Short-term outcomes of da Vinci Xi versus Si robotic systems for minor hepatectomies

Giorgio Bianchi[1], Nicola de'Angelis[1,2], Nicola Musa[1], Nassiba Beghdadi[1,2], Hassen Hentati[1], Michele Ammendola[3], Riccardo Inchingolo[4], Alexis Laurent[1], Daniele Sommacale[1,2], Riccardo Memeo[5]

[1]Unit of Digestive, Hepato-Pancreato-Biliary Surgery, and Liver Transplantation, CARE Department, Henri Mondor Hospital, AP-HP, Créteil, France; [2]Université Paris Est, Faculté de Santé, UPEC, Créteil, France; [3]Department of Health Sciences, General Surgery, Magna Græcia University, Medicine School of Germaneto, Catanzaro, Italy; [4]Interventional Radiology Unit, Miulli Hospital, Acquaviva delle Fonti, Bari, Italy; [5]Unit of Hepato-Pancreatic-Biliary Surgery, General Regional Hospital "F.Miulli", Acquaviva delle Fonti, Bari, Italy

Abstract. *Background and aim:* In the recent years, robotic technology has been drastically improved and the last generation of robotic platforms is hardly comparable with the earlier ones. The present study aims to investigate the short-term outcomes of minor hepatectomies performed with da Vinci Xi surgical system vs. Si surgical systems. *Methods:* Consecutive patients operated on between 2013 and 2020 in two referral centers were selected if underwent elective robotic minor hepatectomy (<3 consecutive segments) for primarily resectable benign or malignant lesions. Operative, postoperative, and cost outcomes were compared between the two groups by univariate and multivariate analyses. *Results:* Eighty-nine patients were selected (64 in the Si system vs. 25 in the Xi system group). Wedge resection was the most performed procedure (49.4%). The Si system group showed a significantly greater total incisional length (+8.99 mm; p<0.0001) related to the use of a higher number of robotic/laparoscopic ports. Pedicle clamping was more frequent in patients operated on by the Xi system (80% vs. 21.9%; p<0.0001) but without group differences in ischemia duration when clamping. A significantly shorter time to flatus (-0.75 days; p=0.015) was observed for patients operated on by the Xi system, whereas no group differences were found for operative time, conversion rate, estimated blood loss, postoperative complications, mortality, use of analgesics, and costs. *Conclusion:* The da Vinci Xi system represents a technological advancement with a potential clinical relevance, although further studies are needed to clearly detect the clinical impact of the use of this robotic platform in liver surgery. (www.actabiomedica.it)

Key words: robotic surgery, minor hepatectomy, da Vinci Xi system, da Vinci Si system, minimally invasive surgery, liver tumor

Introduction

Laparoscopic surgery for liver resection was first described in 1991(1); ever since, laparoscopy has been largely applied and is nowadays considered as a safe and effective approach to the management of surgical liver disease (2, 3), even in elderly patients (4-6). More recently, robotic surgery has been proposed to overcome laparoscopic limitations and offer to surgeons an advanced technology with improved visualization and dexterity (7-11). Perioperative outcomes of robotic surgery have been compared with laparoscopy for several liver surgery procedures, including left lateral sectionectomy, major hepatectomies (resection of ≥3 Couinaud liver segments), and minor hepatectomies (7, 9-15). The majority of these single center

case series concluded that robotic liver surgery is safe and feasible, can be considered as an alternative to laparoscopy, but it is not associated with significant advantages in terms of operative time, blood loss, complication rate, or hospital stay (16). Moreover, oncologic and cost-effectiveness outcomes remain under debate (7, 17).

In the meantime, robotic technology has been drastically improved and the last generation of robotic platform is hardly comparable with the earlier ones (18, 19). The newest da Vinci Xi surgical system was released in 2014 with significant upgrades and modifications compared to the da Vinci Si and S systems. Concerning liver surgery, specific advantages can be identified. First, a simpler and more rapid docking process, guided by a port placement menu and laser; the da Vinci Xi robotic cart can be placed on the right side of the patient, leaving to the anesthesiologist a direct access to the patient's head for monitoring and eventual emergency interventions. Furthermore, the scope can be placed on any of the robotic arms (port hopping) using an 8-mm port, and new robotic endowristed and energy devices are available (e.g., Vessel Sealer, Endowrist Staplers). These technical advancements can impact on the feasibility of robotic liver resections, eventually improve perioperative outcomes and favor the implementation of robotic surgery, as suggested by few studies investigating other surgical procedures, such as for rectal cancer, endometrial cancer, renal cell carcinoma, and urological benign and malignant diseases (20-23).

The aim of the present study was to compare the operative, postoperative and cost outcomes of da Vinci Xi vs. da Vinci Si surgical systems in patients undergoing minor hepatectomy for benign and malignant liver diseases.

Methods

Patient selection

The present analyses were conducted retrospectively on patients' records obtained from prospectively maintained databases of two referral hospital centers: the Henri Mondor University Hospital of Creteil (France) and the Miulli Hospital of Acquaviva delle Fonti, Bari (Italy). Consecutive patients undergoing minor hepatectomy by da Vinci Xi or Si robotic platforms (da Vinci Intuitive Surgical Inc, Sunnyvale CA, USA) between September 2013 and September 2020 were selected if the following criteria were fulfilled: adult patient (> 18 years) operated on in elective surgery; benign or malignant liver diseases; primarily resectable lesion in a single procedure; absence of metastatic extra-hepatic disease. Minor hepatectomy was defined as the liver resection of less than 3 consecutive liver segments (24-26). Both centers were equipped with the two robotic platforms; the choice between the Xi and Si robot was based upon platform availability within each center.

