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Special Article

Comparative Studies of Energy Sources in Gynecologic Laparoscopy

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ABSTRACT Energy sources incorporating "vessel sealing" capabilities are being increasingly used in gynecologic laparoscopic surgery although conventional monopolar and bipolar electrosurgery remain popular. The preference for one device over another is based on a combination of factors, including the surgeon's subjective experience, availability, and cost. Although comparative clinical studies and meta-analyses of laparoscopic energy sources have reported small but statistically significant differences in volumes of blood loss, the clinical significance of such small volumes is questionable. The overall usefulness of the various energy sources available will depend on a number of factors including vessel burst pressure and seal time, lateral thermal spread, and smoke production. Animal studies and laboratory-based trials are useful in providing a controlled environment to investigate such parameters. At present, there is insufficient evidence to support the use of one energy source over another. Journal of Minimally Invasive Gynecology (2013) 20, 308–318 © 2013 AAGL. All rights reserved.

Keywords: Comparative trials; Energy sources; Gynecologic laparoscopy

DISCUSS You can discuss this article with its authors and with other AAGL members at **http://www.AAGL.org/jmig-20-3-12-00582**

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The use of new-generation energy sources in gynecologic laparoscopy is steadily increasing. In addition to conventional monopolar and bipolar electrosurgery, many surgeons use advanced bipolar "vessel sealers" that incorporate tissue feedback monitoring or devices that use ultrasonic technology to both seal vessels and transect tissue. The tissue effects of these instruments are summarized in Table 1. The choice of instrumentation may vary according to the nature of the surgical task being performed and additionally may be influenced by various factors including previous training or experience, the availability and cost of instrumentation, relative tissue transection/hemostatic properties of the instrument, the degree of anticipated pathology in the tissues, and industry marketing. Ideally, the decision to use a particular energy source should be based on the results of well-designed randomized controlled clinical trials. However, there are only a limited number of such clinical studies in general surgery, and even fewer such studies for gynecologic laparoscopic surgery. Comparative laboratory-based and animal studies are also useful in providing a controlled environment to investigate various properties of energy sources available for laparoscopic surgery. This article reviews the comparative literature on laparoscopic energy sources with an emphasis on their usefulness in gynecologic surgery.

Methods

Although there are many comparative clinical studies and 3 meta-analyses of the performance of laparoscopic energy sources in colectomy [1], cholecystectomy [2], and general surgery [3] published in the medical literature, we are unaware of similar systematic reviews in gynecologic laparoscopy. We searched the National Library of Medicine's Medline and the Cochrane Library databases (1946 to October 1, 2012) for comparative clinical trials of energy sources in gynecologic patients. We used the following

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The authors declare that they have no conflict of interest.

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Table 1

The main classes of laparoscopic energy sources and their tissue effects [37]

Energy Source	Tissue Effects
Monopolar electrosurgery	Vaporization (tissue transection), fulguration, desiccation, coaptation*
Conventional bipolar electrosurgery	Desiccation, coaptation
Advanced bipolar technology†	Desiccation, coaptation, tissue transection‡
Ultrasonic technology	Desiccation, coaptation, mechanical tissue transection

* Vessel sealing achieved with coagulation and compression.

† Activation time limited by tissue-response feedback.

‡ Transection with incorporated blade or bipolar energy.

search strategy: randomized controlled trial/ or "randomized" or "randomized" or prospective studies/ or "prospective" AND "monopolar" or "bipolar electrosealing device" or "bipolar electrosurgery" or "bipolar vessel sealing system" or "tripolar" or "EBVS" or "electrothermal bipolar coagulation" or "electrothermal bipolar vessel sealer" or "electrothermal bipolar vessel sealing system" or "electrothermal vessel sealing" or "energized vessel sealing" or "energy-based vessel ligation" or "vessel sealer" or "vessel sealing" or "LSVS" or "LigaSure" or "EnSeal" or "(Gyrus and bipolar)" or "Harmonic Scalpel" or "Harmonic shears" or "Harmonic ACE" or "SonoSurg" or "ultrasonic vessel sealer" or "ultrasonic sealer" or "ultrasonic coagulating shears" or "Thunderbeat" or "AutoSonix" AND gynecology/ or "gynecology" or "gynaecology" or "hysterectomy" or "myomectomy" or "endometriosis" or "ovarian cystectomy" or "oophorectomy" AND laparoscopy/.

This search identified 22 abstracts, which were screened independently by the 2 authors. Animals studies (n = 3), hysteroscopic studies (n = 2), and studies that did not compare 2 or more energy sources (n = 9) were excluded. Eight comparative clinical trials in energy sources relating to laparoscopic gynecologic surgery were identified. Table 2 summarizes the relevant key findings of these studies. These data were analyzed and compared with data from meta-analyses on laparoscopic colectomy [1], cholecystectomy [2], and general surgery [3].

Of the 8 studies, 2 were randomized controlled trials, 2 were nonrandomized trials, and 4 were retrospective comparative studies (Table 2). Seven studies related to benign gynecologic conditions [4–10], and 1 study was undertaken in women with cervical cancer [11]. With the exception of 1 study comparing 2 vessel sealing devices (Harmonic Scalpel [Ethicon Endo-Surgery, Cincinnati, OH] vs LigaSure [Covidien, Mainsfield, MA]) [6], the remaining 7 studies compared vessel sealing devices with conventional electrosurgery [4,5,7–11].

Results and Discussion

Clinical Comparative Studies

This is the first review in the literature looking at comparative clinical trials of energy sources in laparoscopic gynecologic surgery. A Cochrane review has been published on energy source instruments for laparoscopic colectomy [1], and meta-analyses on the performance of laparoscopic energy sources in cholecystectomy [2] and general surgery [3] have also been published. However, given the lack of randomized studies in gynecologic surgery, a meta-analysis of the few studies relating to gynecologic procedures would not yield useful information. Moreover, although such meta-analyses can offer a comparison of different broad categories of vessel sealers, they cannot be used to show significant differences between specific instruments. Six randomized controlled trials (N = 446) were included in the Cochrane review on various energy sources for laparoscopic colectomy, but a major limitation of this meta-analysis is the heterogeneity of the studies [1]. Furthermore, the authors considered LigaSure, Gyrus PlasmaKinetic (PK; Gyrus ACMI, Maple Grove, MN), and EnSeal (Ethicon Endo-Surgery, Cincinnati, OH) collectively as "electrothermal bipolar vessel sealers" although laboratory-based trials (see later) and clinical experience indicate that each of these devices has a different profile of efficacy for the range of evaluated parameters.

