Novel quantum molecular resonance energy source for laparoscopic bipolar vessel sealer: An experimental study in animal model

Jiwoong Yu
Samsung Medical Center
Jungeun Im
Samsung Biomedical Research Institute
Soonyoung Kwon
Samsung Biomedical research Center
Jongchan Kim
Korea Testing Laboratory
Sungmin Kim
Hanyang University - Ansan Campus
Jung Hyun Kim
Hanyang University - Ansan Campus
Byong Chang Jeong (bc2.jung@samsung.com)
Samsung Medical Center

Research

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Abstract

Background: The majority of conventional bipolar energy-based vessel sealing devices utilize energy at frequencies between 300 kHz and 500 kHz. The use of such frequencies has the disadvantages including unintended damage to surrounding tissues and excessive surgical smoke production. Here, we developed an bipolar energy source using Quantum Molecular Resonance (QMR) energy of 4–64 MHz and combined this into a laparoscopic vessel sealer. We investigate the microscopic tissue effect and surgeon's experiences of laparoscopic bipolar vessel sealer using a novel QMR energy source through animal experiments.

Results: In an open surgical setting, QMR energy sources showed higher sealing success rates (100% vs. 66.7%) and higher burst pressure (963 mmHg vs. 802mmHg) of the sealed vessels compared to LigaSure™. Histological analysis showed less vessel wall injury in the QMR energy source (55.0% vs. 73.9%). In the laparoscopic setting experiments, compared to LigaSure™, QMR energy sources showed statistically significantly less smoke formation ($p = 0.014$), less tissue carbonization ($p = 0.013$), and less stickiness ($p = 0.044$) during sealing tissues.

Conclusions: Novel QMR energy source for laparoscopic bipolar vessel sealer could produce better sealing performance and less surrounding tissue damage compared to the conventional devices. Laparoscopic surgery using QMR energy sources showed better surgeon's experiences in terms of surgical smoke formation, tissue carbonization, and stickiness.

Background

The introduction of energy-based vessel sealing technology has facilitated laparoscopic surgery by reducing the complexity of the procedures [1]. These devices have enabled rapid sealing, hemostasis, and cutting of blood vessels and tissues during laparoscopic surgery.

The majority of conventional bipolar energy-based vessel sealing devices utilize energy at frequencies between 300 kHz and 500 kHz. The use of such frequencies has the disadvantage of possible energy transfer to a wide area to cause unintended damage to surrounding tissues [2]. In addition, in the laparoscopic surgical environment, unnecessary energy transfer inevitably produces surgical smoke that compromises the visibility of surgeons and generates binding between the instrument and tissue [3, 4].

Strategies using high-frequencies (4–64 MHz) of quantum molecular resonance (QMR) electrical energy have been studied to compensate for these drawbacks. Theoretically, QMR produces an energy quanta that able to break molecular bonds without raising the kinetic energy of the affected molecules. Using this higher frequencies results in minimizing the area of energy spread, allowing application of strong energy concentrated at contacted sites. By this principle, the surrounding tissue damage could be minimized and the ligation power could be maximized. This advantage has already been shown in the use of general surgical instruments in open surgery [5] and will maximize the effect when incorporated into a laparoscopic device.

We developed an bipolar energy source using QMR energy and combined this energy source into a bipolar laparoscopic sealing device. By conducting both open and laparoscopic animal surgeries, we investigated the performance of the QMR energy source on both the histological effects on tissues and surgeon experience in a laparoscopic environment.

Results

In an open surgical setting, the success rate of ligation of the rabbit aorta was higher using QMR energy sources (100%) compared to LigaSure™ (66.67%) (Table 2). The LigaSure™ demonstrated about five degrees lower mean temperature of the surrounding tissue (73.68°C) compared to the QMR energy source (79.30°C). In comparing the sealing stability by burst pressure, the QMR energy source showed much higher burst pressure (963 mmHg) than LigaSure™ (802 mmHg). The mean sealing width of ligated vessels using LigaSure™ and QMR energy source was 1.92 mm and 1.98 mm, respectively. In microscopic analysis, less collagen denaturation and wall layer cleavage was noted when using QMR energy source compared to LigaSure™ (1.36 mm vs. 1.60 mm, 20.0% vs. 30.0%, respectively). Also significantly less wall injury were identified when using QMR energy source compared to LigaSure™ (54.98% vs. 73.87%).

