28,32). Due to the longer operating time and the similar length of stay generated by similar urinary complications it is still unreasonable to rank robotics as the top approach for these conditions. However the results are promising and our present experience of 13 anterior, supralevator and total pelvectomies confirms the potential of this technique. Nonetheless, medium-term and long-term survival data is needed before conclusions could be drawn.

Globally, the good intraoperative, clinicopathological and postoperative results for pelvic surgery confirm that pelvis is an important target for robotic surgery and completely justify our focusing on this area with a preference for rectal, cervical and endometrial cancer.

Gastroesophageal junction surgery

In gastroesophageal junction surgery it has been showed that there is a lower risk of incidents and complications, specifically less perforations during Heller myotomies and a better subsequent quality of life (39) even though some other authors have found rather similar rates (41). The 2012 SAGES guidelines for the surgical treatment of the esophageal achalasia recommend the use of the robotic approach (++) but state that the level of evidence is still weak (60). Our experience of 73 cases operated by robotic approach has led to good results even in the 7 cases of reintervention for failed Heller myotomy. Robotic redo surgery for failed Heller myotomy is technically challenging particularly in patients where the first operation had been performed several years before. Computer-enhanced surgery should probably be reserved for complex minimally invasive operations like redo Heller myotomy

As far as the robotic fundoplication is concerned, currently there is one systematic review (61) and one meta-analysis (42) that could respond the questions concerning the feasibility and the possible advantages of the DaVinci surgery. The systematic review shows statistical equivalence between laparoscopic and robotic fundoplication except for the postoperative complications where the patients in the robotic group achieve better results. The authors suggest that the possible explanation for this situation would be the greater dexterity and accuracy provided by the robotic assistance which may decrease the degree of injury and increase the quality of fundoplication in the narrow subphrenic space. The meta-analysis reveals similar advantages for the two approaches and both papers warn on the raise of costs associated with the robotic equipment. In our opinion, robotics may have a role in difficult cases such as when the patient is obese, has prior abdominal surgery or a large hiatal hernia (Type III or IV). Hand-like motions of the instruments and the enhanced visualization of the operative field with a genuine three-dimensional view made an impact equivalent to that of an improved open access. All these characteristics facilitate the transhiatal dissection of the intrathoracic stomach and esophagus from the surrounding tissues of the mediastinum compared with the traditional laparoscopic approach. The suturing is superior in robotic surgery when compared to laparoscopy (62,63) and the EndoWrist® instruments allow the operator to place the stitches as precisely as in open surgery, perpendicularly on the pillars, in order to obtain an appropriate closure of the hiatus. Furthermore, recurrent hiatal hernias may equally benefit from the robotic equipment but all these observations need further evidence through comparative studies focused on difficult antireflux valve surgery.

Two digestive cancers may involve dissection in the gastroesophageal region: esophageal cancer and gastric cancer. In the matter of esophageal cancer, the procedure described by Bodner has made robotic esophagectomy an acceptable operative approach due to the possibility of performing fine transhiatal dissection and adequate lymph node retrieval with associated diminished need for thoracotomy or thoracoscopy and reduced mortality compared to the open approach (64). As for robotic gastrectomy, it is associated with better short-term surgical outcomes, less estimated blood loss and more precise lymphodissection (50,65). Whatsomore, Hiki et al suggested that manual handling of the organs was an important factor for the postoperative systemic inflammatory response whilst the robotic instrumental handling would generate less inflammation, thus improving postoperative recovery (66).

Hepatobiliopancreatic and adrenal surgery

A recent debate has shown that it is currently acceptable to recommend and perform laparoscopic resection of a pancreatic tumor for those cases in which the circumstances including size, location, local/regional spread allow for a R0 resection (34). The robotic approach targets the same indications as laparoscopic surgery but makes difficult cases available for minimally invasive surgery in trained hands. We believe that, with the development of this technology, the quality of the dissection may be enhanced and difficult cases may become feasible more frequently and to a larger number of teams.

In the matter of adrenal surgery, recent reviews concluded that a simple adrenalectomy would not make the best use of all the possibilities of the robotic system whereas it would be easily feasible by laparoscopy and with fewer costs. However, in more difficult cases such as obese patients, large tumor or partial resections, the use of the robotic system would be particularly adequate (34,35). Our present attitude illustrates the same reasoning and we successfully used the robot in difficult cases, including several examples of invasive tumors.

