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ORIGINAL ARTICLE

Robotic-assisted adrenalectomy using da Vinci Xi vs. Si: are there differences?

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Abstract
Da Vinci Xi, the fourth generation platform, was released in 2014 and introduced as the successor to the Si platform for minimal invasive surgery. We reviewed our experience with robotic-assisted adrenalectomy and compared peri-operative outcomes using the da Vinci robot model Xi vs. Si. Since June of 2014, 85 consecutive patients underwent robotic-assisted adrenalectomy by a high-volume adrenal surgeon at our institution. Patients were divided into two groups: Xi group ($n=25$) and Si group ($n=60$). The average anesthesia time was 145.8 min for the Xi group and 170.4 min for the Si group ($p=0.001$). The mean procedure time for the Xi group (skin to skin) was 92.1 min and for the Si group it was 122.5 min ($p=0.001$). The average docking time for the Xi group was 18.2 min and for the Si group 20.3 min ($p=0.04$). The average consumables fees for the Xi group were \$1246 and for the Si group \$1106 ($p=0.04$). The calculated relative costs for the Xi group were \$3375 and for the Si group \$3527 ($p=0.03$). The average post-operative hospital stay for the Xi group was 1.6 days and for the Si group 1.7 days ($p=0.18$). Robotic-assisted adrenalectomy using the da Vinci Xi system is effective and efficient. This study shows that outcomes were similar between Xi and Si groups.

Keywords Da Vinci · Robotic-assisted adrenalectomy · Transabdominal approach · Posterior retroperitoneal approach · Anesthesia time · Procedure time · Xi group · Si group

Introduction

Laparoscopic adrenalectomy has been used as the standard surgical approach to treat benign adrenal tumors since 1992 [1, 2]. The da Vinci robot (Intuitive Surgical, Inc., Sunnyvale, CA, USA) was FDA approved over a decade ago and has undergone various redesigns. Horgan et al. [3] reported the first robotic-assisted adrenalectomy in 2001 and since then the approach has been increasingly utilized. The advantages of using robotic technology have been widely publicized.

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Our previous study [4] compared the cost and peri-operative outcomes between laparoscopic and robotic-assisted adrenalectomy (da Vinci model Si only). It showed that anesthesia times and procedure times for the robotic group were similar to the laparoscopic group suggesting a lack of transition learning curve. It also demonstrated that limiting the number of robotic instruments and energy devices can keep the cost of robotic adrenalectomy similar to the laparoscopic approach.

Since spring of 2014, the da Vinci Xi (Intuitive Surgical Inc., Sunnyvale, CA, USA) was launched and introduced. The authors started using the model Xi to perform robotic-assisted adrenalectomies since our institution installed two systems in August of 2017. Previous comparison studies (model Xi vs. Si) have been reported in general surgery cases [5–8] (such as gastric bypass surgery and colorectal surgery) and urology cases [9–12] (such as radical prostatectomy, partial nephrectomy, and nephroureterectomy). To our knowledge, there have been no studies comparing the peri-operative outcomes and costs between da Vinci model Xi and Si for adrenalectomy. In this study, we retrospectively reviewed and compared the peri-operative outcomes

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of robotic-assisted adrenalectomy performed using the model Xi vs. Si by a single high-volume adrenal surgeon at a teaching institution.

Methods

From June 1st, 2014 to September 10th, 2018, 85 consecutive patients underwent robotic-assisted adrenalectomy. Starting in 2014, 54 transabdominal (TA) and 6 posterior retroperitoneal (PR) robotic cases were performed using the model Si. In 2017, the model Xi was acquired and 15 TA and 10 PR procedures were completed. A cost analysis was performed for both the Xi group and Si group which included anesthesia professional fees, procedure time fees, and consumables fees as described in a previous study [4]. The consumables for both groups include surgical supplies, trocars, robotic drapes, and robotic instruments. Two robotic instruments (Cardiere Forceps and Permanent Cautery Hook) were used in both groups. The surgeon professional fees were not included as they were the same for both groups and do not vary by time.

Institution-specific data were collected. The average anesthesia times and procedure times for both the Xi group and Si groups were based on the average data from a high-volume adrenal surgeon who also teaches the procedure to general surgery residents.