This is retrospective study dealing exclusively with anonymous clinical record data routinely collected in health databases. This research complies with the MR004 regulation; it was declared to the National Commission for Data Protection and Liberties (CNIL: 2210699). All personal data were collected after informing the involved patients and were treated in conformity to the ethical standards of the Helsinki Declaration.

The study was reported following the STROBE checklist (27).

Surgical procedure

Procedures were performed by 4 surgeons (RM, NdeA, GB, DS) operating in pairs all experienced in minimally invasive liver surgery. In all cases, the aim of the surgical treatment was to achieve a complete macroscopic resection of the lesion with a remnant liver volume to body weight ratio ≥ 0.5%(28). Intraoperative liver ultrasound was used systematically to confirm the number and size of the lesions, define their relationship to the major intrahepatic vascular structures, and rule out the presence of occult metastases. Upon completion of the liver resection, Doppler ultrasound was performed to assess vessel patency in the remnant liver. In selective cases, indocyanin green fluorescence was used for real-time visualization of biological structures (29).

The patient is placed in reverse Trendelenburg (>15°) supine position, except for posterior section

resections, where the patient is placed in left lateral decubitus position. Patient's arms lay along the body and legs are open. The assistant surgeon stands within the patient's legs. The table height is set as low as possible before docking the robot.

For the da Vinci Si robot, 4 robotic ports were used, including a 12-mm peri-umbilical port for the 30° robotic camera and three 8-mm robotic working ports placed in a semi-circular fashion. One to two additional laparoscopic ports (12-mm and 5-mm ports) were used for intraoperative ultrasound, sutures, and laparoscopic stapling devices. They were placed either on the same line of the robotic working ports on the left quadrant or at 5 cm below this line according to the hepatic lesion location. The robot was docked over the patient's head (Figure 1). As robotic energy devices, Harmonic Scalpel (Ethicon Endosurgery Inc), Endowristed monopolar scissors and Endowristed bipolar forceps (Maryland) were used. In case of difficult dissection, additional laparoscopic energy devices were used, such as LigaSure™ technology (Medtronic, Minnesota, USA) or ultrasonic dissector (Cavitron). Any vessel larger than 3 mm was secured by laparoscopic Hem-o-lok clips (Teleflex Medical, Research Triangle Park, NC, USA) or mechanical stapler (Covidien, Mansfield, USA).

Minor hepatectomies were carried out with 3 robotic working ports, one robotic camera port, and one or two laparoscopic assistant ports.

For the da Vinci Xi robot, four 8-mm robotic ports were used, including the robotic camera, which was placed in the umbilicus. The other ports were placed 8 cm away from each other, on the right (2 ports) and left (1 port) from the umbilical port, on a diagonal line perpendicular to target anatomy and surgical work volume. The 12-mm assistant port was placed left lateral, at least 7 cm from the left robotic port, or 8 cm below the robotic port diagonal line, on the right or left quadrant according to target anatomy. The robot was docked on the right side of the patient (Figure 2).

Minor hepatectomies were carried out with 4 robotic ports (including the robotic camera port), and one laparoscopic assistant ports.

As robotic energy devices, Endowrist Vessel Sealer (da Vinci Intuitive Surgical Inc, Sunnyvale CA, USA), Endowristed monopolar scissors, and Endowristed bipolar forceps (Maryland) were used. If needed, dissected vessels were secured by robotic Hem-o-lok clips (Teleflex Medical, Research Triangle Park, NC, USA) before section or by Endowrist robotic vascular stapler (45 mm).

A Pringle maneuver was done in an intra-corporeal or extra-corporeal fashion, according to the surgeons' preference. In case of extra-corporeal Pringle maneuver, a 5- or 3-mm additional port was used by placing it at the site of the Pfannenstiel incision or along the axillary line in the right flank (30, 31). The surgical specimen was retrieved from the Pfannenstiel incision. All cases were purely robotic procedures.

Study Outcomes

Patient's demographics, clinical characteristics, surgical indications, and types of liver resection were
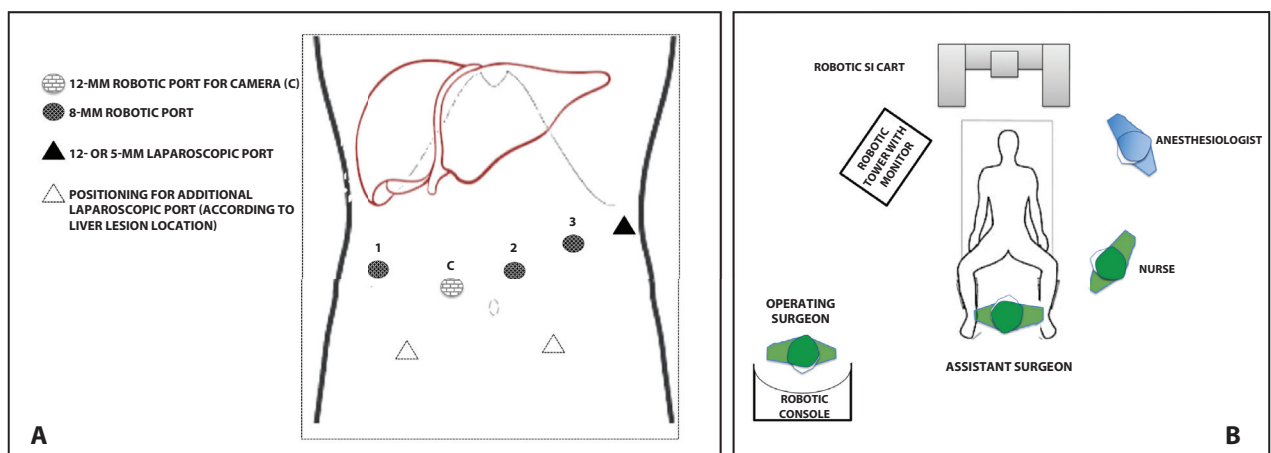

