Surg Endosc (2006) 20: 263–269
DOI: 10.1007/s00464-005-0258-7

SURGICAL ENDOSCOPY
and Other Interventional Techniques

Vascular pedicle ligation techniques during laparoscopic colectomy

A prospective randomized trial

P. W. Marcello,[1] P. L. Roberts,[1] L. C. Rusin,[1] R. Holubkov,[2] D. J. Schoetz[1]

[1] Department of Colon and Rectal Surgery, Lahey Clinic, 41 Mall Road, Burlington, MA 01805, USA
[2] Department of Family and Preventive Medicine, University of Utah, Salt Lake City, UT, USA

Received: 15 April 2005/Accepted: 18 September 2005/Online publication: 9 December 2005

Abstract
Background: A variety of devices are available for pedicle ligation during laparoscopic colectomy including vascular staplers, clips, and electrothermal bipolar vessel-sealing devices. This study assesses their speed, reliability, and cost to guide surgeons in their choice for intracorporeal pedicle ligation.
Methods: A prospective randomized study comparing laparoscopic vascular staplers and disposable clip appliers (S/C) with the LigaSure Atlas (LIG) was performed during elective right, left, and total colectomy. Cases were stratified by procedure. Failure was defined as any bleeding after proper pedicle ligation.
Results: The study included 48 S/C patients and 52 LIG patients with no differences in demographics, diagnosis, procedure, number of vessels ligated per procedure, or operative time. Failure occurred for 14 (9.2%) of the 152 vessels ligated in the S/C group, as compared with 5 (3%) of the 169 vessels ligated in the LIG group ($p = 0.02$). The median blood loss associated with device failure was 50 ml (range, 20–50 ml) in S/C group, as compared with 100 ml (range 25–800 ml) in the LIG group ($p = 0.054$). Major blood loss attributable to device failure and surgeon error occurred in only one LIG case. The mean cost per case of vessel ligation was significantly less in the LIG group ($317 ± $0 vs $400 ± $112; $p < 0.001$). The cost differences were greatest for total colectomy (LIG = $317 ± $0 vs S/C = $565 ± $67; $p = 0.002$).
Conclusions: Device failure, although more common in the S/C group, does not result in significant blood loss. The LigaSure Atlas is more cost effective during laparoscopic colectomy, especially total colectomy, and may allow the surgeon more versatility in its application.

Key words: Electrothermal bipolar vessel sealers — Endoscopic clip appliers — Endoscopic staplers — Intraoperative bleeding — Intraoperative complications — Laparoscopic colectomy — Vascular pedicle ligation — Vessel sealing devices

All colon resections require mobilization and devascularization of the colon and its mesentery, whether performed by a conventional or laparoscopic approach. Most surgeons performing laparoscopic colectomy proceed with colonic mobilization and vascular pedicle ligation intracorporeally, whereas some surgeons complete only colonic mobilization laparoscopically, then perform the remainder of the procedure extracorporeally.

Currently, a variety of options exist for laparoscopic division of the large vascular pedicles to the colon. These options include laparoscopic staplers, laparoscopic clip appliers, suture ligature, and electrothermal bipolar vessel sealers (EBVS) such as the LigaSure Atlas device (Valleylab, Boulder, CO, USA). Ultrasonic shears may be used for the smaller vessels, but are not currently recommended for dividing the larger pedicles such as the ileocolic and inferior mesenteric arteries. The costs of these devices are significant, ranging from $100 to $350. Laparoscopic staplers and clip appliers require reloads, whereas EBVS may be used throughout a procedure without additional cost. The EBVS devices also may be used to divide other tissue and control bleeding in the mesentery, retroperitoneum, or omentum.

The time required to occlude and divide a vascular pedicle varies depending on which device is used. Recent studies have evaluated EBVS and found them to be effective in both open and laparoscopic surgery [1, 2, 4, 7, 9, 10, 12]. However, no published randomized studies in laparoscopic colectomy have compared these devices in the division of vascular pedicles. The current study assessed the speed, reliability, and cost of the various

Presented at the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) meeting, Hollywood, FL, USA, 15 April 2005
Correspondence to: P. W. Marcello

devices to guide surgeons in their choice for intracorporeal pedicle ligation.