Table 2
Evaluated parameters and histological analysis for ligated vessels

	LigaSure™	**QMR energy source**
Vessel width (mm)	3.08 ± 0.20	2.90 ± 0.37
Time to seal (sec)	4.00 ± 0.45	5.00 ± 0.00
Sealing success rate	66.7% (4/6)	100.0% (5/5)
Temperature (°C)	73.68 ± 1.28	79.30 ± 3.92
Burst pressure (mmHg)	802.00 ± 0.00	963.00 ± 3.00
Seal width (mm)	1.92 ± 0.07	1.98 ± 0.25
Collagen denaturation (mm)	1.60 ± 0.47	1.36 ± 0.16
Wall layer cleavage (%)	30.00 ± 22.80	20.00 ± 15.49
Wall injury (%)	73.87 ± 16.93	54.98 ± 16.16

In the laparoscopic setting, a total of 26 video clips of sealing of the peritoneum, vessel (renal vein), and ureter was obtained (Fig. 3 and Fig. 4). Regarding the formation of surgical smoke, the surgeons involved in the study reported statistically less surgical smoke when using the QMR energy source to separate the peritoneum and vessels compared to LigaSure™ ($p = 0.025$ and $p = 0.013$, respectively), and reported no difference when separating the ureters ($p = 0.430$, Table 3). For the tissue carbonization parameter, the QMR energy source showed more favorable outcome when dissecting the peritoneum ($p = 0.014$). The use of the QMR energy source to seal and cut the peritoneum and ureter showed significantly less likely to stick to the instrument compared to LigaSure™ ($p = 0.036$ and $p = 0.044$, respectively).

Table 3
Evaluated parameters in the surgeon's experience of laparoscopic nephrectomy

	Peritoneum			**Vessel**			**Ureter**		
	LigaSure™	QMR energy	p	LigaSure™	QMR energy	p	LigaSure™	QMR energy	p
Surgical smoke formation	1.29 ± 0.60	0.98 ± 0.64	0.025	1.83 ± 0.64	1.28 ± 0.75	0.013	1.11 ± 0.58	1.00 ± 0.00	0.430
Tissue carbonization	1.45 ± 0.63	1.17 ± 0.38	0.014	2.00 ± 0.89	1.56 ± 0.92	0.121	1.72 ± 0.75	1.33 ± 0.78	0.182
Stickiness	2.21 ± 0.93	1.83 ± 0.70	0.036	2.38 ± 1.17	1.78 ± 0.88	0.078	3.28 ± 1.45	2.25 ± 1.06	0.044

Discussion

As laparoscopic surgery becomes evolved, the use of electrosurgical instruments is able to achieve reliable and rapid sealing of blood vessels and tissues [6]. However, current technologies still present limitations such as collateral tissue damage and surgical smoke generation [2–4]. Previously, laparoscopic energy-based devices with various sealing mechanisms, including bipolar electric current (e.g., LigaSure™), ultrasonic energy (e.g., Harmonic Scalpel™), and nanotechnology (e.g., EnSeal PTC™), have been studied. It has been reported that devices using bipolar electrical energy have the highest burst pressure and shortest sealing time [7].

Application of an QMR energy source into general monopolar surgical devices has resulted in a surgical device that has favorable tissue effects in both short- and long-term animal study [5]. A previous study suggested that waves with a specific form at high-frequencies (4–64 MHz) from QMR transmitted to the tissue into quanta, which disrupts the molecular bonds of tissue without causing damage to surrounding tissue [8, 9]. Recently, researches on the molecular cell biological effects of QMR had been also conducted. Researchers reported the up-regulation of vascular endothelial growth factor expression in chronic wounds treated by QMR technology [10]. There was also a study that suggested the QMR stimulation could trigger angiogenesis and tissue regeneration of human mesenchymal stromal cells [11].

In this study, we combined an QMR energy source with a bipolar laparoscopic instrument and developed a novel laparoscopic sealing energy source using a frequency of 4 MHz, which is 10 times higher than that of conventional instruments. Bipolar electrical energy melts collagen and elastin within the tissue bundles, forming a durable seal. Unlike the circuits of monopolar devices, the advantage of bipolar device is more controlled spread of energy since it is only transmitted between the jaws of an instrument [12]. Moreover, the theoretical attenuation of the QMR electrical energy is large, resulting in application of strong energy concentrated at contacted sites thus less damage to surrounding tissues.