Figure 1. Port placement (A) and robotic docking (B) for the da Vinci Si System.
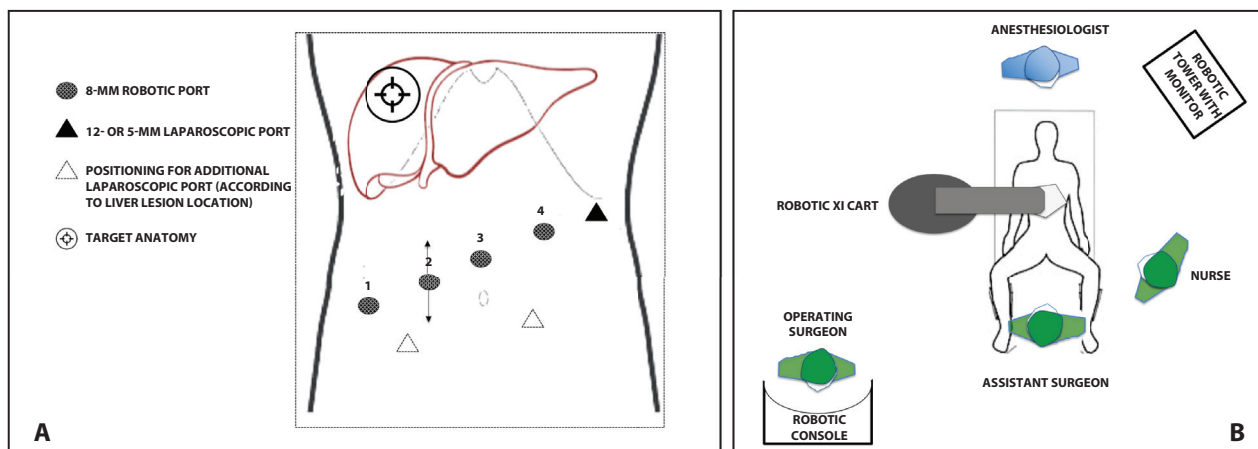
Figure 2. Port placement (A) and robotic docking (B) for the da Vinci Xi System.

described and compared between the da Vinci Xi and Si groups. Study outcomes include: number of ports used, total incisional length, operative time, conversion rate (to laparoscopy or open surgery), estimated blood loss, completeness of liver resection, postoperative complication rate (based on Clavien-Dindo classification (32)), intensive care unit (ICU) stay, hospital stay, mortality rate, and costs. Postoperative mortality and morbidity were defined as events occurring during the hospital stay or within 90 days after surgery. The ICU was scheduled preoperatively for patients with cirrhosis and/or cardiac comorbidities.

All patients were followed-up postoperatively according to standard protocols.

Cost Analysis

A differential cost analysis was performed comparing the da Vinci Xi and Si procedure-related costs (estimated in Euros)(11, 33, 34). The total cost of the robotic procedure includes: the costs of the operating room (estimated per minute of occupation of the operative theater and including the costs of surgery and anesthesia (35)), the costs of the laparoscopic and robotic devices used (estimated based on the prices for the Assistance Publique des Hopitaux de Paris (AP-HP)(11)), and the costs related to the postoperative period (corresponding to the hospital stay and estimated based on the reimbursements to public hospitals by the health-care insurance system (11, 33)).

Costs were specifically estimated for liver resections by identifying the type of intervention/indication on the Groupe Homogene de Malade (GHM) database, with specific codes for hepatectomy for malignant tumor (07C09) and for hepatectomy for benign tumor (07C10). The costs associated with the purchase and maintenance of the robotic platforms were not considered.

Statistical Analysis

For bivariate two-sided comparisons between the da Vinci Xi and the da Vinci Si groups, Chi-square test or Fisher's Exact test and Mann–Whitney U test were used for categorical and continuous variables, respectively. Continuous variables were expressed as mean and standard deviation (SD) or median and rage, whereas categorical variables were expressed as frequency (n and %). Mixed model ANOVA was used for postoperative outcomes expressed as continuous variables and costs, with the type of robotic platform as fixed factor and the center as random factor. The assumption of homogeneity of variance was checked by Levene's test. Binary logistic regression models were performed for outcomes expressed as categorical variables. Pre-operative patient- and tumor-related variables that may impact on the study outcomes were entered in the models as covariates, including: age, sex, BMI, number of lesions, tumor size, tumor location, indication for surgery, difficulty index, and center. A

p value <0.05 was considered to be statistically significant. Statistical analyses were performed with SPSS (Statistical Package for Social Science, IBM SPSS Statistics, Version 22 for Macintosh).

Results

Between 2013 and 2020, 92 consecutive patients underwent liver resection by using robotic Si or Xi systems. Of these, 89 were minor hepatectomies and were selected for the present analyses, including 64 (79.1%) procedures carried out by the da Vinci Si system and 25 (28.1%) by the da Vinci Xi system (Figure 3).

When comparing the demographics and clinical characteristics of the two groups of patients, significant differences were observed for the indication for liver surgery, the location of the liver lesion, the mean size of the largest nodule, and the type of liver resection (Table 1). Particularly, patients operated on by the Si system presented with a higher proportion of hepatocellular carcinoma (59.4% vs. 32%) and a lower proportion of colorectal cancer metastasis (14.1% vs. 52%) compared to patients operated on by the Xi system (p=0.025). The mean size of the liver lesion was significantly larger in patients operated on by the Si system than the Xi system (p=0.001) with the most prevalent location being the left lateral segments.