Materials and methods

The objective of this study was to determine whether use of the LigaSure Atlas device during laparoscopic colectomy reduces any or all of the following variables, as compared with staples and clips: procedure time, device failure, and cost of vascular pedicle ligation per case.

A prospective randomized study comparing laparoscopic vascular staplers and disposable clip appliers (S/C) with the LigaSure Atlas (LIG) during laparoscopic colectomy was performed. The laparoscopic vascular stapler used was the ETS-Flex45 Endoscopic Linear Cutter (Ethicon Endosurgery, Cincinnati, OH, USA) with the white 1-mm staple loads, and the laparoscopic clip applier was the ER420 Large Ligaclip (Ethicon Endosurgery).

Patients undergoing elective right, left, and total colectomy were included in the study. Randomization was accomplished with sealed envelopes stratified by procedure to provide an equal distribution of cases to each group. Patients who underwent conversion to a conventional approach before pedicle ligation or colon mobilization were excluded from the analysis because no vessels were divided laparoscopically.

Vascular pedicle ligation was performed using a standardized technique. The pedicle was isolated from surrounding structures, then ligated and divided. The endovascular stapler was applied to the ileocolic and inferior mesenteric pedicle, ensuring that all the tissue would be incorporated into the staple line. A single firing was used in all cases after a 15- to 30-s wait. A large clip applier, which held 20 titanium clips, was used for smaller vessels. In an effort to conserve clips, typically two clips were applied to the proximal side of the vessel and one clip to the distal side. We have used this pattern of clip application successfully for more than 600 laparoscopic procedures.

When the LigaSure Atlas was used on the ileocolic and inferior mesenteric pedicles, the device was applied sequentially along the pedicle at least three or four times to ensure an adequate seal before the internal blade was deployed. On these larger pedicles, the initial cut did not routinely transect the entire pedicle, and it was reapplied to the remaining portion of the pedicle. Additionally, at the first application of the device to one of these large pedicles, we carefully inspected for calcified plaque. According to our experience, if there is extrusion of plaque, the device may sometimes fail, so we opened an Endoloop in the event that significant bleeding occurred.

On smaller vessels, the device was applied one or two times, often without the need for it to be reapplied after deployment of the blade. Failure of vascular pedicle ligation was defined as any bleeding after proper pedicle ligation technique. Clips and the LigaSure Atlas also were used when the omentum was resected with the colon or if bleeding occurred during separation of the colon from the omentum.

The technical steps of the procedure were similar for both groups, whether performed by straight laparoscopic or hand-assisted techniques [6, 11]. For the straight laparoscopic resections, a four- or five-port technique was adopted using a flexible-tip or rigid 0° laparoscope. For hand-assisted laparoscopic resection, the Gelport (Applied Medical Resources, Rancho Santa Margarita, CA, USA) was used as the hand-assist device. The device was placed through an 8-cm Pfannenstiel incision two fingerbreadths above the pubic symphysis. In the hand-assisted cases, vascular pedicle ligation and colonic mobilization proceeded in the exact order used for the straight laparoscopic group. For right-sided resections, the ileocolic pedicle was divided at its origin. In cases of ileocolic Crohn's disease, this was the only vessel ligated intracorporeally. For polyps and cancers, the right and middle colic vessels were divided intracorporeally depending on the location of the lesion. For left-sided resections, the inferior mesenteric pedicle was divided either distal to the left colic vessels in cases of diverticular disease or proximal to the left colic vessels in cases of cancer and polyps. The left colic vessels and the proximal inferior mesenteric vein also were sometimes divided depending on the vascular anatomy and the extent of the planned resection. The colonic mesentery then was mobilized using a medial to lateral approach.

The appropriate flexure was mobilized completely in all cases. This included separation of the omentum from the colon, beginning at the flexure and proceeding to the midtransverse colon. For proctocolectomy, the rectum was partially mobilized intracorporeally, after which the colon and rectum were extracted through the Pfannenstiel incision.