Operative technique

The patient's position using the da Vinci Xi is same as on the model Si which is the lateral decubitus flank position for transabdominal (TA) approach and prone jackknife position on the Wilson frame for posterior retroperitoneal (PR) approach.

Trocar placement for the da Vinci Si was previously described by our group [13, 14]. Da Vinci Xi universal linear port placement has been used and described for colorectal surgery [6–8] and kidney surgery [10–12]. But our modified port placement on the model Xi is the same as on the model Si (Fig. 1). The robotic Cardiere Forceps and Cautery Hook are the only two robotic instruments used for both Xi and Si groups.

The robotic procedure details that were used with the da Vinci Si system were previously described by our group [13, 14]; the operative technique in the Xi group was similar to the Si group excluding docking. Unlike the model Si docking, we do not have to rotate the operating table to side dock the robot for the transabdominal approach or for the posterior retroperitoneal approach and we do not have to use the over-the-head dock we needed to use with the Si robot. The Xi robot is side docked on all robotic procedures and the boom is rotated to desired position (Figs. 2, 3).

Statistical analysis

Data were analyzed using GraphPad software (GraphPad Software, La Jolla, CA). The *t* test was used to compare groups. Data were expressed as mean ± standard deviation (SD). Statistical significance was reached with $p < 0.05$.

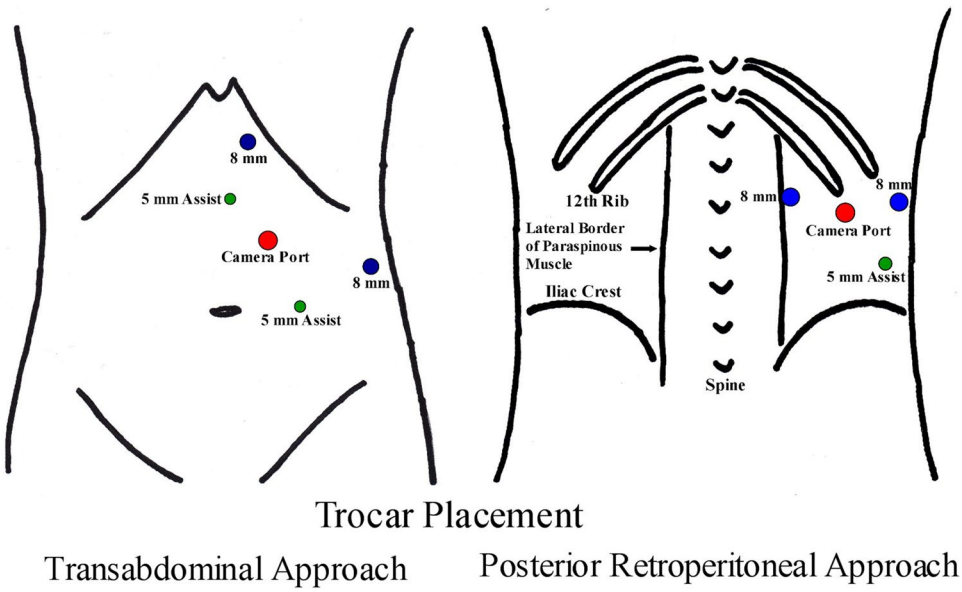

Fig. 1 Port placement. **a** Transabdominal approach; **b** posterior retroperitoneal approach