In our open surgical experiment with aorta of living rabbits, the stability of sealing and tissue effects of the QMR energy source was confirmed compared to a conventional device. Then, laparoscopic surgical experiments were performed to evaluate the experiences of the operator when using the QMR energy source in an actual laparoscopic environment. During laparoscopic nephrectomies in swine, the QMR energy source produced effective performance with a more favorable surgeon experience in investigated parameters of surgical smoke, carbonization of tissue, and stickiness to the instruments. Although not addressed by the measurement criteria, during surgery, the operator

experienced smoother coagulation and cutting of tissues with the QMR energy source compared to the conventional device.

There were several limitations to our study. First, our results were based on experiments using two species of animal. Although we used the same laparoscopic surgical environment as in human surgery, the results may not be directly transferable to humans. Second, in the laparoscopic experiment, we used the jaw of the LigaSure™ connected to the QMR. The feedback-controlled response system of LigaSure™ which automatically discontinues energy delivery when the seal cycle is complete has not been applied to the QMR energy source. However, the use of the same jaw increased the objectivity of the experiment due to identical experimental conditions other than the energy source. Furthermore, the results that QMR energy source in this study showed more favorable performance even without the feedback-controlled system, may demonstrate the excellence of the novel energy source.

Conclusions

Novel bipolar QMR energy sources for laparoscopic surgery could produce better sealing performance and less surrounding tissue damage than LigaSure™. Laparoscopic surgery using QMR energy sources show an improved surgeon experience in terms of surgical smoke formation, tissue carbonization, and stickiness.

Methods

The two energy sources for bipolar device compared in this study included LigaSure™ V Lap System (Valleylab, Boulder, CO) and the novel bipolar QMR electrical energy generator. The QMR energy generator produces a specific form of waves with the combination of 4 MHz and its components of high-frequency. The laparoscopic jaw of LigaSure™ was used to switch between the two energy sources. Each device was used in a surgical experiment and evaluated by basic ligation performance, microscopic tissue effects, and surgeon experience in the laparoscopic environment.

Open surgery experiment

1) Animals and procedures

A total of three abdominal aortas from three adult male rabbits were used. All the rabbits were New Zealand white rabbits (Oryctolagus cuniculus) and all weighed 3.6 kg.

Anesthesia was performed using an intramuscular injection of glycopyrrolate (0.01 mg/kg) and intravascular injection of propofol (1.5 mg/kg). Animals were positioned in dorsal recumbency and prepared for aseptic surgery. The abdomen was incised to expose the abdominal aorta. Vascular ligation was performed by applying LigaSure™ or QMR electrosurgical instruments to the abdominal aorta in the distal and proximal directions. A total of 11 ligations was conducted, six times using LigaSure™ and five times using the QMR energy source.

2) Measurements

The outer diameter of the abdominal aorta was measured before the ligations, and time to sealing, peak tissue temperature, and burst pressure of sealed vessels were measured during and after the ligations. Among the three rabbits, burst pressure was measured using the aorta of two rabbits, and the other aorta was histologically analyzed. The burst pressure was measured by instilling normal saline into both ends of the vessel lumen. Using a previously described technique [7], pressure was slowly increased until the vessel leaked. Histological analyses were performed

on both proximal and distal portions of the sealing site (Fig. 1). Each sealed vessel was processed for staining with Masson trichrome stain and hematoxylin and eosin stain. Histological analysis was performed on the following items (Fig. 2a and 2b): seal width (width of ligation site), adventitial collagen denaturation (length of denatured collagen in the total collagen surrounding the vascular outer membrane of both ligature sites), wall layer cleavage (portion of the whole blood vessel walls on both sides of the ligation site where layer separation occurred, as indicated by qualitative evaluation), and wall injury (ligation site including the length of the entire vessel wall length of damaged blood vessels, expressed as numerical qualitative value). At the time of ligation, the temperature of the surrounding tissue was measured using a thermal imaging camera. While applying energy to the abdominal aorta, a video was acquired using a thermal imaging camera (FLIR-T62101, FLIR Systems, USA). The stored images were analyzed using a temperature analysis program (FLIR R & D software 3.3, FLIR Systems, USA).