Consequently, significant differences were observed in the type of procedure performed (p<0.0001), although wedge resection was the most commonly performed in both groups representing 51.6% of liver resections in the Si system group and 44% of liver resections in the Xi system group (Table 1).

Concerning the operative and postoperative outcomes (Table 2), the Si system group was associated with a significantly greater total incisional length (estimated at +8.99 mm) related to the use of a higher number of ports (p<0.0001). In details, for the da Vinci Si system, 49 (76.6%) procedures were carried out with 6 ports, 13 (20.3%) procedures with 7 ports, and 2 (3.1%) with 8 ports. For the da Vinci Xi system, 21 (84%) procedures were performed with 5 ports and 4 (16%) procedures with 6 ports. Also, the recur to pedicle clamping was more frequent in patients operated on by the Xi system in both the non-adjusted and adjusted model, but the duration of ischemia when clamping was not different between the two groups (adjusted p=0.957). Postoperatively, a significantly shorter time to flatus was observed in patients operated on by the Xi system (estimated at -0.75 day; p=0.015). No differences were found in postoperative complications and mortality at 90 days, as well as for the duration of hospital stay and the use of analgesics.

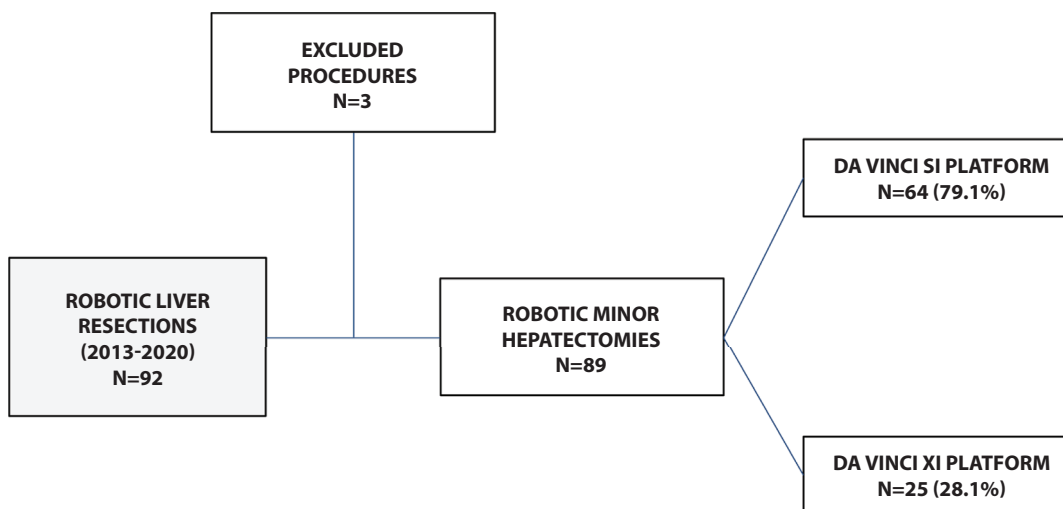The cost analysis showed that the costs for the needed instruments/devices (robotic and

Figure 3. Flowchart of patient selection.

Table 1. Demographic characteristics and pre-operative variables of patients operated on by *da Vinci Si* or *da Vinci Xi* for minor hepatectomy.

	Total study population (n=89)	da Vinci Si (n=64)	da Vinci Xi (n=25)	p value
Age (yr) [median(range)]	63(25-83)	63(25-83)	63(31-82)	0.898[a]
Age >65 (yr) [n (%)]	36(40.4)	25(39.1)	11(44)	0.811[b]
Gender (F/M) (n)	32/57	22/42	10/15	0.631[b]
BMI (kg/m^2) [median(range)]	26.26(18-36.73)	26.19(18.82-36.73)	27.5(18-36)	0.243[a]
Obesity (BMI > 30 kg/m^2) [n (%)]	18(20.2)	13(20.3)	5(20)	1[b]
ASA score (I/II/III) (n)	7/44/38	5/31/28	2/13/10	0.948[c]
Comorbidity >1 [n (%)]	30(33.7)	21(32.8)	9(36)	0.806[b]
Diabetes [n (%)]	16(18)	12(18.8)	4(16)	1[b]
Cardiovascular diseases [n (%)]	31(34.8)	19(29.7)	12(48)	0.138[b]
Kidney diseases [n (%)]	2(2.2)	1(1.6)	1(4)	0.485[b]
Pulmonary diseases [n (%)]	13(14.6)	10(15.6)	3(12)	1[b]
Smoking [n (%)]	17(19.1)	13(20.3)	4(16)	0.770[b]
Previous abdominal surgery [n (%)] • Open surgery • Laparoscopy	 20(22.5) 20(22.5)	 16(25) 12(18.8)	 4(16) 8(32)	 0.413[b] 0.257[b]
ALT >40 UI/L [n (%)]	8(9)	6(9.4)	2(8)	1[b]
AST >40 UI/L [n (%)]	9(10.1)	6(9.4)	3(12)	0.707[b]
Hypoprotidemia (<30 g/L) [n (%)]	2(2.2)	2(3.1)	0	1[b]
Liver parenchyma [n(%)] • Normal • Fibrosis • Cirrhosis • Nonalcoholic steatohepatitis	 47(52.8) 5(5.6) 32(36) 5(5.6)	 31(48.4) 4(6.3) 25(39.1) 4(6.3)	 16(64) 1(4) 7(28) 1(4)	 0.624[c]
Indication for liver resection [n(%)] • Hepatocellular carcinoma • Gallbladder cancer • Metastasis from colorectal cancer • Metastasis from breast cancer • Metastasis from esophagus cancer • Focal nodular hyperplasia • Liver hemangioma • Ciliated hepatic forgut cyst • Hepatocellular adenoma • Biliary cyst • IPNB	 46(51.7) 1(1.1) 22(24.7) 2(2.2) 1(1.1) 4(4.5) 4(4.5) 3(3.4) 3(3.4) 2(2.2) 1(1.1)	 38(59.4) 0 9(14.1) 2(3.1) 1(1.6) 3(4.7) 4(6.3) 2(3.1) 3(4.7) 1(1.6) 1(1.6)	 8(32) 1(4) 13(52) 0 0 1(4) 0 1(4) 0 1(4) 0	 **0.025**[c]
Number of lesions [n(%)] • Single lesion • Multiple lesions	 74(81.3) 15(16.9)	 55(85.9) 9(14.1)	 19(25.7) 6(24)	 0.345[b]
Size of largest nodule (mm) [men(SD)]	28.66(20.53)	32.98(22.67)	18.13(6.83)	**0.001**[a]