The operative time was recorded as the time from skin incision to wound closure. Patients requiring concomitant procedures were not excluded from the study. The time needed to perform additional procedures was recorded and subtracted from the total operative time for the case so as not to bias either group. The cases were managed by a primary surgeon (P.W.M.), who instructed and assisted general surgical residents, colorectal residents, and other colorectal staff during the procedures.

Sample size calculation

On the basis of prior reports evaluating EBVS [1, 7, 9] and our personal experience with the EBVS devices, we hypothesized that the use of the LigaSure Atlas may reduce the operative time for segmental and total colectomy. Sample size was calculated to yield high power for detecting a 10% reduction in procedure time when the procedure was performed with LigaSure versus staples and clips. On the basis of preliminary chart review, a standard deviation of 23 min was used for both hemostatic methods. An average procedure time of 150 min was found for laparoscopic segmental colectomy performed with staples and clips. A 10% reduction in procedure time, or 15 min, was determined to be clinically significant. It was determined that a sample size of 50 patients per study arm would be sufficient (alpha, 0.05; beta, 0.10; power, 90%) to detect an effect of this magnitude if one truly existed.

Statistical analysis

Distributions of dichotomous variables were compared between treatment arms using the chi-square test or Fisher's exact test for tables in which expected cell sizes were less than 5. Because many continuous variables tended to have skewed distributions, the nonparametric Wilcoxon rank-sum test was used to compare distributions between treatment arms. For the cost analysis, the institutional cost for the devices at initiation of the study (February 2003) was used for all procedures. The costs of ligation in the LigaSure treatment arm were treated as a fixed value of $317. Therefore, the costs of ligation were compared between treatment arms using a Wilcoxon signed-rank test to test the hypothesis that the true cost in the staple/clip arm was equal to this fixed value. All reported p values are two-sided.

This study was approved by the Institutional Review Board of the Lahey Clinic, Burlington, Massachusetts, USA. The lead author (P.W.M.) is a consultant to Valleylab, Boulder, CO.

Results

From February 2003 to October 2004, 101 patients were entered into the study and randomized before surgery. At the time of initial laparoscopy, one patient found to have a cecal cancer invading the retroperitoneum underwent conversion to an open procedure before vessel ligation or colon mobilization. This patient was excluded from the analysis. The remaining 100 randomized patients (48 S/C patients and 52 LIG patients) had a completed laparoscopic procedure. There were no differences in patient demographics and diagnosis, except for body mass index (BMI) (Table 1). The mean BMI was higher by 3 kg/m^2 in the S/C group, but this was not thought to have a clinical impact on operative time, blood loss, or failure of pedicle ligation. There were no differences in operative procedure or number of vessels ligated per procedure (Table 2). The operative

Table 1. Patient characteristics

Demographics	LIG (n = 52)	S/C (n = 48)	p Value
Sex (M/F)	29/23	25/23	0.71
Age (years)[a]	51 ± 15 (21–81)	55 ± 16 (22–84)	0.21
BMI (kg/m^2)*	26 ± 5 (18–39)	29 ± 6 (18–46)	0.02
Prior abdominal surgery: n (%)	17 (33)	24 (50)	0.08
ASA score[b]: n (range)	2 (1–3)	2 (1–4)	0.45
Diagnosis: n (%)			0.69
Diverticulitis	17 (33)	17 (35)	
Ulcerative colitis	12 (23)	8 (17)	
Colon cancer	11 (21)	13 (27)	
Polyp	7 (13)	5 (10)	
Crohn's disease	3 (6)	5 (10)	
Other	2 (4)	0 (0)	

LIG, LigaSure Atlas group; S/C, staple/clips group; BMI, body mass index; ASA, American Society of Anesthesiology classification
[a] Values listed as mean ± standard deviation (range)
[b] Values listed as median (range)