Laparoscopic surgery: surgeons' experience

1) Animals and Laparoscopic simple nephrectomy

Two female pigs (conventional farm pigs weighing 40 kg) were used and underwent bilateral laparoscopic simple nephrectomy. Pigs were pretreated by intramuscular injection of rompun (2 mg/kg) and zoletil (10 mg/kg), intubated, and maintained under general anesthesia using 2.5% enflurane and 100% O_2. Animals were placed in a left lateral decubitus position, and CO2 was injected to form a pneumoperitoneum on the side of the papilla at the umbilical level. CO2 was injected into the abdominal cavity at a rate of 3–5 L/min, and the intraperitoneal pressure was maintained at 12 mmHg during surgery. A 12 mm camera port was inserted and two 5 mm ports were inserted between the umbilical region below the lateral rib of the camera port and the outside of the anterior superior iliac spine, respectively. After placement of the port, the abdominal organs and fascia were incised as in conventional procedures of simple nephrectomy, exposing the kidney to secure the blood vessels. Then vascular ligation was performed using laparoscopic energy-based devices. By dissecting into the pelvic cavity along the lateral part of the colon, the peritoneum and ureters were dissected and ligated with the device. After left side laparoscopic nephrectomy was performed, we reversed the position and performed the right side laparoscopic nephrectomy with the other energy-based device.

2) Measurements

All laparoscopic surgical procedures were recorded and divided into video clips of ligation of three types of tissue (peritoneum, renal vein, and ureter). Six experienced urologic surgeons watched randomly mixed video clips in a single-blind condition and scored each clip according to the evaluation criteria in Table 1. The surgeons’ experiences regarding surgical smoke, carbonization, and stickiness of tissue to the device were measured according to the established criteria (Table 1).

Table 1
Criteria in the surgeon's experience during laparoscopic surgery

1. Amount of surgical smoke formation	
Grade	Evaluation criteria
0	No smoke formation
1	Mild smoke formation but no visual interference
2	Moderate smoke formation, must be removed to increase visibility
3	Severe smoke formation, difficult to proceed with surgery
2. Tissue carbonization	
Grade	Evaluation criteria
0	No carbonization
1	Mild carbonization, brown-colored tissue observed
2	Moderate carbonization, blackened tissue observed
3	Severe carbonization, all tissue is black
3. Stickiness	
Grade	Evaluation criteria
1	No stickiness
2	Stick a little but falls off by itself
3	Must be removed by holding the tissue with the opposite hand but involves no tissue damage
4	Sticking caused damage tissue but no bleeding
5	Sticking is severe and produces tissue damage and bleeding when removing the instrument

Statistical analysis

The groups were compared using Fisher's exact test for categorical variables and Student's t-test for continuous variables. Statistical analyses were performed using SPSS® (version 21.0, SPSS Inc., Chicago, IL, USA). All p-values were two-sided, and $p < 0.05$ was considered statistically significant.

Abbreviations

QMR
Quantum Molecular Resonance

Declarations

Ethics approval and consent to participate

All intervention and care of animals were conducted with the approval of our Institutional Animal Care and Use Committee (KBIO-IACUC-2018-090). Animal experiments were carried out in accordance with the Institute for Laboratory Animal Research Guide for Care, and this study procedure was performed in accordance with the Animal Experiment Guidelines of Samsung Animal Research Institute.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors have no competing interests.

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Authors' contributions

BCJ designed the experiments and coordinated the project. JK, SK and JHK developed the QMR energy generator. JI and SYK performed the open surgery experiments. JY, JI and BCJ performed the laparoscopic experiments. The manuscript was written by JY and revised by all authors. All authors read and approved the final manuscript.