Table 1 (*Continued*)

	Total study population (n=89)	da Vinci Si (n=64)	da Vinci Xi (n=25)	p value
Lesion location [n(%)]				
• Posterior Segment (6-7)	18(20.2)	12(18.8)	6(24)	
• Anterior Segment (8-5)	9(10.1)	6(9.4)	3(12)	
• Medial Segment (4-1)	11(12.4)	8(12.5)	3(12)	
• Left lateral segments (2-3)	41(46.1)	35(54.7)	6(24)	
• Posterior + anterior segments	4(4.5)	0	4(16)	**0.003**[c]
• Anterior + medial segments	1(1.1)	0	1(4)	
• Medial + left lateral segments	2(2.2)	2(3.1)	0	
• Posterior + medial segments	1(1.1)	1(1.6)	0	
• Posterior + anterior + medial segmentss	2(2.2)	0	2(8)	
Preoperative chemotherapy [n(%)]				
• With biological addition	1(4)	1(8.3)	0	0.566[c]
• Without biological addition	15(60)	7(58.3)	8(61.5)	
Type of liver resection [n(%)]				
• Segmentectomy	15(16.9)	6(9.4)	9(36)	
• Bisegmentectomy	3(3.4)	0	3(12)	
• Left lateral sectionectomy	25(28.1)	24(37.5)	1(4)	**<0.0001**[c]
• Wedge resection	44(49.4)	33(51.6)	11(44)	
• Left lateral sectionectomy + wedge resection	1(1.1)	1(1.6)	0	
• Segmentectomy + wedge resection	1(1.1)	0	1(4)	
Difficult Index Score High [n(%)]	12(13.5)	7(10.9)	5(20)	0.306[b]

Footnotes: ASA American Society of Anesthesiology, AST enzyme aspartate aminotransferase, ALT enzyme alanine aminotransferase, BMI body mass index, IPNB Intraductal papillary neoplasm, SD standard deviation.
Assessed in 25 patients with colorectal, breast or esophagus liver metastasis.
[a]Mann-Whitney U test; [b]Fisher's Exact test; [c]Chi square test

Table 2. Operative and post-operative outcomes of patients operated on by *da Vinci Si* or *da Vinci Xi* for minor hepatectomy.

	Total study population (n=89)	da Vinci Si (n=64)	da Vinci Xi (n=25)	p value	Adjusted p value OR or MD (95%CI)
Conversion rate [n (%)]					
• To open	2(2.2)	1(1.6)	1(4)	0.485	0.994
• To laparoscopy	1(1.1)	0	1(4)	0.281	0.989
Operative time (min) [median(range)]	170(45-600)	150(45-600)	185(120-450)	0.108	0.351
Total incision port length (mm) [median(range)]	53(44-63)	53(53-63)	44(44-49)	**<0.0001**	**<0.0001** MD: 8.99 (6.82-11.11)
Pedicle clamping [n (%)]	34(38.2)	14(21.9)	20(80)	**<0.0001**	**0.008** OR: 7.10 (1.65-30.37)
Total duration of ischemia when clamping (min) [median (range)]	22(6-100)	23(7-100)	22(6-50)	0.743	0.957
Estimated blood loss (ml) [mean (SD)]	144.3(142)	134.1(142.33)	168.4(141.11)	0.158	0.794

	Total study population (n=89)	da Vinci Si (n=64)	da Vinci Xi (n=25)	p value	Adjusted p value OR or MD (95%CI)
Blood transfusion [n (%)]	3(3.5)	2(3.3)	1(4)	1	0.996
Time to flatus (days) [median (range)]	3(1-5)	3(1-5)	2.5(1-3)	**0.011**	**0.015** MD: 0.75 (0.15-1.36)
ICU stay (days) [median (range)]	1(0-9)	1(0-9)	0(0-2)	**>0.0001**	0.086
Hospital stay (days) [median (range)]	5(2-22)	5(2-22)	5(2-13)	0.586	0.613
R1 surgical margins [n (%)]	9(10.1)	7(10.9)	2(8)	1	0.992
Postoperative complications [n (%)]	15(16.9)	10(15.6)	5(20)	0.754	0.405
Type of complication [n (%)] • Prolonged pain • Hemorrhage • Ascites • Pulmonary infection • Surgical site infection	 5(5.6) 3(3.4) 3(3.4) 3(3.4) 7(7.9)	 4(6.3) 3(4.7) 3(4.7) 2(3.1) 4(6.3)	 1(4) 0 0 1(4) 3(12)	 1 0.556 0.556 1 0.396	 0.814 0.997 0.998 0.999 0.104
Severe morbidity (Dindo-Clavien >III) [n (%)]	5(5.6)	4(6.3)	1(4)	1	0.496
Reoperation [n (%)]	1(1.1)	1(1.6)	0	1	1
90-day post-operative mortality [n (%)]	0	0	0	NA	NA
Analgesic use (days) [median (range)]	16(7-30)	15.5(7-30)	19(13-30)	0.092	0.212

Footnotes: SD standard deviation; MD mean difference; OR odds ratio.