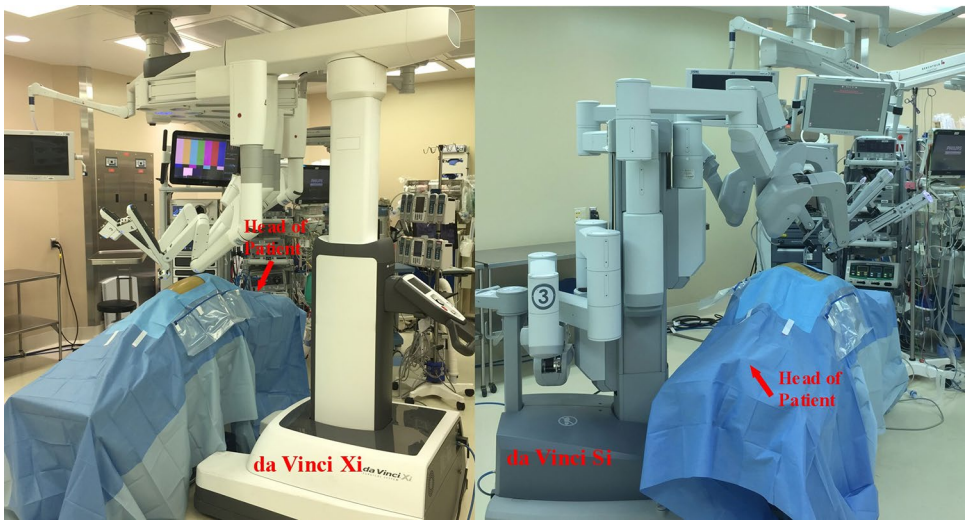

Fig. 2 Docking with the patient in right lateral decubitus position for transabdominal approach robotic adrenalectomy. **a** Da Vinci Xi; **b** da Vinci Si. The operating room table is not rotated when using the Xi system. The operating room table is rotated so as to have the Si system dock over the patient's shoulder

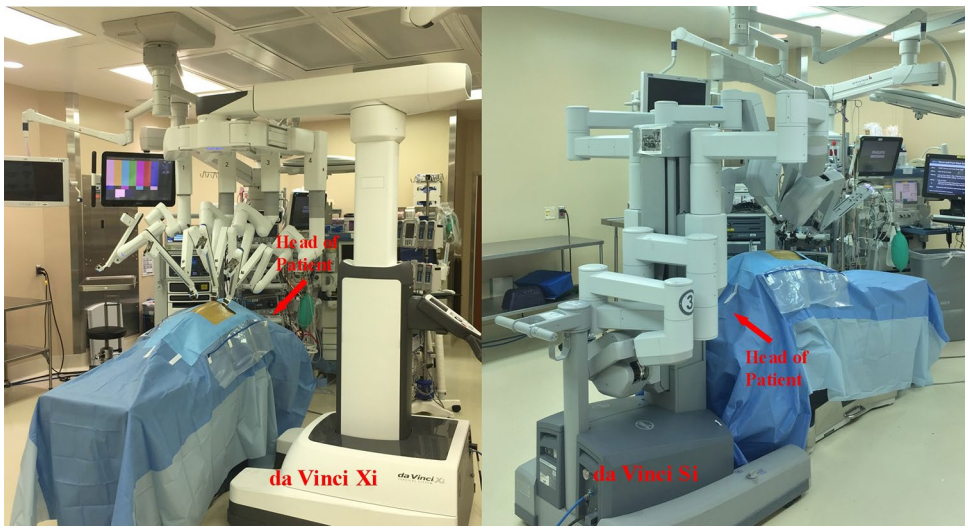

Fig. 3 Docking with the patient in the prone jackknife position on the Wilson frame for posterior retroperitoneal approach adrenalectomy. **a** Da Vinci Xi; **b** da Vinci Si. The table is not rotated when using the Xi

Results

The patient's general data are shown in Table 1. Between the Xi group and Si group, there were no significant differences regarding patient's age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) score, tumor type and size (cm). The average anesthesia time was 145.8 min for the Xi group and 170.4 min for the Si group ($p = 0.001$). The mean procedure times for the Xi group (skin to skin) and Si group were 92.1 and 122.5 min, respectively ($p = 0.001$). The average docking time was 18.2 min for the Xi group and 20.3 min for the Si group ($p = 0.04$).

Because there was an imbalance in the TA and PR approaches used within each group, we analyzed the anesthesia and procedure times according to approach and by robot model used (Tables 2, 3). For the TA approach, the average anesthesia time was 148.1 min in the Xi group vs. 174.1 min in the Si group ($p = 0.001$). The average procedure time was 94.5 min in the Xi group vs. 124.9 min in the Si group ($p = 0.008$). On the other hand, for the RP approach, the average anesthesia time was 142.4 min in the Xi group vs. 137.1 min in the Si group ($p = 0.72$). The average procedure time was 88.9 min in the Xi group vs. 100.9 min in the Si group ($p = 0.3$) (Tables 2, 3). There was no difference in anesthesia or operative times by approach (TA or RP) in the Xi group. There was a significant difference in anesthesia and operative times between TA and RP approaches in the Si group. There was a decline in anesthesia and operative times as we transitioned from Si to Xi era regardless of operative approach.