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Figures

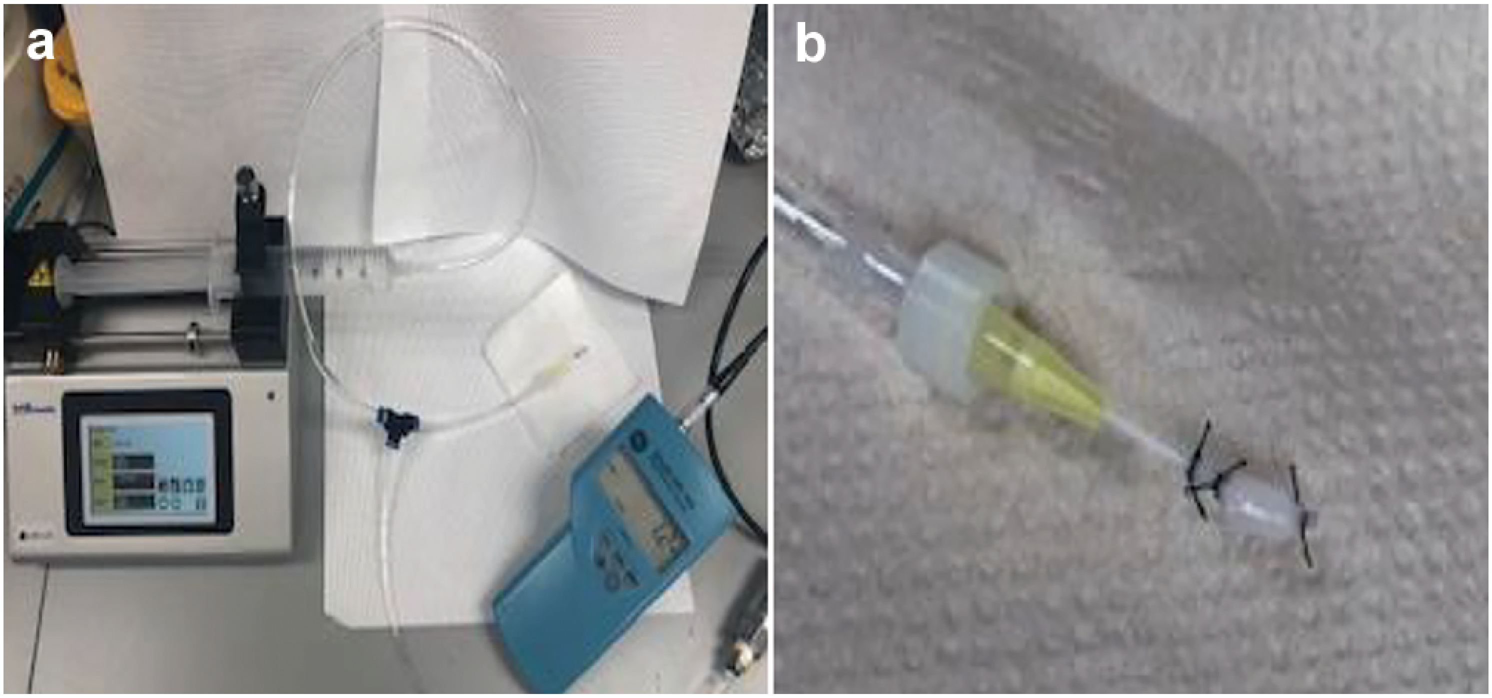

Figure 1

Measurement of burst pressure

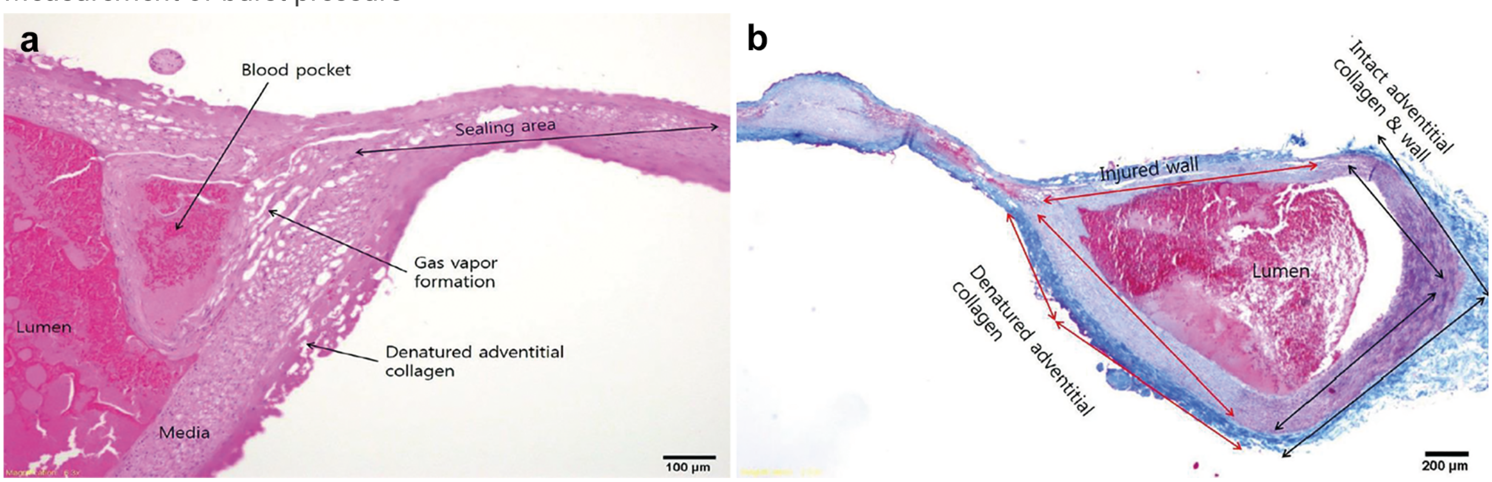

Figure 2