A recent systematic review concerning the robotic liver resections highlighted that the most frequently performed procedures were partial resections and segmentectomies followed by left lateral segmentectomy and right hepatectomy. In these authors' experience, the use of the robot could improve the looping and isolation of the left Glissonian pedicles which is useful in left-sided hepatic resections whilst the right-sided resections would require laparoscopic mobilization of the liver prior to docking the robotic arms (37). Many hepatic procedures are available for the robotic approach but the application of the technology is still surgeon-dependant and it is still perceived as challenging. Throughout our 29 cases, we approached several major hepatectomies in which we appreciated the suturing qualities of the robotic instruments as well as their ability to perform fine dissection within the pedicle. Many of the hemostatic instruments others than those for suturing are still manipulated by the assistant as they are laparoscopic instruments; recent innovations have made some of these devices available for robotic use but bleeding control is still very dependent on the assistant surgeon's abilities (37,45).

Thoracic surgery

Although it is a general surgery department, several thoracic interventions were performed robotically in our series: thymectomy for non tumoral myasthenia gravis as well as thymectomy with lymphadenectomy for thymoma, ectopic goiter that benefited from a robotic thoracic dissection which was complementary to the cervical dissection, esophagectomy, a rather rare indication in our series due to the advanced stage of these neoplasms at presentation. Like the pelvis or the gastroesophageal junction, the thoracic cavity offers only a reduced space for the surgeon to work in and can benefit, thus, from the presence of CO_2 insuflation and articulated instruments. Nevertheless, in a recent review, several reasons that limited the expansion of robotic thoracic surgery were identified: many important blood vessels are present in the thoracic cavity, the target area is usually wide, thoracic operations are more frequently resections than reconstructions thus requiring less suturing, only a few facilities perform thoracoscopic surgery with a single display, and the learning curve is slow compared to other specialties (67).

However, the robotic approach gains an important place in the minimally invasive surgery of the anterior mediastinum. Thymectomy is adequate for computer-enhanced surgery because it is performed in a small space with rigid walls and difficult access. Enhanced optics with 3D visualization associated with the seven degrees of freedom of the robotic instruments allow the operator to make an extensive thymectomy more easily, safely and ergonomically than in the usual thoracoscopic approach, despite the lack of tactile sense. The cervical and contralateral parts of the dissection are better solved when using the device. Proctoring and training using the robotic technique is more rapid and efficient than with either the thoracoscopic or the transcervical thymectomy. This is the reason why most of the surgeons with a small experience in thoracoscopy and with access to a robotic device prefer the computer-enhanced approach and learn to do an extended thymectomy more rapidly and more efficiently. For the surgeons with a large experience in laparoscopy and thoracoscopy, robotics is mostly reserved for difficult cases.

Nevertheless there are some limitations, as well. During the procedure, it is difficult to place additional ports or to change the position of the operating table. The robotic arms are still bulky and conflicts between the arms or the arms and the patient are possible thus limiting the movement of the instruments (68).

Intraoperative incidents and difficulties

Fine dissection, meticulous bleeding control and precise suturing techniques represent important advantages for addressing complex oncologic cases with the help of this technology. As stated by Ho et al (37) concerning liver surgery, the ability to lock the EndoWrist® instruments in one place as a substitute for vascular clamping is essential and, in our experience, it is a key to approaching cancer surgery or, more specifically, complex hepatopancreatic resections as well as gastric DII and pelvic lymphadenectomies.

The same attribute was repeatedly identified as the key to a team integrated approach (38) as it gives all the staff the opportunity to respond: the surgical assistant may provide or change instruments, the anesthesiologist may formulate a management plan for intraoperative complications related to bleeding, the circulating nurse can provide adequate materials and the surgeon may plan hemostasis with diminishing pressure. These advantages seemed relevant in our own experience of complex surgical interventions that included extended right hepatectomy, cephalic duodeno-pancreatectomy and pelvectomies. Furthermore, throughout such interventions, the team should be prepared and trained to solve almost every incident robotically because conversion to an open procedure can be challenging. When all these requirements are fulfilled, extended indications will be regularly performed in most centers.

Learning curve

We previously demonstrated the role of a well trained assistant surgeon in the optimization of robotic operating time (45). In the present study, our CUSUM analysis pointed out that the time needed for installing the equipment should be less of a concern for the robotic team coordinator if the personnel is qualified. In a well trained team, after the initial 100 cases, about eleven minutes are to be counted for the docking of the system for the most frequent interventions. An expanding range of interventions implies new peaks that can be solved rather rapidly. Therefore, even with this bulky equipment, surgery theatre coordinators should be less concerned than before about the time lost in the operating room turnover.