A systematic review has previously reported on LigaSure versus other energy sources and included gynecologic and nongynecologic studies [3]. Results from nongynecologic studies may not always be generalizable to gynecologic procedures. For example, fewer vessels need to be sealed during a hysterectomy compared with a left colectomy. Accordingly, the total time saved by using vessel sealing devices in laparoscopic gynecologic surgery may not be as significant as in colorectal surgery. A review of the clinical data on blood loss, operating time, postoperative pain, and complications from comparative clinical studies of laparoscopic energy sources follows.

Blood Loss

One of the purported advantages of the modern vessel sealers is the reduction of intraoperative blood loss. Seven of the 8 comparative studies in gynecologic laparoscopy reported data on blood loss [4–9,11]. Because of the heterogeneity of the surgical procedure among the studies, and the differing energy sources used in the studies, it is not possible to pool data from these studies (Table 2). Of the 2 randomized controlled trials in gynecologic surgery, one showed no significant difference in intraoperative blood loss (234.1 vs 273.1 mL, $p = .46$) [4], whereas the other showed a statistically significant difference of 47.6 mL (135.2 ± 89.1 vs 182.8 ± 116.8 mL, $p = .004$) [5]. The study that showed no significant difference in blood loss was for total laparoscopic hysterectomy (TLH) using LigaSure versus conventional bipolar forceps [4]. The study showing

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Table 2

Comparative trials on energy sources in gynecologic laparoscopy

Authors	Study design	Sample size	Procedure	Study groups	Relevant key findings
Janssen et al., 2011 [4]	Randomized controlled trial	140	Laparoscopic hysterectomy	LS vs CB	Operating time from skin incision to detachment of uterus: 97.6 vs 91.8 minutes ($p = .39$) Total operating time: 148.1 vs 142.1 minutes ($p = .46$) Intraoperative blood loss: 234.1 vs 273.1 mL ($p = .46$)
Litta et al., 2010 [5]	Randomized controlled trial	160	Laparoscopic myomectomy	HS vs EV	Post-operative pain: at 24 hours (VAS 0 to 10): 4.4 ± 1.1 vs 5.6 ± 0.8 ($p < .001$) (at 48 hours: no significant difference) Operation time: 71.8 ± 26.7 vs 88.8 ± 35.5 minutes ($p < .0001$) Intraoperative blood loss: 135.2 ± 89.1 vs 182.8 ± 116.8 mL ($p = .004$) Blood transfusion rate: no transfusions in either group Myoma recurrence rate: no recurrence in any patient (6-month follow-up)
Demirturk et al., 2007 [6]	Retrospective comparative study	40	TLH + BSO	LS vs HS	Operation time: 59.57 ± 3.71 vs 90.95 ± 5.73 minutes ($p < .001$) Blood loss: 87.76 ± 25.48 vs 152.63 ± 60.90 mL ($p < .001$)
Lee et al., 2007 [11]	Retrospective case-control study	76	Laparoscopic radical hysterectomy with pelvic lymphadenectomy	PK vs CB	Blood loss: 397 vs 564 mL Blood transfusion rate: no significant difference Operation time: 172 vs 229 minutes ($p < .001$) Postoperative complications: less for PK
Wang et al., 2005 [7]	Prospective, nonrandomized trial	62	LAVH	PK vs CB	Operation time, blood loss, transfusion rate, length of hospital stay: no significant difference
Ou et al., 2004 [8]	Retrospective comparative study	50 PM 73 CB	TLH	PM vs CB	Blood loss: less for PM cost per case: $70 more per case for PM
Ou et al., 2002 [9]	Retrospective cohort study	168	Laparoscopic myomectomy	Uterine incision using HS vs CM	Blood loss: 243 vs 378 mL ($p < .01$)
Holub et al., 2002 [10]	Nonrandomized controlled trial	60	TLH		C-reactive protein, interleukin-6, creatine kinase, white blood cell count: no significant difference

CB = conventional bipolar; CM = conventional monopolar; EV = electrosurgery with vasoconstrictive solution (epinephrine); HS = Harmonic Scalpel; LAVH = laparoscopically assisted vaginal hysterectomy; LS = LigaSure; PK = PlasmaKinetic pulsed bipolar system; PM = PlasmaKinetic multifunction cutting forceps and monopolar spatula electrode; TLH = total laparoscopic hysterectomy.

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a difference in blood loss was in laparoscopic myomectomy using the Harmonic Scalpel compared with conventional electrosurgery [5].

For laparoscopic colectomy, a Cochrane review has reported that advanced bipolar technologies and ultrasonic shears are associated with better hemostatic control. However, even though the blood loss with the ultrasonic energy source was less than the blood loss with monopolar scissors, the difference was only 42 mL [1]. An industry-sponsored meta-analysis of 29 prospective randomized trials in general surgery comparing LigaSure ($n = 1107$) with either clamping with suture ligation/monopolar electrosurgery ($n = 1079$), or ultrasonic energy also reported that LigaSure was associated with 43 mL less blood loss (95% confidence interval [CI], 14–73 mL; $p = .0021$) [3].

Such small volumes, even though statistically significant, are unlikely to make clinically significant differences to patient outcomes. A statistically significant difference in transfusion rates would be more clinically relevant. Three gynecologic comparative studies reported on transfusion rates, and none showed any significant difference in transfusion rates [5,7,11].

In contrast, a retrospective comparative study of open radical hysterectomy and pelvic lymphadenectomy reported a significantly lower transfusion rate of 5.6% (1/18) in the LigaSure group compared with 40.3% (27/67) in the traditional clamping and suture ligation group [12]. The fact that this was a study of open surgery, and the retrospective nature of this study, limit the relevance of this finding to gynecologic laparoscopy.