Table 2. Perioperative results

Overall	LIG (n = 52)	S/C (n = 48)	p Value
Procedures: n (%)			0.88
Right colectomy	17 (33)	17 (35)	
Left/sigmoid colectomy	22 (42)	21 (44)	
Total colectomy	13 (25)	10 (21)	
TAC	5	2	
TPC	3	2	
IPAA	5	6	
Hand-assisted laparoscopy: n (%)	35 (67)	34 (71)	0.70
Operative time (min)[a]	179 ± 62 (92–363)	190 ± 70 (86–383)	0.44
Adjusted operative time[b] (min)[a]	177 ± 62 (92–363)	186 ± 70 (86–383)	0.46
Conversions	0	0	1.00
Total EBL (ml)[a]	217 ± 167 (50–800)	231 ± 166 (50–1,000)	0.33
Vessels ligated/case[a]	3.3 ± 2.0 (1–7)	3.2 ± 2.1 (1–9)	0.78
Ligation failures: n (%)	5/169 (3)	14/152 (9.2)	0.02
Failure EBL[c]	100 (25–800)	50 (20–50)	0.054
Right colectomy	(n = 17)	(n = 17)	
Hand-assisted laparoscopy: n (%)	1 (6)	3 (18)	0.60
Operative time (min)[a]	139 ± 37 (92–227)	143 ± 33 (86–232)	0.45
Adjusted operative time[b] (min)[a]	136 ± 37 (92–227)	141 ± 27 (86–187)	0.25
Vessels ligated/case[a]	2.2 ± 1.0 (1–4)	2.2 ± 1.0 (1–4)	0.96
Ligation failures n (%)	1/37 (2.7)	3/37 (8.1)	0.61
Left/sigmoid colectomy	(n = 22)	(n = 21)	
Hand-assisted laparoscopy: n (%)	22 (100)	21 (100)	1.00
Operative time (min)[a]	160 ± 23 (123–226)	176 ± 38 (124–298)	0.15
Adjusted operative time[b] (min)[a]	159 ± 24 (123–226)	170 ± 37 (124–298)	0.29
Vessels ligated/case[a]	2.2 ± 0.6 (1–3)	2.2 ± 0.9 (1–4)	0.97
Ligation failures: n (%)	3/48 (6.3)	3/47 (6.4)	1.00
Total colectomy	(n = 13)	(n = 10)	
Hand assisted laparoscopy: n (%)	12 (92)	10 (100)	1.00
Operative time (min)[a]	264 ± 56 (165–363)	296 ± 57 (230–383)	0.35
Adjusted operative time[b] (min)[a]	261 ± 55 (165–363)	294 ± 60 (210–383)	0.32
Vessels ligated/case[a]	6.5 ± 0.5 (6–7)	6.8 ± 1.0 (5–9)	0.33
Ligation failures: n (%)	1/84 (1.2)	8/68 (12)	0.011

LIG, LigaSure Atlas group; S/C, staple/clips group; TAC, total abdominal colectomy/ileostomy or ileorectal anastomosis; TPC, total proctocolectomy/ileostomy; IPAA, total proctocolectomy with ileal pouch anal anastomosis; EBL, estimated blood loss
[a] Values listed as mean ± standard deviation (range)
[b] Ooperative times were adjusted for concomitant procedures
[c] Values listed as median (range)

times were adjusted for five patients in the LIG group (15–30 min) and seven patients in the S/C group (10–45 min) because of additional procedures. The mean operative times (both the total and adjusted times) were slightly less for the LIG group (179 vs 190 min) overall, and also for each of the three procedural categories, but

Table 3. Vascular pedicle ligation failures

Procedure	Technique used	Pedicle	Site of failure	EBL (ml)	Technique to secure
LIG failures 5/169 vessels (3%)					
Right colectomy	LigaSure	Ileocolic	Proximal vein	25	Endoloop
Left colectomy	LigaSure	IMP	Proximal	100	Reseal with LIG
Sigmoid colectomy	LigaSure	IMP	Proximal artery	300	Endoloop
Left colectomy	LigaSure	IMV	Proximal	800	Reseal with LIG
TPC	LigaSure	IMP	Proximal	50	Endoloop
S/C Failures 14/152 vessels (9.2%)					
Right colectomy	Stapler	Ileocolic	Distal	25	Endoloop
Right colectomy	Stapler	Ileocolic	Proximal artery	50	Endoloop
Right colectomy	Clip	Right colic	Distal	50	Reclip
Sigmoid colectomy	Stapler	IMP	Proximal vein	20	Endoloop
Sigmoid colectomy	Stapler	IMP	Proximal artery	30	Endoloop
Sigmoid colectomy	Stapler	IMP	Proximal	50	Compression
IPAA	Stapler	Ileocolic	Distal	50	Endoloop
	Clip	Right colic	Distal	50	Reclip
	Clip	Left colic	Proximal	50	Reclip
TAC	Stapler	Ileocolic	Distal	20	Endoloop
	Stapler	Right middle colic	Proximal	25	Endoloop
IPAA	Stapler	IMP	Proximal	50	Endoloop
IPAA	Clip	Right colic	Proximal	20	Reclip
TPC	Clip	Right middle colic	Proximal	50	Reclip