The average consumables fees for the Xi group were $1246 and $1106 for the Si group (0.04) (Table 4). The

Table 1 Patient demographics and clinicopathologic data

	Xi ($n=25$)	Si ($n=60$)	p value
Age (years)	52.8 ± 12.5	53.2 ± 12.8	0.20
Gender			
Male	10	25	NA
Female	15	35	NA
Body mass index (kg/m^2)	29.8 ± 6.1	32.6 ± 6.4	0.49
Left/right side	13/12	38/22	NA
Surgical approach			
Transabdominal	15	54	NA
Posterior retroperitoneal	10	6	NA
Tumor size (cm)	3.2 ± 1.4	3.9 ± 1.8	0.14
Anesthesia time (min)	145.8 ± 28.1	170.4 ± 36.1	0.001
Procedure time (min)	92.1 ± 20.4	122.5 ± 36.8	0.001
Docking time (min)	18.2 ± 2.9	20.3 ± 3.5	0.04
EBL (ml)	21.4 ± 4.8	21.2 ± 5.1	0.11
ASA	3.0 ± 0.5	3.1 ± 0.5	0.27
Hospital stay (day)	1.6 ± 0.1	1.7 ± 0.1	0.18
Pathologic data			NA
Adrenocortical adenoma	14	33	
Pheochromocytoma	4	14	
Metastatic renal cell carcinoma	1	5	
Cushing's	4	4	
Paraganglioma	1	1	
Adrenocarcinoma	1	3	

calculated relative cost was $3375 for the Xi group and $3527 for the Si group ($p=0.03$) (Table 5). The average post-operative hospital stay for the Xi group was 1.6 days and for the Si group ($p=0.18$) 1.7 days.

Discussion

Previous studies comparing the model Xi vs. Si have been reported for general surgery procedures [5–8] such as gastric bypass and colorectal surgery. Urologic cases have also been analyzed [9–12] including radical prostatectomy, partial nephrectomy, and nephroureterectomy. The majority of these studies showed that average anesthesia, operative, and docking times for the da Vinci robot Xi were slightly or significantly shorter than those for the Si [5–8, 10–12]. The one exception was radical prostatectomy which showed that the operative time on the model Xi (117 min) was longer than on the model Si (106 min) [9]. Our study demonstrates that the average anesthesia time in the Xi group was significantly shorter than in the Si group (145.8 vs. 170.4 min) ($p=0.001$). The mean procedure time (skin to skin) in the Xi group was significantly shorter than in the Si group (92.1 vs. 122.5 min) ($p=0.001$). The average docking time in the Xi group was also shorter than in the Si group (18.2 vs. 20.3 min) ($p=0.04$).

Da Vinci Xi universal linear port placement has been used and described for colorectal surgery [6–8] and kidney surgery [10–12]. But our port placement (Fig. 1) on the model Xi is the same as on the model Si [13, 14]. Raheem et al. [10] showed that changing port configuration to the suggested universal linear port placement for the Xi system, did not affect the results of the procedure and there was a significant shortening in the console time when they used their original Si port placement configuration as compared to the universal linear arrangement. With the da Vinci Xi single dock technique "skipping" the need to rotate the operating table, can significantly reduce the room and operative times. As mentioned above, unlike the model Si robotic docking, we do not have to rotate the operating table to over-the-shoulder dock the robot for a transabdominal decubitus approach and over-the-head dock for the posterior

Table 2 Comparison of OR times of TA and PR approach for Si vs. Xi

Approach	Time (min)	Si (number of cases)	Xi (number of cases)	p value
TA	Anesthesia	174.1 ± 28.3 ($n=54$)	148.1 ± 35.4 ($n=15$)	0.001
	Procedure	124.9 ± 13.9 ($n=54$)	94.5 ± 21.2 ($n=15$)	0.008
PR	Anesthesia	137.1 ± 18.6 ($n=6$)	142.4 ± 33.2 ($n=10$)	0.72
	Procedure	100.9 ± 12.9 ($n=6$)	88.9 ± 20.8 ($n=10$)	0.3