Operating Time

The other purported advantage of modern laparoscopic energy sources is a decreased operating time. This may be attributable to the reduction in instrument traffic (for instruments with an integrated cutting function) as well as a shorter vessel seal time. However, the reliability of the vessel sealing is more important as a time saver because it usually takes substantially longer to identify and control hemostasis after a blood vessel has started to bleed (with or without vessel retraction into the tissues). In the Cochrane review of laparoscopic colectomy, the operating time was 40 minutes shorter with advanced bipolar technologies than with monopolar scissors [1]. Similarly, the meta-analysis of laparoscopic cholecystectomy ($N = 695$) showed that, compared with monopolar electrosurgery, the operating time with ultrasonic energy sources is significantly shorter in elective surgical cases (weighted mean difference [WMD] = -8.19; 95% CI, -10.36 to -6.02; $p < .0001$), acute cholecystitis cases (WMD = -17; 95% CI, -28.68 to -5.32; $p = .004$), and complicated cases (WMD = -15, 95% CI, -28.15 to -1.85; $p = .03$) and if surgery was performed by trainee surgeons who had performed <10 procedures ($p = .043$) [2]. In the general surgical meta-analysis, LigaSure was associated with a shorter operating time (normalized mean reduction in operative time of 28%, $p < .0001$) compared with suture ligation/monopolar electrosurgery [3]. Such time savings are not only statistically significant but may also result in real cost savings in operating room time. Much larger studies would be required to evaluate whether shorter operating times would result in improved clinical outcomes.

Despite these findings from general surgical studies, similar time savings have not been consistently reported in gynecologic studies. For laparoscopic radical hysterectomy with pelvic lymphadenectomy, Gyrus PK was reported to be associated with a time saving of 57 minutes compared with conventional bipolar electrosurgery (229 vs 172 minutes, $p < .001$) [11]. However, another study of laparoscopically assisted vaginal hysterectomy using the same instruments did not show any significant difference in operation time [7]. The randomized controlled trial for TLH also reported that there was no significant difference in the total operating time between LigaSure (148.1 minutes) and conventional bipolar electrosurgery (142.1 minutes, $p = .46$) [4]. One plausible explanation for this discrepancy is that the time-sparing effect of using vessel sealing devices is proportional to the complexity of the surgery. In an uncomplicated TLH, there are only 2 major vessels to be sealed (uterine arteries), whereas more vessels or vascular pedicles need to be sealed when performing a colectomy or a radical hysterectomy.

Postoperative Pain

For general surgery, the meta-analysis showed that postoperative pain was 2.8 units less on a 0 to 10 visual analog scale (95% CI, 1.5–4.1; $p < .0001$) for LigaSure compared with suture ligation/monopolar electrosurgery [3]. In cholecystectomy, postoperative abdominal pain scores at 1, 4, and 24 hours were also significantly lower with ultrasonic dissection compared with monopolar electrosurgery [2].

There are limited data on postoperative pain from randomized gynecologic laparoscopy trials, but a similar reduction in postoperative pain was reported for laparoscopic myomectomy. Visual analog scale pain scores for postoperative pain after myomectomy were significantly less at 24 hours with the Harmonic Scalpel compared with conventional electrosurgery (5.6 ± 0.8 vs 4.4 ± 1.1, $p = .0001$), but there was no significant difference at 48 hours (2.5 ± 0.8 vs 2.4 ± 1.1, $p = .2$) [5].

Complications

In the general surgery meta-analysis, LigaSure was associated with fewer complications compared with suture ligation/monopolar electrosurgery, ranging in severity from minor (e.g., pruritus) to severe (e.g., pelvic abscess) [3]. In gynecologic surgery, 7 of the 8 comparative studies reported on complications (Table 2) [4–9,11]. A retrospective case-control study ($N = 76$) of radical hysterectomy and bilateral pelvic lymphadenectomy reported 1 intraoperative complication (rectal perforation during the right uterosacral ligament dissection) and postoperative complications in 4 women (2 cases of intestinal obstruction, 2 cases of acute

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Table 3

Comparative laboratory-based and animal studies comparing 2 or more vessel sealing devices

Authors	Study design	Devices compared*	Vessel type	Significant findings
Milsom et al., 2012 [17]	Ex vivo study	Thunderbeat, Harmonic ACE, LigaSure V, EnSeal	Small (2–3 mm), medium (4–5 mm), large (6–7 mm) porcine vessels	Burst pressure: no significant difference between devices Lateral thermal spread: similar for Thunderbeat and Harmonic ACE ($p = .4167$), EnSeal ($p = .6817$), and LigaSure ($p = .8254$)
Noble et al., 2011 [18]	Ex vivo study	LOTUS, Harmonic ACE, LigaSure	Human mesenteric vessels ($n = 93$)	Burst pressure: no difference between instruments ($p = .058$) Lateral thermal spread: greater with LigaSure (3.37 mm) than Lotus (2.18 mm, $p < .001$), Harmonic ACE (1.95 mm, $p < .001$)
Katsuno et al., 2010 [38]	Ex vivo study	LSAt, LSAFt, Endoclip II	Inferior mesenteric, splenic, hepatic, renal, iliac, femoral arteries	Sealing time: shorter with LSAFt (3.5 seconds) than LSAt (7.6 seconds) Burst pressure: higher with LSAFt (1375 mm Hg) than LSAt (961 mm Hg); no Significant difference between LSAt and Endoclip Lateral thermal spread: less with LSAFt (1.0 mm) than LSAt (2.1 mm)
Newcomb et al., 2009 [13]	Ex vivo study	GC, GP, Harmonic Scalpel, EnSeal, LS, LSFt, LC	2- to 3-mm, 4- to 5-mm, 6- to 7-mm vessels	Burst pressure: 2–3 mm or 6–7 mm vessels: no significant difference 4–5 mm vessels: LS had the highest mean burst pressure (1261 mm Hg), statistically higher than other devices except EnSeal (928 mm Hg)
Person et al., 2008 [20]	In vivo study: vessels are sealed, then harvested for testing (burst pressure, histology)	Harmonic ACE, 5-mm LigaSure V, 10-mm LigaSure Atlas, EnSeal	3.3- to 4.1-mm bovine vessels	Burst pressure: higher with EnSeal (678 mm Hg) than LigaSure V (380 mm Hg), Harmonic ACE (435 mm Hg), and LigaSure Atlas (489 mm Hg) Sealing time: shorter with Harmonic ACE (3.3 seconds) than EnSeal (4.1 seconds), LigaSure Atlas (7.9 seconds), LigaSure V (5.2 seconds)
Phillips et al., 2008 [21]	Ex vivo study	Harmonic ACE, LigaSure V	<5-mm porcine arteries and veins	Burst pressure: ≤ 3 mm vessels: elevated with supraphysiologic for both Harmonic ACE and LigaSure V 3.1–5 mm arteries: no significant difference
Lamberton et al., 2008 [14]	Ex vivo study: harvested vessels were sealed in a simulated laparoscopic environment created using a neonatal incubator	LigaSure V, Gyrus PK, Harmonic ACE, EnSeal	5-mm arteries	Sealing time: shorter for LigaSure (10.0 seconds) and Gyrus (11.1 seconds) than EnSeal (19.2 seconds) and Harmonic ACE (14.3 seconds) Lateral thermal spread: less with Harmonic ACE (49.9°C) with Gyrus (64.5°C) but similar to LigaSure (55.5°C) and EnSeal (58.9°C) Smoke production: less with Harmonic ACE (mean 2.88 ppm) than Gyrus PK (74.1 ppm, $p < .0001$) and EnSeal (21.6 ppm, $p < .0001$), no difference with LigaSure (12.5 ppm, $p = .11$) 12.5; blinded) Blinded reviewers rated the Harmonic ACE the best visibility score