EBL, estimated blood loss; LIG, LigaSure Atlas group; IMP, inferior mesenteric pedicle; IMV, inferior mesenteric vein; TPC, total proctocolectomy/ileostomy; S/C, staple/clips group; IPAA, total proctocolectomy with ileal pouch anal anastomosis; TAC, total abdominal colectomy/ileostomy or ileorectal anastomosis

this difference did not reach statistical significance. There were no conversions in the study group.

Failure of pedicle ligation occurred for 14 (9.2%) of 152 vessels ligated in the S/C group, as compared with 5 (3%) of the 169 vessels ligated in the LIG group ($p = 0.02$) (Table 2). The median blood loss associated with device failure was 50 ml (range, 20–50 ml) in S/C group, as compared with 100 ml (range, 25–800 ml) in the LIG group ($p = 0.054$) (Tables 2). To control bleeding compression, clips and Endoloops (Ethicon Endosurgery) were used in the S/C group, and Endoloops and resealing were used in the LIG group (Table 3).

Major blood loss (800 ml) occurred in only one LIG case, as a result of device failure and surgeon error. This patient, with a carcinomatous polyp of the left colon, underwent a hand-assisted laparoscopic left colectomy. The inferior mesenteric vein was isolated near its origin, with less than 1 cm distance to the tail of the pancreas. When the LigaSure Atlas was applied, the vessel tore and retracted under the pancreas. There was no tension on the vessel at the time of attempted ligation. However, if the vessel had been transected further away from its origin, the blood loss from this failure would have been much less. The failure therefore related to both device failure and the surgeon's error in choosing the site for pedicle ligation. There were no cases of delayed postoperative hemorrhage in either group.

The overall mean cost per case of vessel ligation was significantly less in the LIG group ($317 ± $0 vs $400 ± $112; $p < 0.001$; Table 4). In the right and sigmoid colectomy groups, a single stapler and clip applier were used most commonly because only one major pedicle was divided and the remaining one or two smaller vessels were ligated with the single-clip applier. The cost differences were greatest for total colectomy (LIG = $317 ± $0 vs S/C = $565 ± $67; $p = 0.002$) because the S/C cases typically required one stapler, one staple reload, and two clip appliers for the division of six to nine major vessels.

Discussion

To divide vascular pedicles laparoscopically, two currently available sealing technologies are in use today: ultrasonic energy–based sealers and EBVS devices. The ultrasonic devices are commonly used in foregut procedures, but are not approved for handling the large arteries encountered during colon resection. However, several studies have evaluated these technologies in a nonrandomized fashion during laparoscopic colectomy [1, 7, 12]. Takada et al. [12] compared the two devices for 30 patients undergoing segmental colon resection and found that the EBVS device was associated with fewer episodes of rebleeding (0.3 vs 1.2 episodes/case) and less time required to mobilize and divide the mesentery. In this study, the ileocolic and inferior mesenteric vessels were not ligated.

In a separate study by Akari et al. [1], similar results were seen during hand-assisted laparoscopic total colectomy. The mean operative times were 55 min shorter in the EBVS group than in the ultrasonic shear group. The mean operative blood loss and the number of rebleeding episodes also were less. We have not used the ultrasonic shears during laparoscopic colectomy because they were not designed or approved by the Food and Drug Administration (FDA) for successful ligation of the larger pedicles encountered during laparoscopic colectomy.