Longer operative time was initially reported for most of these interventions. However, the learning curve was proved to be steep as it usually consists of only 20-50 cases. These data are favorable especially when compared to the laparoscopic learning curve that usually sums up more than 50-100 cases (68-72).

Risk factors

Univariate and multivariate analysis revealed several risk factors for the selected unfavorable outcomes (conversion, complications, major Clavien III-V complications, prolonged hospital stay). Independent risk factors for conversion were age of more than 65 years and intraoperative incidents, the latter being a logical phenomenon. The presence of complications of any type as well as of major complications was associated with independent risk factors like age and oncologic conditions. The risk factors for longer hospital stay were age over 65 years, male sex, oncologic disease.

Oncologic conditions were significantly related with a higher morbidity risk than benign conditions in our series but this seems rather as a logical consequence of the systemic impact of the disease than as a genuine risk factor. It should not prevent us from referring oncologic patients to robotic surgery but it should determine the surgeons to perform a thorough preoperative evaluation in order to exclude high risk patients (43).

While preoperative radiotherapy is generally feared as a potential risk factor, it did not have any impact in our study with the exception of the univariate analysis for the prolonged hospital stay. Even in rectal cancer alone, some authors report an increased risk of anastomotic leakage and postoperative morbidity while other authors did not find any difference in morbidity after laparoscopic TME in patients with or without preoperative radiotherapy (73). Further studies are needed to clarify whether preoperative radiation treatment represents a real concern for surgeons.

Cost analysis

An important step in health technology assessment is the cost analysis. Some articles suggest that costs associated with robotic surgery are higher than those associated with laparoscopic or open surgery and that both industry and medical practitioners should work together for decreasing (33,74). However some groups state that performing intracorporeal robotic sutures should offer an economic advantage in favour of robotics when associated with a 2% decrease in anastomotic leaks (75,76). More savings could be related to direct costs such as reduced hospitalization and management of resultant surgical reduced morbidity, and indirect costs such as earlier patient return to the workforce (74). Cost difference between laparoscopy and robotics could equally be compensated by maintaining a high case volume for each robotic system of at least 100–150 procedures per year (77). Furthermore a preference for difficult cases (oncologic cases, redo surgery) in which robotics brings value to the patient care should be a solution for a better-cost efficiency in the hospitals that have a robotic system.

Limitations

Even though the present study is based on a very large cohort and represents possibly one of the few long-term evaluations of an on-going robotic program, it still has important limitations. The most noticeable disadvantage of the present article is the absence of a control group, either from laparoscopic surgery or from open surgery. Randomized controlled trials are impossible to conceive on mixed series, such as this one, as it is already hard to implement them for specific procedures. In this context it is laborious to estimate whether the risk factors impact the evolution of patients after robotic surgery alone or it would be the case after all types of surgery. The trend over time is the cumulative result of the available technology, of the good postoperative results obtained for different sets of procedures as well as of the surgeons' experience and personal convictions which could have biased the curves. Furthermore, due to lack of exact data, no cost-analysis was performed for our cohort while cost-analysis is identified by most recent publications as a leading concern (78).

Conclusions

Compared to our conclusions at the end of our first year of robotic surgery (23), we gained more confidence in the robot for the indications mentioned above (rectal, cervical and endometrial cancer surgery, achalasia and complicated hiatal hernia) where we really believe in the utility of this tool within a general surgery department, we reduced the indications that were as easy to perform laparoscopically or thoracoscopically (eg. uncomplicated colon cancer surgery, total splenectomy, simple hysterectomy, thymectomy for non tumoral myasthenia gravis) and we expanded our range of procedure to complex interventions (right hepatectomy, cephalic duodenopancreatectomy, extended thymectomy for thymoma, esophagectomy and pelvectomy). Complex procedures may become the future of robotic surgery if associated with equal oncologic performances, less morbidity, earlier return to social and professional activity.

The present data support the feasibility of different and complex procedures in a general surgery department as well as the ascending evolution of a well-designed and well-conducted robotic program. From the large variety of surgical interventions, we think that a robotic program could be focused on solving oncologic cases and different types of pelvic and gastroesophageal junction conditions, especially rectal, cervical and endometrial cancer, achalasia and complicated or redo hiatal hernia.

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