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Hruby et al., 2007 [19]	In vivo study	LigaSure V, Harmonic ACE, Harmonic LCS-C5, Trissector	Porcine arteries and veins	Burst pressure: arteries: LigaSure V 536 mm Hg, Harmonic ACE 436 mm Hg, LCS-C5 363 mm Hg, Trissector 328 mm Hg Veins: LigaSure V 386 mm Hg, Harmonic ACE 160 mm Hg, LCS-C5 215 mm Hg, Trissector 237 mm Hg Lateral thermal spread (for sealing arteries): LigaSure V 4.5 mm, Harmonic ACE 0.6 mm, LCS-C5 0.3 mm, Trissector 8.0 mm ($p < .0001$) Lateral thermal spread (for sealing veins): LigaSure V 6.3 mm, Harmonic ACE 1.5 mm, LCS-C5 1.3 mm, Trissector 8.5 mm ($p = .003$)
Richter et al., 2006 [39]	Ex vivo study	LigaSure, BiClamp	Splenic, renal, salpingo-ovarian, mesenteric	Initial seal failure: no significant difference (Biclamp: 2.78%; LigaSure 8.57%)
Carbonell et al., 2003 [40]	Ex vivo study, with histologic examination for lateral thermal damage	Gyrus PK, LigaSure	2- to 3-mm, 4- to 5-mm, 6- to 7-mm bovine vessels	Burst pressure: Burst pressure (4–5 mm vessels): 2–3 mm vessels: no significant difference 4–5 mm vessels: lower with Gyrus PK (389 mm Hg) than LigaSure (573 mm Hg) 6–7 mm vessels: lower with Gyrus PK (317 mm Hg) than LigaSure (585 mm Hg) Lateral thermal spread (2–3 mm, 4–5 mm and 6–7 mm vessels): no difference between LigaSure (1.2, 2.4, 2.5 mm) and Gyrus PK (1.5, 2.4, 3.2 mm)
Landman et al., 2003 [15]	In vivo study: vessels harvested for histologic examination	LigaSure, LC, Endo-GIA, Klepinger and Trimax bipolar forceps, Harmonic Scalpel	Porcine arteries up to 6 mm, veins up to 12 mm	Lateral thermal spread: LigaSure 1–3 mm, conventional bipolar 1–6 mm, Harmonic Scalpel 0–1 mm
Harold et al., 2003 [16]	Ex vivo study	LCS, EBVS, LC, PC	2- to 3-mm, 4- to 5-mm, 6- to 7-mm porcine arteries	Mean burst pressure: 2–3 mm arteries: EBVS vs LCS no significant difference 4–5 mm arteries: EBVS (601 mm Hg) vs LCS (205 mm Hg) ($p < .0001$) 6–7 mm arteries: EBVS (442 mm Hg) vs LCS (175 mm Hg) ($p < .0001$) Lateral thermal spread: EBVS vs LCS no significant difference (EBVS mean = 2.57 mm vs LCS mean = 2.18 mm)
Goldstein et al., 2002 [41]	Ex vivo study	LCS, LigaSure	Bovine ureters	Lateral thermal spread: no significant difference (LigaSure: 2.11 mm, LCS: 1.92 mm)
Matthews et al., 2001 [42]	After cholecystectomy, cystic ducts were resealed ex vivo In vivo common bile duct in 6 pigs	LCS, LigaSure, LigaClip	Human cystic duct	Burst pressure: more for LigaClip and LigaSure than LCS Lateral thermal spread: less for LCS (3.5 mm) than LigaSure (13.4 mm)

EBVS = electrothermal bipolar vessel sealer; GC = Gyrus PK cutting forceps; GP = Gyrus Plasma Trissector; LC = titanium laparoscopic clips; LCS = LaparoSonic coagulating shears; LOTUS = Laparoscopic Operation by Torsional Ultrasound; LS = LigaSure V with LigaSure vessel sealing generator; LSAt = 10-mm LigaSure Atlas with LigaSure vessel sealing generator; LSAFt = 10-mm LigaSure Atlas with ForceTriad Generator; LSFt = LigaSure V with ForceTriad Generator; PC = plastic laparoscopic clips.

* Five-millimeter laparoscopic instruments unless otherwise specified.

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renal failure, and 1 case of vesicovaginal fistula) in the conventional bipolar group, whereas there were no complications reported for the Gyrus PK group ($p = .02$) [11]. In the other comparative trials of energy sources in laparoscopic gynecology, no significant difference in complication rates was reported [4–9]. All of these other trials related to laparoscopy for benign gynecologic conditions, and because complication rates are generally low for these procedures, studies with much larger sample sizes would be required to detect any statistically significant difference in complication rates.

Laboratory and Animal Studies

Laboratory-based studies and (to a lesser extent) animal studies offer a controlled environment in which various properties of laparoscopic energy sources can be tested and compared. In such studies, confounding factors inherent in the clinical situation can be controlled for; nonetheless, care must be taken when drawing conclusions based on laboratory studies that may not be reproducible in the clinical setting. Moreover, results from different studies cannot be readily compared because the observed result in each study can depend greatly on the study design (e.g., the duration of device activation, environmental control including temperature and humidity, and method of histologic staining of tissue samples). For these reasons, when comparing one laparoscopic energy source with another using data derived from laboratory-based research, studies that investigate 2 or more instruments in the same controlled environment are the most valuable (Table 3). There is no study that compares all properties of the various energy sources available to gynecologic surgeons. Despite this, the available studies are somewhat useful for clinicians to compare the properties of different energy sources (Table 4). Four important parameters of laparoscopic energy sources have been assessed in laboratory-based and animal studies: mean burst pressure, vessel seal time, lateral thermal spread, and smoke/plume.