One additional study by Heniford et al. [7] compared the LigaSure with staples, ultrasonic shears, and sutures

Table 4. Cost of vascular pedicle ligation

Cost of devices (February 2003)			
LigaSure Atlas	$317	Clip applier (large)	$105
		Endoscopic stapler	$269
		Each stapler reload	$87
Cost of pedicle ligation/case	LIG	S/C[a]	*p* Value
Total group	$317	$400 ± 112 $375 (105–672)	< 0.001
Right colectomy	$317	$348 ± 95 $375 (105–548)	0.02
Left/sigmoid colectomy	$317	$362 ± 52 $375 (270–462)	< 0.001
Total colectomy	$317	$565 ± 67 $567 (462–672)	0.002

LIG, LigaSure Atlas group; S/C, staple/clips group
[a] Values listed in the S/C group as mean ± standard deviation and median (range)

during a variety of laparoscopic and open procedures, including laparoscopic colectomy. The LigaSure device rarely failed, and it shortened the operating time during conventional surgical procedures. A shortened procedural time during conventional surgery also was reported in a randomized study comparing the LigaSure device with sutures during gynecologic procedures [9].

The current study remains the only prospective randomized study to compare an EBVS device with endoscopic staplers and clip appliers during laparoscopic colectomy. The objectives of the current study were to evaluate the speed, reliability, and cost of these devices. The LigaSure Atlas was chosen as the EBVS device because it was able to both coagulate and divide tissue by use of its internal blade. Prior LigaSure devices could seal the vessel, but could not divide tissue.

With this advance in engineering design as well as previous reports in the literature and our prior personal experience with the Atlas device, we believed that the LigaSure Atlas might shorten the procedural times by at least 15 min. The study findings showed only an average 10-min reduction in operative time, and with a broadened standard deviation, this difference did not reach statistical significance. A larger study might demonstrate a statistically significant difference in operative time, but is a reduction of 5 to 10 min clinically significant?

The results of the current study do, however, demonstrate that the use of the LigaSure device is not associated with a prolongation in operative time, as suggested in an earlier nonrandomized study [7]. Many factors other than the time required to ligate a pedicle can alter the overall operative time, such as the experience of the surgeon and surgical team, the presence of adhesions, the degree of inflammation in diverticular and inflammatory bowel disease cases, and the need for concomitant procedures. We did adjust the operative times for additional procedures, but this did not alter the outcome. The other variables, we believe, should have been approximately equalized by the randomization. The BMI was slightly higher in the S/C group, but we do not think this affected the operative time because most of our surgical patients undergoing a laparoscopic colectomy have a BMI of at least 25 to 30 kg/m^2.

Intraoperative bleeding remains one of the most common intraoperative complications associated with laparoscopic colectomy and the cause for conversion to an open procedure [2, 5, 8]. As the surgeon's skill improves, there appears to be a reduction in intraoperative bleeding episodes [2, 8]. Intraoperative bleeding typically occurs when either a surgeon inadvertently injures a vessel or the technique of vessel ligation fails. As experience is gained, the inadvertent injuries should subside, but device failures still will occur.

In a recent review of 430 laparoscopic colorectal procedures by the Cleveland Clinic [5], conversion to an open procedure was necessary in 51 cases (12%). Conversion occurred during vascular pedicle ligation in eight cases, four of which were related to stapler or clip applier misfire. Equipment failure often goes unreported, but a recent review of the FDA database demonstrated 22,804 surgical stapler adverse events, which resulted in 112 deaths and 2,180 patient injuries [3]. In performing a surgical procedure, almost any device can malfunction or fail. With experience, the surgeon can salvage the majority of these failures.