Table 3. Cost analysis (estimated in euros) for patients operated on by da Vinci Si (n=64) or da Vinci Xi (n=25) for minor hepatic resections.

	Da Vinci Si (n=64)	Da Vinci Xi (n=25)	P value	Mean Difference (SE)	Adjusted p Value
Instruments costs [mean(SD)]	1703.12 (331.86)	1398 (115.90)	**<0.0001**	182.50(127.42)	0.156
Operative room occupation costs [mean(SD)]	1095.1 (636.1)	1177.44 (423.26)	0.108	-221.57 (236.27)	0.351
Hospital stay costs[mean(SD)]	5684.37 (6048.64)	4516 (1931.25)	0.542	287.07 (2188.33)	0.896
Total costs [mean(SD)]	8482.59 (6186.84)	7091.44 (2200.38)	0.309	326.14 (2236.42)	0.884

laparoscopic) for the procedures carried out by the Si system were significantly higher than those needed for the Xi system. However, when adjusted on patient- and tumor-related confounders and the center, the difference was no longer significant. Similarly, no differences were noted for the costs related to the occupation of the operative room, the hospital stay costs, and the total costs in the fully adjusted model (Table 3).

Discussion

The present study shows that minor hepatectomies can be performed with the da Vinci Xi surgical system by using a lower number of ports, with the consequent advantages of a shorter total incisional length for the patient compared to the Si system. Moreover, patients operated on by the Xi system showed a shorter time to flatus, probably reflecting a more rapid recovery, which

however cannot be detected on the overall hospital stay and complication rate, which were not different between the two groups.

The main technical advantage of the shift from the Si to the Xi system can be seen in the use of less laparoscopic assistant ports and laparoscopic devices. Indeed, with the Si surgical system, several procedural steps of the minor hepatectomy are carried out using laparoscopic energy devices, such as the Harmonic Scalpel, LigaSure™, mechanical staplers, and ultrasonic dissector (Cavitron), operated by the assistant surgeon (9, 13, 14, 36). On the contrary, the Xi surgical system is associated with a new generation of robotic vessels sealer that, in combination with all other Endowrist devices and the robotic Maryland forceps, allows to divide the majority of the hepatic parenchyma and to coagulate small vessel branches. This new robotic device is characterized by an enhanced access and control due to a 30% slimmer jaw profile for more precise dissection, a grasp with a textured surface to secure tissue, and an approach to anatomy from the preferred angle by articulating the wrist. It allows to seal and cut vessels up to 7 mm in diameter and consents to reproduce the clamp crashing technique, considered as one of the most efficient parenchyma liver transection (37). Practically, the entire procedure is performed by the first operating surgeon at the robotic Xi system console using all robotic working ports and devices under 3-D view, translating into a "less hybrid" technique compared to the Si system and previous robotic platforms, because the need of laparoscopic device during the hepatic transection is minimized. Another advantage of the Xi surgical system is that the robotic camera can be placed in any of the 8-mm robotic ports; this can also be changed during the procedure in the need to have the third robotic working arm on the right side or on the left side of the operative field.

In the present study, these technical advantages appeared to have an impact on the instrument/device related costs, which were lower when operating with the Xi than the Si system. However, no conclusion on the potential economic benefit of the Xi robotic platform can be ascertained from the present study because once taken into account confounders, no group difference was noted for total costs, operative room occupation costs, hospital stay costs, and instrument costs. Although previous studies suggested further advantages of the Xi system in term of operative time (23, 38, 39) with potential impact on improved efficacy and reduced costs, this was not observed in the present analyses and further investigations are needed to conclude about the cost-effectiveness of both robotic surgical systems.

On the patient's perspective, the use of one laparoscopic assistant port instead of two and an 8-mm port instead of 12-mm one for the robotic camera, translates to a shorter total incisional length, which is an important determinant of postoperative pain, analgesic need, recovery time, and finally cosmetic results (40, 41). However, in this first report, patients operated on by the da Vinci Xi system only showed a shorter time to flatus, without differences in postoperative complication rate, analgesic use, need of re-operation, and hospital stay. It can be hypothesized that the use of Xi system may be associated with improved outcomes and faster recovery related to a reduced abdominal wall stress and pain compared to the Si System. However, this needs to be investigated in further studies, ideally randomized trials in which the role of confounders is minimized and the internal validity is maximized.