Table 4

Summary of comparative studies of energy sources for gynecologic laparoscopy

	Energy source			
	Monopolar electrosurgery	Conventional bipolar electrosurgery	Advanced bipolar electrosurgery	Ultrasonic
Configuration(s)	Scissors Hook Forceps	Forceps Forceps + blade	Forceps with tissue response feedback ± cutting mechanism[†]	Shears hook
Overall dissection rating (1 [worse]–4 [best])	4	1	2	3
Tissue effect				
Transection	Vaporization Fulguration Sharp*	Sharp (blade, e.g., “Tripolar”)	Sharp (blade, e.g., LigaSure, EnSeal) Bipolar “cut” mode (e.g., Gyrus PK)	Thermal (cavitation) and mechanical tissue disruption
Hemostasis	Fulgaration Desiccation Coaptation	Desiccation Coaptation	Desiccation Coaptation	Desiccation Coaptation
Vessel seal diameter	<2 mm	7 mm	7 mm	5 mm
Burst pressure	NA	NA	Largest	Smallest
Seal time	NA	NA	Faster	Slower
Intraoperative blood loss	More than advanced bipolar or ultrasonics	More than advanced bipolar or ultrasonics	Less than conventional electrosurgery	Less than conventional electrosurgery
Blood transfusion rate	NSD	NSD	NSD	NSD
Operation time	Longer than advanced bipolar or ultrasonics	Longer than advanced bipolar or ultrasonics	Shorter than conventional electrosurgery	Shorter than conventional electrosurgery
Complications	NSD	NSD	NSD	NSD
Lateral thermal spread	Significant	Significant	Significant	Significant
Instrument tip temperature	Above “cell kill” range	Above “cell kill” range	Above “cell kill” range	Above “cell kill” range
Smoke/vapor rating (1–4, worst-best)	4	3	3–4	4
Availability	High	High	Intermediate/High	Intermediate/High
Cost	Low	Low	Intermediate/High	Intermediate/High

NA = not applicable; NSD = no significant difference.
* Blade or bipolar energy.
[†] Scissors.

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Vessel Burst Pressure

United States Food and Drug Administration approval has been granted for ultrasonic devices to seal vessels up to 5 mm in diameter and for advanced bipolar devices (i.e., LigaSure, EnSeal, and Gyrus PK) to seal vessels up to 7 mm in diameter [13]. These "sealed" vessels can theoretically withstand up to 3 times the normal systolic blood pressure [14]. The fact that these burst pressures are lower than that achieved with traditional laparoscopic stapling devices and clips [15,16] may not be clinically relevant; as long as the burst pressure is in the supraphysiologic range (with a reasonable buffer), the vessel seal should remain stable despite usual fluctuations in postoperative blood pressure.

However, seal failures still occur despite supraphysiologic burst pressures. For example, in 1 study, the Plasma Trissector (Gyrus ACMI, Maple Grove, MN) had a mean burst pressure of 322.7 mm Hg for sealing 6- to 7-mm vessels, but the failure rate (defined in this study as the number of seal failures divided by the total number of attempted seals required to obtain 13 seals for burst pressure testing) was 92% [13]. Such a high failure rate is unacceptable in clinical practice, and surgeons should be aware of this when using such devices for sealing 6- to 7-mm vessels.

A number of studies have reported no significant difference in burst pressures between advanced bipolar and ultrasonic devices, with both groups of devices achieving results in the supraphysiologic range [17–19]. In contrast, a statistically significant difference in burst pressure was reported for LigaSure (385 ± 76 mm Hg) versus the Harmonic ACE (Ethicon Endo-Surgery, Cincinnati, OH) (204 ± 59 mm Hg) in a simulated laparoscopic environment using harvested 5-mm bovine vessels [14]. Despite LigaSure having a higher mean burst pressure than the Harmonic ACE, Gyrus PK (290 ± 110 mm Hg), and EnSeal (255 ± 80 mm Hg), the burst pressures for all these devices were in the supraphysiologic range [14]. In a study performed in live pigs sponsored by the manufacturers of EnSeal, this device was found to yield significantly higher burst pressures than other vessel sealing devices [20]. This difference in findings may be explained partly by the difference in study methodology, namely ex vivo and in vivo. One of the disadvantages of ex vivo studies is that the absence of blood and clotting factors may spuriously affect the sealing abilities of a device. In support of this notion, another laboratory-based study has shown that increasing hematocrit in harvested blood vessels is associated with increasing burst pressures [21].

Vessel Seal Time

Seal time is defined as the duration of time between device activation and when the device emits a signal that the vessel is sealed or when there is gross visual evidence of seal division. In the previously mentioned study [14], which also included cutting of the vessel in the seal time, the time to seal for the Harmonic Scalpel, LigaSure, Gyrus PK, and EnSeal were 14.3, 10.0, 11.1, and 19.2 seconds, respectively. The LigaSure and Gyrus PK had the shortest vessel sealing times compared with the group ($p < .0001$). However, upon transection, the "sealed vessel" was found to be completely open in 30% of the vessels sealed with the Gyrus PK. Hence, although this device had a statistically shorter seal time, the overall operating time may be extended when using this device if extra time is needed to identify and control bleeding vessels in the event of initial seal failure.

Lateral Thermal Spread

Tissue damage may be caused at temperatures above 42°C [22,23], especially with prolonged exposure, and this has been shown histologically in a rat model [24]. Such tissue damage can occur some distance from the point of application of the laparoscopic energy source in a phenomenon referred to as "lateral thermal spread." Lateral thermal spread occurs with all laparoscopic energy sources, to a lesser or greater extent, whether the delivered tissue effect is electrosurgical vaporization, fulguration, desiccation, or coaptation, or ultrasonic tissue transection or vessel sealing. Apart from histologic assessment, lateral thermal spread may also be quantified using real-time thermal imaging or temperature probes.

Tissue healing could be impaired by lateral thermal spread, but evidence for this is limited; it would require large studies with long follow-up to show any significant difference in outcomes for different energy sources. In a study comparing the use of the Harmonic Scalpel (at a power setting of 3), CO_2 laser, monopolar scissors, and bipolar forceps at oral surgery in guinea pigs, use of the Harmonic Scalpel was associated with the fastest tissue re-epithelialization and greater tensile strength, similar to the steel scalpel [25].