Table 3 Comparison of OR times of Si and Xi for TA and PR approach

Group	Time (min)	TA approach	PR approach	p value
Xi	Anesthesia time	148.1 ± 35.4 ($n=15$)	142.4 ± 33.2 ($n=10$)	0.69
	Procedure time	94.5 ± 21.2 ($n=15$)	88.9 ± 20.8 ($n=10$)	0.52
Si	Anesthesia time	174.1 ± 28.3 ($n=54$)	137.1 ± 18.6 ($n=6$)	0.003
	Procedure time	124.9 ± 13.9 ($n=54$)	100.9 ± 12.9 ($n=6$)	0.001

Table 4 Cost of consumables for Xi vs. Si (USD)

Variable	Xi	Si
Surgical packs, supplies, trocars, etc.	$506	$506
Robotic drapes and cannula seals	$280	$200
Robotic instruments		
Cardiere Forceps	$210	$200
Permanent Cautery Hook	$250	$200
Total cost	$1246	$1106

Table 5 Operative costs: Xi vs. Si robotic adrenalectomy

	Xi	Si	*p* value
Procedure time cost	$513	$513	N/A
Anesthesia time cost	$1616	$1908	N/A
Consumables cost	$1246	$1106	0.16
Total cost	$3375	$3527	0.03

retroperitoneoscopic approach. We side dock the model Xi on all robotic procedures and rotate the boom due to its new overhead instrument arm architecture (Figs. 2, 3). This Xi capability could be part of the explanation for the shorter docking, anesthesia and procedure times observed in this study.

Many factors are considered in deciding which surgical approach is best suited for adrenalectomy in any particular patient. These factors include prior abdominal surgery, body habitus, retroperitoneal fat, tumor size and pathology and the location of the tumor in relation to the kidney and its hilum. In addition, when our team began using the robotic approach to adrenalectomy, we decided to "learn" the TA approach first and only after we were comfortable and adept as a team using the TA approach we transition to the RP approach. This is reflected in the larger number of RP cases done with the Xi vs. the Si. To address this, we evaluated the anesthesia and operative times according to approach and as expected RP times tended to be shorter than TA times, but this was only significantly different in the Si era. Interestingly, anesthesia and operative times decreased between the Si and Xi eras regardless of approach.

Another explanation for the shorter operative times observed in this study is the experience of the team and surgeon. The model Si robot was used starting in 2014. The surgeon (CCS) had been performing laparoscopic adrenalectomies for 12 years before using the robot. In a separate manuscript, we reported that anesthesia and operative times during the transition from laparoscopic to robotic approach were not different suggesting a lack of a "learning curve" for such transition [4]. Yet we believe that the robot when coupled with an experienced team can make the procedure quicker when compared to laparoscopy. For this discussion, we analyzed the operative time for the first 20 robotic adrenalectomies and compared it to the next 40. After performing 20 robotic-assisted adrenalectomies on the Si system, the procedure time has significantly decreased. The average procedure time for our first 20 robotic adrenalectomy cases (136.8 min) was significantly higher than the latter 40 cases (112.6 min) ($p = 0.01$) [4]. A recent study of robotic radical prostatectomy using the Xi platform, demonstrated that there is a learning curve to transition from the da Vinci surgical platform Si to Xi, but after reviewing their outcomes, this transition and learning curve did not affect outcomes [9]. In contrast, the transition from Si to Xi to perform adrenalectomy does not appear to have a learning curve. From our robotic adrenalectomy experience accumulated over the past 5 years, a highly trained surgical team can help in reducing the operating time by facilitating patient positioning, docking, and assisting with the operation.

Despite the da Vinci robot Xi's advantages, one of its disadvantages is unintentionally switching its camera from 0° to 30° back and forth in some procedures such as robotic radical prostatectomies. This procedure requires the surgical team to switch the camera frequently during surgery to operate using different angles. From our experience and observations in other robotic procedures such as prostatectomy, it takes longer to switch the camera from 0° to 30° in the Xi system than in the Si model. Procedures such as adrenalectomy, partial nephrectomy/nephroureterectomy, and colorectal cases use the 30° scope for the majority of the case, and therefore the Xi appears to be very favorable in saving time.