The present study has several limitations, mainly related to the retrospective design and small simple size. Selection and reporting bias cannot be excluded. Despite the statistical adjustments made, residual confounding factors must be considered while interpreting the present results. Moreover, findings cannot be generalized without caution, since all procedures were performed by experienced surgeons having completed their learning curve and operating in referral centers. Indeed, evidence suggests that to ensure safety and efficacy of robotic liver procedures, the surgical team must be optimally trained and experienced (38, 42). Further studies are awaited to detect potentially relevant differences between the Xi and Si robotic surgical systems, which may not have been identified in the present study due to the small sample size, and to confirm the present preliminary report. It would be interesting to assess docking time separately to the procedure time and the cost-effectiveness of Xi robotic system compared to laparoscopy. Indeed, laparoscopy is nowadays considered as the gold standard approach for selected minor hepatectomy (43, 44). Particularly, previous studies on

the use of robotic surgery for left lateral sectionectomy showed that it yields similar or slightly inferior clinical outcomes than laparoscopy, but with increased costs and time (45-48). However, these data should be updated after the widespread implementation of the da Vinci Xi surgical system, which has the technical characteristics to definitively overcome laparoscopic drawbacks and reduce robotic surgery inconveniences.

Conclusion

Within the limitations of the present study, which is in our knowledge the first one to compare two generations of robotic surgical systems for minor hepatectomies, the da Vinci Xi system represents a technological advancement with potential clinical relevance. However, further studies are needed to clearly detect the clinical impact of the use of this new generation robotic platform in liver surgery.

List of abbreviation: ICU: intensive care unit.

References

1. Reich H, McGlynn F, DeCaprio J and Budin R. Laparoscopic excision of benign liver lesions. Obstet Gynecol 1991; 78: 956-8.
2. Nguyen KT, Gamblin TC, Geller DA. World review of laparoscopic liver resection-2,804 patients. Ann Surg 2009; 250: 831-41.
3. Qiu J, Chen S, Chengyou D. A systematic review of robotic-assisted liver resection and meta-analysis of robotic versus laparoscopic hepatectomy for hepatic neoplasms. Surg Endosc 2016; 30: 862-75.
4. de'Angelis N, Baldini C, Brustia R, et al. Surgical and regional treatments for colorectal cancer metastases in older patients: A systematic review and meta-analysis. PLoS One 2020; 15: e0230914.
5. Notarnicola M, Felli E, Roselli S, et al. Laparoscopic liver resection in elderly patients: systematic review and meta-analysis. Surg Endosc 2019; 33: 2763-73.
6. Delvecchio A, Conticchio M, Ratti F, et al. Laparoscopic major hepatectomy for hepatocellular carcinoma in elderly patients: a multicentric propensity score-based analysis. Surg Endosc 2020.
7. Choi SB, Park JS, Kim JK, et al. Early experiences of robotic-assisted laparoscopic liver resection. Yonsei Med J 2008; 49: 632-8.
8. Giulianotti PC, Coratti A, Angelini M, et al. Robotics in general surgery: personal experience in a large community hospital. Arch Surg 2003; 138: 777-84.
9. Giulianotti PC, Coratti A, Sbrana F, et al. Robotic liver surgery: results for 70 resections. Surgery 2011; 149: 29-39.
10. Patriti A, Ceccarelli G, Bartoli A, Spaziani A, Lapalorcia LM, Casciola L. Laparoscopic and robot-assisted one-stage resection of colorectal cancer with synchronous liver metastases: a pilot study. J Hepatobiliary Pancreat Surg 2009; 16: 450-7.
11. Salloum C, Lim C, Lahat E, et al. Robotic-Assisted Versus Laparoscopic Left Lateral Sectionectomy: Analysis of Surgical Outcomes and Costs by a Propensity Score Matched Cohort Study. World J Surg 2017; 41: 516-24.
12. Berber E, Akyildiz HY, Aucejo F, Gunasekaran G, Chalikonda S, Fung J. Robotic versus laparoscopic resection of liver tumours. HPB (Oxford) 2010; 12: 583-6.
13. Fruscione M, Pickens R, Baker EH, Cochran A, Khan A, Ocuin L, et al. Robotic-assisted versus laparoscopic major liver resection: analysis of outcomes from a single center. HPB (Oxford) 2019; 21: 906-11.

14. Salloum C, Subar D, Memeo R, et al. Laparoscopic robotic liver surgery: the Henri Mondor initial experience of 20 cases. J Robot Surg 2014; 8: 119-24.

15. Rahimli M, Perrakis A, Schellerer V, et al. Robotic and laparoscopic liver surgery for colorectal liver metastases: an experience from a German Academic Center. World J Surg Oncol 2020; 18: 333.

16. Montalti R, Berardi G, Patriti A, Vivarelli M, Troisi RI. Outcomes of robotic vs laparoscopic hepatectomy: A systematic review and meta-analysis. World J Gastroenterol 2015; 21: 8441-51.

17. Magistri P, Tarantino G, Assirati G, et al. Robotic liver resection for hepatocellular carcinoma: A systematic review. Int J Med Robot 2019; 15: e2004.

18. Wilson TG. Advancement of technology and its impact on urologists: release of the daVinci Xi, a new surgical robot. Eur Urol 2014; 66: 793-4.

19. Ngu JC, Tsang CB and Koh DC. The da Vinci Xi: a review of its capabilities, versatility, and potential role in robotic colorectal surgery. Robot Surg 2017; 4: 77-85.

20. Patel MN, Aboumohamed A and Hemal A. Does transition from the da Vinci Si to Xi robotic platform impact single-docking technique for robot-assisted laparoscopic nephroureterectomy? BJU Int 2015; 116: 990-4.

21. Giannini A, Malacarne E, Sergiampietri C, et al. Comparison of perioperative outcomes and technical features using da Vinci Si and Xi robotic platforms for early stages of endometrial cancer. J Robot Surg 2020.

22. Morelli L, Di Franco G, Lorenzoni V, et al. Structured cost analysis of robotic TME resection for rectal cancer: a comparison between the da Vinci Si and Xi in a single surgeon's experience. Surg Endosc 2019; 33: 1858-69.