Many variables may affect the degree of lateral thermal spread apart from the individual laparoscopic energy source in use. Such variables include the power settings, the current waveform (continuous or interrupted for monopolar electrosurgery), contact or noncontact application (for monopolar electrosurgery), the duration of device activation, and the tissues to which the device is applied. Just as it is important to control for these variables, study methodology is also very important. For example, in a porcine study ($N = 8$) using the 5-mm LigaSure, lateral thermal spread was reported to be 4.4 mm by real-time thermal imaging, but when examined histologically, the lateral thermal spread was <1 mm [26]. For these reasons, it is also difficult to compare results from one study to another.

Laboratory-based studies that control for these variables and compare several devices in the same study are the most useful. An ex vivo study using the Harmonic Scalpel, LigaSure, conventional bipolar forceps, and monopolar hook on porcine muscle reported that tissues at or beyond 1 cm from the instruments are generally safe from lateral thermal spread [23]. Even so, surgeons must be alert of the fact that important structures (e.g., ureters) may be within 1 cm of a vessel being sealed (e.g., uterine arteries). Moreover, exceptions to the 1-cm "safety margin" for

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lateral thermal spread have been identified with the monopolar hook, which when activated for greater than 15 seconds with a power setting of 30 W, or for greater than 10 seconds with a power setting of 40 W, a temperature rise to over 42°C may be measured at tissue 1 cm away from the instrument tip [23]. Caution is necessary in extrapolating these data to the clinical situation because extended activation of any energy source to a fixed tissue site is not recommended.

Another histologic study has shown that monopolar electrosurgery is associated with greater lateral thermal spread compared with bipolar electrosurgery, the Harmonic Scalpel, and a CO_2 laser [27]. The Harmonic ACE has also been reported to cause less lateral thermal spread compared with LigaSure (for sealing arteries: 0.6 vs 4.5 mm, $p < .0001$; for sealing veins 1.5 vs 6.3 mm, $p = .003$) [19]. This is in contrast to a comparative study that reported that the laparoscopic coagulating (ultrasonic) shears were associated with more than double the lateral thermal spread compared with monopolar electrosurgery during transection of the uteri and bowel of sheep [28].

Lateral thermal spread sustained at the time of colpotomy during conventional or robotic total laparoscopic hysterectomy has been implicated in vaginal cuff dehiscence [29]. A study using a porcine model for performing colpotomy using the bipolar PKS Plasma J-Hook (Gyrus ACMI, Southborough, MA), bipolar PKS Lyons forceps (Gyrus ACMI, Southborough, MA), monopolar scissors (continuous waveform at 50-W power), or the Harmonic Scalpel (at a power setting of 5) showed histologically that the lateral thermal spread at the vaginal cuff was 3.7, 2.5, 2.0, and 0.78 mm, respectively [29]. There are no data available to causally link the extent of vaginal cuff lateral thermal spread with an increased rate of vault dehiscence.

In clinical practice, surgeons may reduce lateral thermal spread by avoiding prolonged device activation using the lowest energy settings to achieve the desired tissue effects as well as applying irrigation fluid after device activation. In a urologic study of 20 robotic radical prostatectomies using EnSeal, it was reported that the application of cold (<4°C) saline to the device after activation reduced the lateral thermal spread from 0.98 to 0.31 mm ($p < .0002$) [30].

One of the purported advantages of ultrasonic technology is that of lower operating temperatures and, therefore, less lateral thermal spread [31]. This notion is supported by a study using a needle thermistor to record temperature at 2 mm from the cut edge of vessels, which reported that the Harmonic Scalpel had a significantly lower mean maximum temperature compared with the Gyrus PK (49.9 ± 1.8°C vs 64.5 ± 2.7°C, $p < .001$) [14]. Analogous results might not be replicated in studies of vessel sealing because the tissue effects with ultrasonic and advanced bipolar devices is the same in this instance (desiccation, coagulation, and coaptation).

If the instrument tip is used for tissue handling when it is still hot after activation, thermal conductivity may cause injury to tissues [22]. The temperature at the tip of a monopolar hook reaches 100.1°C after 15 seconds of activation of the continuous waveform at a power setting of 40 W, and it takes another 55 seconds for it to cool to 42°C [23]. Similarly, the device head of the 5-mm LigaSure was reported to have a temperature of 97°C during activation, and, even after activation ceased, it remained hot enough to cause injury (>45°C) for 14 seconds [26].

An ex vivo thermographic study has shown that the monopolar hook, LigaSure, and Harmonic ACE can cause a temperature rise of over 20°C by thermal conductivity at 2.5 seconds after activation [22]. Even at 20 seconds after activation at a power setting of 5, the Harmonic ACE can increase tissue temperature by 24°C [22]. An ischemic bowel lesion (undetected at the time of surgery) has been reported after contact of the bowel with the active blade of the Harmonic ACE after instrument activation ceased [32]. Therefore, surgeons must remember to allow adequate time for the instrument tips to cool and to avoid tissue handling with the instruments before this time.

Smoke Plume

The activation of all laparoscopic energy sources results in the production of a smoke or vapor plume. This cloud not only hinders surgical vision but also may be a hazard to staff in the operating room, with potential cytotoxic, genotoxic, and mutagenic properties [33,34].

An objective comparison of the degree of smoke produced by various energy sources is difficult, and there are limited comparative trials in this area. By applying light-scattering theories to the measured particle size of the smoke/plume/vapor produced, a study has reported that in a controlled environment (relative visibility = 1.0) bipolar forceps (relative visibility = 0.887) offers similar visibility to the Harmonic Scalpel (relative visibility = 0.801), and both offer better visibility compared with monopolar scissors (relative visibility = 0.026) [35]. Another study using an aerosol density meter reported that the Harmonic Scalpel (2.88 ppm) produced less smoke than the Gyrus PK (74.1 ppm, $p < .0001$) and EnSeal (21.6 ppm, $p < .0001$), but there was no statistically significant difference with LigaSure (12.5 ppm, $p = 0.11$) [14]. Reviewers who were blinded to the energy source also subjectively rated visibility with the Harmonic Scalpel better than with LigaSure or EnSeal, with the worst subjective visibility reported for the Gyrus PK [14]. Of the ultrasonic devices, a study using digital image analysis software has shown that Sonicision (Covidien, Mansfield, MA; 8.76% of image filled by plume; range, 4.32%–17.41%) and SonoSurg (Olympus USA, Center Valley, PA; 9.46%; range, 5.68%–22.12%) produce less smoke than the Harmonic ACE (18.04%; range, 9.07%–55.12%; $p = .026$) [36].