Failure of a device during vascular pedicle ligation in a laparoscopic colon resection remains one of the greatest challenges to a surgeon's skill and reserve. In the current study, device failure was not common in either group, and did not require conversion in any instance. Fortunately, the majority of the device failures did not result in significant blood loss (Table 3). Given the experience of the operating team at our institution, we prepare for possible device malfunctions during every pedicle ligation. Although device failure resulted in an incomplete ligation, in most cases the pedicle was partially or nearly completely sealed by the device. Most device failures resulted in a blood loss of 50 ml or less. If any bleeding was noted after pedicle ligation, the pedicle was immediately grasped and compressed by fingers or instrument. When bleeding persisted, the Endoloop often was used to secure the pedicle. In some cases, the vessels were resealed with the LigaSure Atlas device or by the further application of clips. When there was a failure of the endovascular stapler, there often was not sufficient tissue proximally to apply a second row of

vascular staples. The Endoloop, by its design, allows the pedicle to be secured with the least manipulation and remains our preferred approach to staple line bleeding. It is therefore our current practice (and strongly recommended) to have Endoloops, endovascular clip appliers, and a EBVS device available in the room during every laparoscopic colorectal procedure.

As reported earlier, a single patient did experience a significant blood loss during pedicle ligation with the LigaSure Atlas. However, we believe that the failure could have been minimized if the surgeon had not performed such a proximal ligation of the inferior mesenteric vein. Since this complication, we have had no further failures when dividing the proximal inferior mesenteric vein, and have left an adequate margin in case of a device malfunction.

Device failure occurred more frequently during the application of staples and clips than during use of the LigaSure Atlas (9.2% vs 3%; $p = 0.02$). This difference was most evident during laparoscopic total colectomy, in which the stapler or clip applier failed in 8 (12%) of 68 vessel ligations, as compared with 1 (1.2%) of 84 LigaSure Atlas seals. Failure in the S/C group occurred with both staples and clips and on both the proximal and distal sides of the divided pedicle. The site of the failure during laparoscopic colectomy, whether on the proximal or distal side of the divided vessel, is not often described. Failure on the proximal side of a divided vessel is intuitive, and likely relates to the higher intraluminal pressure of the proximal vessel. Failure on the distal side of a pedicle was identified after application of staples and clips, but not with use of the LigaSure Atlas. Distal failure of a staple line was found in three cases, all on the ileocolic pedicle. None of these failures resulted in substantial blood loss. Failure of a clip on the distal end may relate to the routine application of a single clip on the distal side of the vessel. Whether placing two clips distally on every vessel would have prevented the failure remains unknown.

Distal vessel ligation failure also may have been caused by the necessary continued manipulation of the colon mesentery after pedicle ligation. After the pedicle is divided, the surgeon purposely avoids the proximal side of the vessel in the retroperitoneum, but still needs to handle the divided mesentery during the remaining portions of the procedure. In the LigaSure Atlas group, all the failures occurred on the proximal side of the vessel, suggesting that once the vessel is divided, the distal seal maintains durability despite the continued manipulation of the tissues by the surgeon.

The cost of laparoscopic surgery is significant. Although the increased operative costs can be offset with a reduction in hospital costs related to a shorter length of hospital stay, operative costs must be controlled. This is the only study to evaluate the cost of vascular pedicle ligation during laparoscopic colectomy. We demonstrated a significant overall average cost savings of approximately \$80 with the use of the LigaSure Atlas, as compared with the use of endovascular staples and clips (\$317 vs \$400; $p < 0.001$). As expected, the savings were less with segmental resection than with total colectomy. For right colectomy, the mean savings were \$31 (\$317 vs \$348; $p = 0.02$), and for sigmoid/left colectomy, the mean savings were \$45 (\$317 vs \$362; $p < 0.001$). For total colectomy, in which a stapler, one staple reload, and two clip appliers often were used to divide the six to nine major vessels, the mean cost savings were substantially higher at \$248 (\$317 vs \$565; $p = 0.002$).

Numerous options for vascular pedicle ligation exist, each with varying costs. The costs of endovascular staplers and staple reloads are relatively comparable among the various suppliers. A variety of clip appliers exist, which have a much broader range of prices depending on whether they are single-fire or multifire devices, and whether they are reusable or disposable. Other combinations of devices may not have cost more than the LigaSure Atlas. Some surgeons do not routinely use an endovascular stapler, applying only clips to ligate the pedicles. This approach would favor clips over EBVS devices, but may require additional skills and experience to avoid an increase in blood loss or operative time. The protocol chosen for the study is a common choice of pedicle ligation technique used by a majority of practicing surgeons. In this case, the LigaSure Atlas was more cost effective for each of the procedure categories than staples and clips.