The higher costs associated with robotic surgery include the expense of the robotic system, maintenance fees, and robotic instruments. Because our institution already purchased robotic systems, we did not include the cost of such systems and their maintenance fees. Our previous study [4] compared the cost and peri-operative outcomes between laparoscopic and robotic-assisted adrenalectomy (da Vinci model Si only). It showed that the anesthesia times and procedure times for the robotic group were similar to the laparoscopic group (Fig. 4). It also demonstrated that limiting the number of robotic instruments and energy devices can keep the costs of robotic adrenalectomy comparable to that of the laparoscopic approach. In this study, our consumables fees (calculated from our institution doctor preference cards) were $1246 for the Xi group and $1106 for LA (Table 2) because the Cardiere Forceps and Permanent Cautery Hook of Xi model were slightly more expensive than those of the Si model (Table 4). In this study, the cost of robotic-assisted adrenalectomy using model Xi ($3375) was lower than using model Si ($3430) (Table 5).

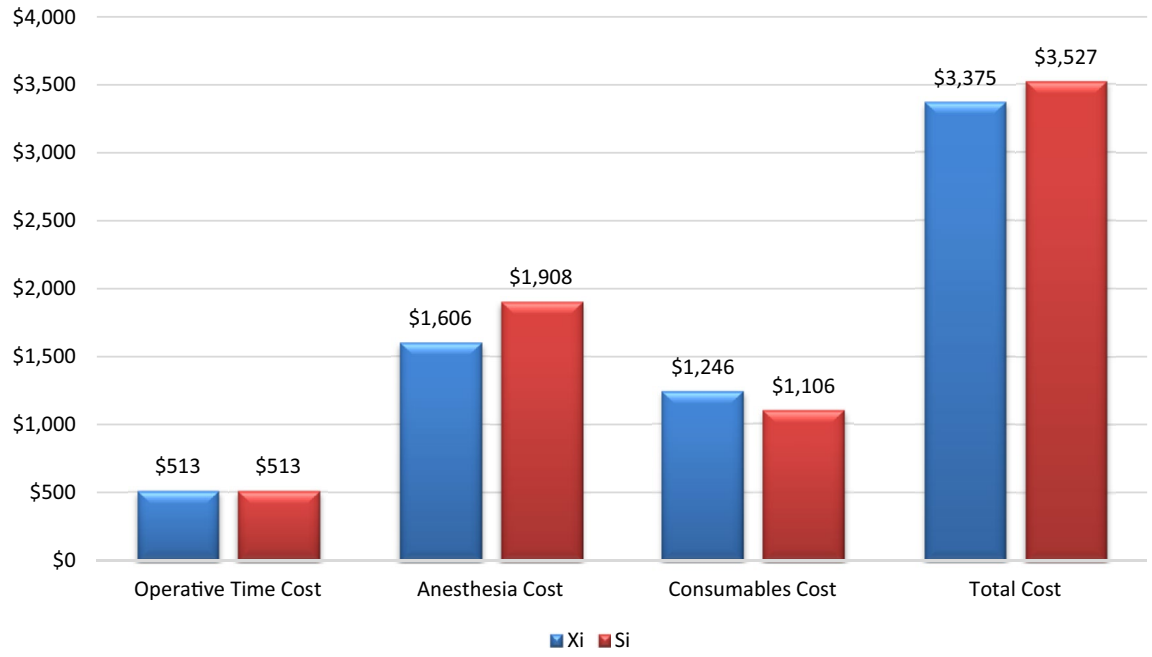

Fig. 4 Mean cost differences between Xi group and Si group

Conclusion

Robotic-assisted adrenalectomy using the da Vinci Xi system is feasible and efficient. This study shows that general outcomes between the Xi and Si groups were similar. Anesthesia and operative times appeared to decline regardless of adrenalectomy approach between the Si and Xi eras.

Funding No funding or financial support was received for the study.

Compliance with ethical standards

Conflict of interest Zuliang Feng, Michael P Feng, David P Feng, and Carmen C. Solórzano declare that they have no conflict of interest.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). Informed consent was obtained from all patients for being included in the study.

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