Conclusions

This review highlights the lack of adequately powered comparative clinical trials of laparoscopic energy sources,

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especially for gynecologic laparoscopy. Furthermore, although comparative laboratory-based trials are useful in defining functional properties of energy sources in a controlled environment, it is clear that perceived benefits in the laboratory may not translate to clinically significant advantages. In addition, clinical and laboratory-based trials often compare only 2 categories of the available laparoscopic energy sources, and extrapolation between different studies to indirectly compare and contrast the pros and cons of energy sources is fraught with confounding factors.

A number of these studies are industry sponsored; this is an important consideration given the fact that negative findings from such trials are often not published. However, from the data presented the following conclusions may be drawn: (1) advanced bipolar devices may be associated with less intraoperative blood loss than monopolar, conventional bipolar, and ultrasonic devices, and the latter 2 are more effective in vessel sealing than monopolar devices; (2) laboratory data consistently show advanced bipolar devices can seal larger vessels than ultrasonic devices; (3) seal burst pressures are also generally higher with advanced bipolar devices; (4) despite the previously mentioned conclusions, none of the available data translate to a significant benefit in perioperative blood transfusion rates for any device category; (5) an anticipated decreased operating time with ultrasonic and advanced bipolar devices over conventional electrosurgical devices may only be valid with more complicated laparoscopic procedures; (6) postoperative pain is lower in the early postoperative period with ultrasonic and advanced bipolar devices, but there are limited data for gynecologic laparoscopy; (7) the complication rate in gynecologic laparoscopic surgery is small, and there is no significant difference in complication rates between the different energy sources; (8) lateral thermal spread occurs with all laparoscopic energy sources, to a lesser or greater extent, whether the delivered tissue effect is vaporization, fulguration, desiccation, or coaptation; (9) a temperature rise above the "cell kill" threshold occurs in the tips of all laparoscopic energy sources and inadvertent tissue contact may result in patient morbidity and mortality; and (10) all laparoscopic energy sources give rise to smoke or vapor plumes, with visibility most affected with monopolar electrosurgery and least affected with ultrasonic devices.

Many laparoscopic surgeons will use several energy sources for a particular procedure. For example, advanced bipolar electrosurgery might be the most appropriate technology for sealing larger vessels and vascular pedicles, and ultrasonic technology may be used for the transection of adhesions and pericolic adipose tissue, with monopolar electrosurgery retaining its general utility in simple tasks such as peritoneal transection and in more difficult cases requiring maximal dissection capability in which tissue planes are distorted by pathology. It is clear that adequately powered clinical trials with direct head-to-head comparisons of the various energy sources are required in order to guide surgeons in choosing the most appropriate energy source for laparoscopic surgery.

References

1. Tou S, Malik AI, Wexner SD, Nelson RL. Energy source instruments for laparoscopic colectomy. *Cochrane Database Syst Rev.* 2011;(5): CD007886.
2. Sasi W. Dissection by ultrasonic energy versus monopolar electrosurgical energy in laparoscopic cholecystectomy. *J Soc Laparoendosc Surg.* 2010;14:23–34.
3. Macario A, Dexter F, Sypal J, Cosgriff N, Heniford BT. Operative time and other outcomes of the electrothermal bipolar vessel sealing system (LigaSure) versus other methods for surgical hemostasis: a meta-analysis. *Surg Innov.* 2008;15:284–291.
4. Janssen PF, Brolmann HAM, van Kesteren PJM, et al. Perioperative outcomes using LigaSure compared with conventional bipolar instruments in laparoscopic hysterectomy: a randomised controlled trial. *BJOG.* 2011;118:1568–1575.
5. Litta P, Fantinato S, Calonaci F, et al. A randomized controlled study comparing harmonic versus electrosurgery in laparoscopic myomectomy. *Fertil Steril.* 2010;94:1882–1886.
6. Demirturk F, Aytan H, Caliskan AC. Comparison of the use of electrothermal bipolar vessel sealer with harmonic scalpel in total laparoscopic hysterectomy. *J Obstet Gynaecol Res.* 2007;33:341–345.
7. Wang C-J, Yuen L-T, Yen C-F, Lee C-L, Soong Y-K. Comparison of the efficacy of the pulsed bipolar system and conventional bipolar electrosurgery in laparoscopically assisted vaginal hysterectomy. *J Laparoendosc Adv Surg Tech A.* 2005;15:361–364.
8. Ou C-S, Joki J, Wells K, et al. Total laparoscopic hysterectomy using multifunction grasping, coagulating, and cutting forceps. *J Laparoendosc Adv Surg Tech A.* 2004;14:67–71.
9. Ou C-S, Harper A, Liu YH, Rowbotham R. Laparoscopic myomectomy technique. Use of colpotomy and the harmonic scalpel. *J Reprod Med.* 2002;47:849–853.
10. Holub Z, Jabor A, Sprongl L, Kliment L, Fischlova D, Urbanek S. Inflammatory response and tissue trauma in laparoscopic hysterectomy: comparison of electrosurgery and harmonic scalpel. *Clin Exp Obstet Gynecol.* 2002;29:105–109.
11. Lee C-L, Huang K-G, Wang C-J, Lee P-S, Hwang L-L. Laparoscopic radical hysterectomy using pulsed bipolar system: comparison with conventional bipolar electrosurgery. *Gynecol Oncol.* 2007;105: 620–624.
12. Kyo S, Mizumoto Y, Takakura M, et al. Experience and efficacy of a bipolar vessel sealing system for radical abdominal hysterectomy. *Int J Gynecol Cancer.* 2009;19:1658–1661.
13. Newcomb WL, Hope WW, Schmelzer TM, et al. Comparison of blood vessel sealing among new electrosurgical and ultrasonic devices. *Surg Endosc.* 2009;23:90–96.
14. Lamberton GR, Hsi RS, Jin DH, Lindler TU, Jellison FC, Baldwin DD. Prospective comparison of four laparoscopic vessel ligation devices. *J Endourol.* 2008;22:2307–2312.
15. Landman J, Kerbl K, Rehman J, et al. Evaluation of a vessel sealing system, bipolar electrosurgery, harmonic scalpel, titanium clips, endoscopic gastrointestinal anastomosis vascular staples and sutures for arterial and venous ligation in a porcine model. *J Urol.* 2003;169: 697–700.
16. Harold KL, Pollinger H, Matthews BD, Kercher KW, Sing RF, Heniford BT. Comparison of ultrasonic energy, bipolar thermal energy, and vascular clips for the hemostasis of small-, medium-, and large-sized arteries. *Surg Endosc.* 2003;17:1228–1230.
17. Milsom J, Trencheva K, Monette S, et al. Evaluation of the safety, efficacy, and versatility of a new surgical energy device (THUNDERBEAT) in comparison with Harmonic ACE, LigaSure V, and EnSeal devices in a porcine model. *J Laparoendosc Adv Surg Tech A.* 2012; 22:378–386.