What is not captured in the data, but relevant to the choice of sealing and coagulation equipment, is the ability to control bleeding and divide tissue with the EBVS devices in areas other than the major pedicles. The EBVS devices are very efficient in the resection of the omentum when colon cancer has invaded omentum, or when the omentum is densely adherent in the setting of colitis. Control of mesenteric or retroperitoneal bleeding also is very reliable with these devices. Future generations of EBVS likely will combine technologies, providing standard monopolar electrocautery in the same device that provides EBVS. These future devices may then replace or complement other sealing technologies such as ultrasonic energy or radiofrequency devices.

Conclusions

Vascular pedicle ligation can be performed safely with a variety of techniques and devices. In this prospective randomized study, the choice of devices did not alter the operative times. Device failure, although more common with the use of the stapler and clips, did not result in significant blood loss. In a comparison of costs for vascular pedicle ligation, the LigaSure Atlas proved to be more cost effective during laparoscopic colectomy, especially total colectomy, and may allow the surgeon more versatility in its application.

Acknowledgment. This study was funded in part by a grant from Valleylab, Boulder, Colorado, USA.

References

1. Akari Y, Noake T, Kanazawa M, Momosaki K, Nozoe Y, Inoue A, Ishibashi N, Ogata Y, Shirouzu K (2004) Clipless hand-assisted laparoscopic total colectomy using Ligasure Atlas. Kurume Med J 51: 105–108

2. Bennett CL, Stryker SJ, Ferreira MR, Rosario M, Adams J, Beart R (1997) The learning curve for laparoscopic colorectal surgery: preliminary results from a prospective analysis of 1,194 laparoscopic-assisted colectomies. Arch Surg 132: 41–44
3. Brown SL, Woo EK (2004) Surgical stapler-associated fatalities and adverse events reported to the Food and Drug Administration. J Am Coll Surg 199: 374–381
4. Carbonell AM, Joels CS, Kercher KW, Matthews BD, Sing RF, Heniford BT (2003) A comparison of laparoscopic bipolar vessel sealing devices in the hemostasis of small-, medium-, and large-size arteries. J Laparoendosc Adv Surg Tech A 13: 377–380
5. Casillas S, Delaney CP, Senagore AJ, Brady K, Fazio VW (2004) Does conversion of a laparoscopic colectomy adversely affect patient outcome? Dis Colon Rectum 47: 1680–1685
6. Chang YJ, Marcello PW, Rusin LC, Roberts PL, Schoetz DJ (2005) Hand-assisted laparoscopic colectomy: a helping hand or hindrance. Surg Endosc 19: 656–661
7. Heniford BT, Matthews BD, Sing RF, Backus C, Pratt B, Greene FL (2001) Initial results with an electrothermal bipolar vessel sealer. Surg Endosc 15: 799–801
8. Larach SW, Patankar SK, Ferrara A, Williamson PR, Perozo SE, Lord AS (1997) Complications of laparoscopic colorectal surgery: analysis and comparison of early vs latter experience. Dis Colon Rectum 40: 592–596
9. Levy B, Emery L (2003) Randomized trial of suture versus electrosurgical bipolar vessel sealing in vaginal hysterectomy. Obstet Gynecol 102: 147–151
10. Matthews BD, Pratt BL, Kercher KW, Mostafa G, Lentzner A, Lipford EH, Sing RF, Heniford BT (2001) Effectiveness of the ultrasonic coagulating shears, LigaSure vessel sealer, and surgical clip application in biliary surgery: a comparative analysis. Am Surg 67: 901–906
11. Rivadeneira DE, Marcello PW, Roberts PL, Rusin LC, Murray JJ, Coller JA, Schoetz DJ (2004) Benefits of hand-assisted laparoscopic restorative proctocolectomy: a comparative study. Dis Colon Rectum 47: 1371–1376
12. Takada M, Ichihara T, Kuroda Y (2005) Comparative study of electrothermal bipolar vessel sealer and ultrasonic coagulating shears in laparoscopic colectomy. Surg Endosc 19: 226–228