23. Abdel Raheem A, Sheikh A, Kim DK, et al. Da Vinci Xi and Si platforms have equivalent perioperative outcomes during robot-assisted partial nephrectomy: preliminary experience. J Robot Surg 2017; 11: 53-61.

24. Reddy SK, Barbas AS, Turley RS, et al. A standard definition of major hepatectomy: resection of four or more liver segments. HPB (Oxford) 2011; 13: 494-502.

25. Couinaud C. [Contribution of anatomical research to liver surgery]. Fr Med 1956; 19: 5-12.

26. Strasberg SM. Nomenclature of hepatic anatomy and resections: a review of the Brisbane 2000 system. J Hepatobiliary Pancreat Surg 2005; 12: 351-5.

27. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 2008; 61: 344-9.

28. Truant S, Oberlin O, Sergent G, et al. Remnant liver volume to body weight ratio > or =0.5%: A new cut-off to estimate postoperative risks after extended resection in noncirrhotic liver. J Am Coll Surg 2007; 204: 22-33.

29. Ishizawa T, Saiura A and Kokudo N. Clinical application of indocyanine green-fluorescence imaging during hepatectomy. Hepatobiliary Surg Nutr 2016; 5: 322-8.

30. Piardi T, Lhuaire M, Memeo R, Pessaux P, Kianmanesh R, Sommacale D. Laparoscopic Pringle maneuver: how we do it? Hepatobiliary Surg Nutr 2016; 5: 345-9.

31. Rotellar F, Pardo F, Bueno A, Martí-Cruchaga P, Zozaya G. Extracorporeal tourniquet method for intermittent hepatic pedicle clamping during laparoscopic liver surgery: an easy, cheap, and effective technique. Langenbecks Arch Surg 2012; 397: 481-5.

32. Clavien PA, Barkun J, de Oliveira ML, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg 2009; 250: 187-96.

33. de'Angelis N, Notarnicola M, Martínez-Pérez A, et al. Robotic Versus Laparoscopic Partial Mesorectal Excision for Cancer of the High Rectum: A Single-Center Study with Propensity Score Matching Analysis. World J Surg 2020.

34. Merola G, Sciuto A, Pirozzi F, et al. Is robotic right colectomy economically sustainable? a multicentre retrospective comparative study and cost analysis. Surg Endosc 2020; 34: 4041-47.

35. Raft J, Millet F and Meistelman C. Example of cost calculations for an operating room and a post-anaesthesia care unit. Anaesth Crit Care Pain Med 2015; 34: 211-5.

36. Magistri P, Tarantino G, Guidetti C, et al. Laparoscopic versus robotic surgery for hepatocellular carcinoma: the first 46 consecutive cases. J Surg Res 2017; 217: 92-99.

37. Lesurtel M, Selzner M, Petrowsky H, McCormack L, Clavien PA. How should transection of the liver be performed?: a prospective randomized study in 100 consecutive patients: comparing four different transection strategies. Ann Surg 2005; 242: 814-22, discussion 22-3.

38. Hill A and McCormick J. In experienced hands, does the robotic platform impact operative efficiency? Comparison of the da Vinci Si versus Xi robot in colorectal surgery. J Robot Surg 2020; 14: 789-92.

39. van der Schans EM, Hiep MAJ, Consten ECJ, Broeders I. From Da Vinci Si to Da Vinci Xi: realistic times in draping and docking the robot. J Robot Surg 2020.

40. de'Angelis N, Abdalla S, Carra MC, et al. Low-impact laparoscopic cholecystectomy is associated with decreased postoperative morbidity in patients with sickle cell disease. Surg Endosc 2018; 32: 2300-11.

41. de Carvalho GL, Cavazzola LT. Can mathematic formulas help us with our patients? Surg Endosc 2011; 25: 336-7.

42. Di Benedetto F, Petrowsky H, Magistri P, Halazun KJ. Robotic liver resection: Hurdles and beyond. Int J Surg 2020; 82s: 155-62.

43. van der Poel MJ, Fichtinger RS, Gorgec B, et al. International multicenter propensity score matched study on laparoscopic versus open left lateral sectionectomy. HPB (Oxford) 2020.

44. Dokmak S, Raut V, Aussilhou B, et al. Laparoscopic left lateral resection is the gold standard for benign liver lesions: a case-control study. HPB (Oxford) 2014; 16: 183-7.

45. Packiam V, Bartlett DL, Tohme S, et al. Minimally invasive liver resection: robotic versus laparoscopic left lateral sectionectomy. J Gastrointest Surg 2012; 16: 2233-8.

46. Hu M, Liu Y, Li C, et al. Robotic versus laparoscopic liver resection in complex cases of left lateral sectionectomy. Int J Surg 2019; 67: 54-60.
47. Kim JK, Park JS, Han DH, et al. Robotic versus laparoscopic left lateral sectionectomy of liver. Surg Endosc 2016; 30: 4756-64.
48. Guan R, Chen Y, Yang K, et al. Clinical efficacy of robot-assisted versus laparoscopic liver resection: a meta analysis. Asian J Surg 2019; 42: 19-31.

Correspondence:
Received: 31 January, 2022
Accepted: 28 February, 2022
Giorgio Bianchi, MD
Department of Digestive Surgery, Hepato-Pancreato-Biliary Surgery, and Liver Transplantation
Henri-Mondor Hospital, AP-HP.
Address: 51, avenue du Maréchal de Lattre de Tassigny, 94010 Créteil, France.
Tel. +33-1-49812348; Fax. +33-1-49812432
E-mail: 87.giorgio.bianchi@gmail.com