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18. Noble EJ, Smart NJ, Challand C, Sleigh K, Oriolowo A, Hosie KB. Experimental comparison of mesenteric vessel sealing and thermal damage between one bipolar and two ultrasonic shears devices. *Br J Surg*. 2011;98:797–800.
19. Hruby GW, Marruffo FC, Durak E, et al. Evaluation of surgical energy devices for vessel sealing and peripheral energy spread in a porcine model. *J Urol*. 2007;178:2689–2693.
20. Person B, Vivas DA, Ruiz D, Talcott M, Coad JE, Wexner SD. Comparison of four energy-based vascular sealing and cutting instruments: a porcine model. *Surg Endosc*. 2008;22:534–538.
21. Phillips CK, Hruby GW, Mirabile G, et al. The effect of intraluminal content on the bursting strength of vessels ligated with the harmonic ACE and LigaSure V. *J Endourol*. 2008;22:1383–1387.
22. Govekar HR, Robinson TN, Stiegmann GV, McGreevy FT. Residual heat of laparoscopic energy devices: how long must the surgeon wait to touch additional tissue? *Surg Endosc*. 2011;25:3499–3502.
23. Sutton PA, Awad S, Perkins AC, Lobo DN. Comparison of lateral thermal spread using monopolar and bipolar diathermy, the Harmonic Scalpel and the Ligasure. *Br J Surg*. 2010;97:428–433.
24. Perko Z, Pogorelic Z, Bilan K, et al. Lateral thermal damage to rat abdominal wall after harmonic scalpel application. *Surg Endosc*. 2006;20:322–324.
25. Sinha UK, Gallagher LA. Effects of steel scalpel, ultrasonic scalpel, CO2 laser, and monopolar and bipolar electrosurgery on wound healing in guinea pig oral mucosa. *Laryngoscope*. 2003;113:228–236.
26. Campbell PA, Cresswell AB, Frank TG, Cuschieri A. Real-time thermography during energized vessel sealing and dissection. *Surg Endosc*. 2003;17:1640–1645.
27. Tulikangas PK, Smith T, Falcone T, Boparai N, Walters MD. Gross and histologic characteristics of laparoscopic injuries with four different energy sources. *Fertil Steril*. 2001;75:806–810.
28. Kwok A, Nevell D, Ferrier A, Graf N, Lam A, Ford R. Comparison of tissue injury between laparosonic coagulating shears and electrosurgical scissors in the sheep model. *J Am Assoc Gynecol Laparosc*. 2001;8:378–384.
29. Gruber DD, Warner WB, Lombardini ED, Zahn CM, Buller JL. Laparoscopic hysterectomy using various energy sources in swine: a histopathologic assessment. *Am J Obstet Gynecol*. 2011;205:494.e1–494.e6.
30. Zorn KC, Bhojani N, Gautam G, et al. Application of ice cold irrigation during vascular pedicle control of robot-assisted radical prostatectomy: EnSeal instrument cooling to reduce collateral thermal tissue damage. *J Endourol*. 2010;24:1991–1996.
31. EthiconEndo-Surgery. Available at: http://www.ees.com/clinicians/products/energy-devices/harmonic-ace. Accessed February 22, 2013.
32. Campagnacci R, de Sanctis A, Baldarelli M, Rimini M, Lezoche G, Guerrieri M. Electrothermal bipolar vessel sealing device vs. ultrasonic coagulating shears in laparoscopic colectomies: a comparative study. *Surg Endosc*. 2007;21:1526–1531.
33. Alp E, Bijl D, Bleichrodt RP, Hansson B, Voss A. Surgical smoke and infection control. *J Hosp Infect*. 2006;62:1–5.
34. Barrett WL, Garber SM. Surgical smoke: a review of the literature. Is this just a lot of hot air? *Surg Endosc*. 2003;17:979–987.
35. Weld KJ, Dryer S, Ames CD, et al. Analysis of surgical smoke produced by various energy-based instruments and effect on laparoscopic visibility. *J Endourol*. 2007;21:347–351.
36. Kim FJ, Sehrt D, Pompeo A, Molina WR. Comparison of surgical plume among laparoscopic ultrasonic dissectors using a real-time digital quantitative technology. *Surg Endosc*. 2012;26:3408–3412.
37. Lyons SD, Law KS. Laparoscopic Vessel Sealing Technologies. *J Minim Invasive Gynecol*. 2013;20:307–310.
38. Katsuno G, Nagakari K, Fukunaga M. Comparison of two different energy-based vascular sealing systems for the hemostasis of various types of arteries: a porcine model-evaluation of LigaSure ForceTriadTM. *J Laparoendosc Adv Surg Tech A*. 2010;20:747–751.
39. Richter S, Kollmar O, Schilling MK, et al. Efficacy and quality of vessel sealing: comparison of a reusable with a disposable device and effects of clamp surface geometry and structure. *Surg Endosc*. 2006;20:890–894.
40. Carbonell AM, Joels CS, Kercher KW, et al. A comparison of laparoscopic bipolar vessel sealing devices in the hemostasis of small-, medium-, and large-sized arteries. *J Laparoendosc Adv Surg Tech A*. 2003;13:377–380.
41. Goldstein SL, Harold KL, Lentzner A, et al. Comparison of thermal spread after ureteral ligation with the Laparo-Sonic ultrasonic shears and the Ligasure system. *J Laparoendosc Adv Surg Tech A*. 2002;12:61–63.
42. Matthews BD, Pratt BL, Backus CL, et al. Effectiveness of the ultrasonic coagulating shears, LigaSure vessel sealer, and surgical clip application in biliary surgery: a comparative analysis. *Am Surg*. 2001;67:901–906.

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