(a) Histological images of vessel sealing: Hematoxylin and eosin staining, (b) Histological images of vessel sealing: Masson’s trichrome staining

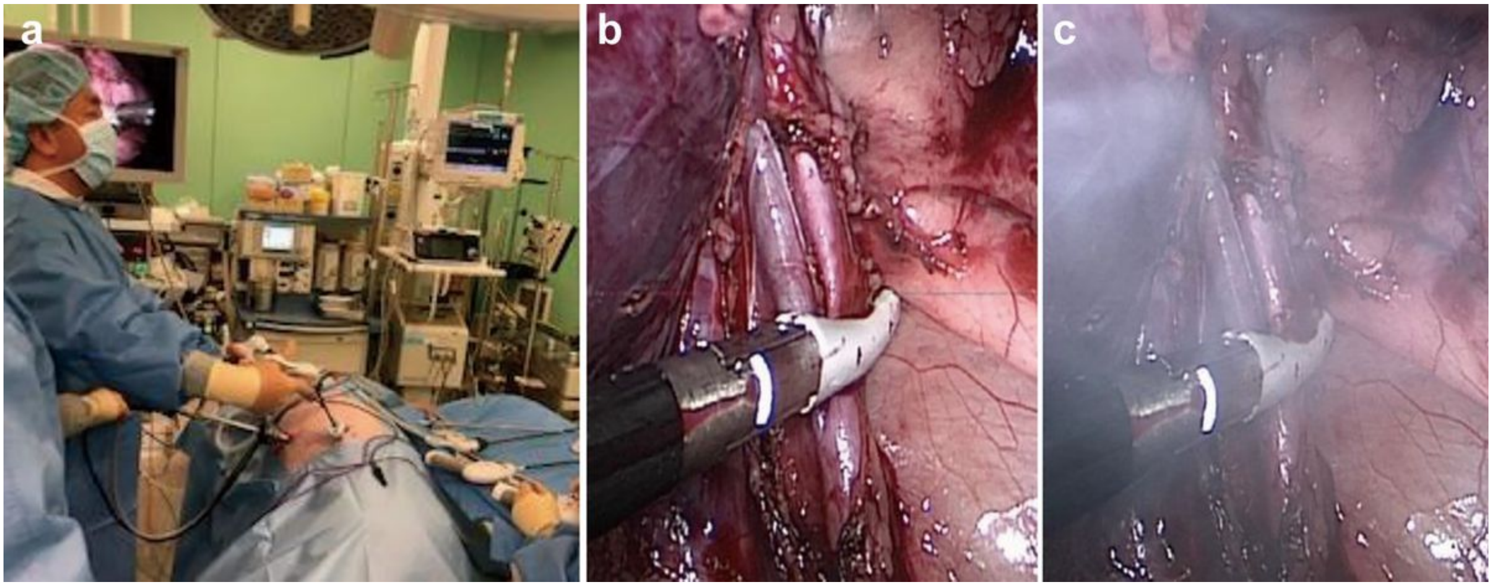

Figure 3

Laparoscopic surgical environment and evaluated video clip

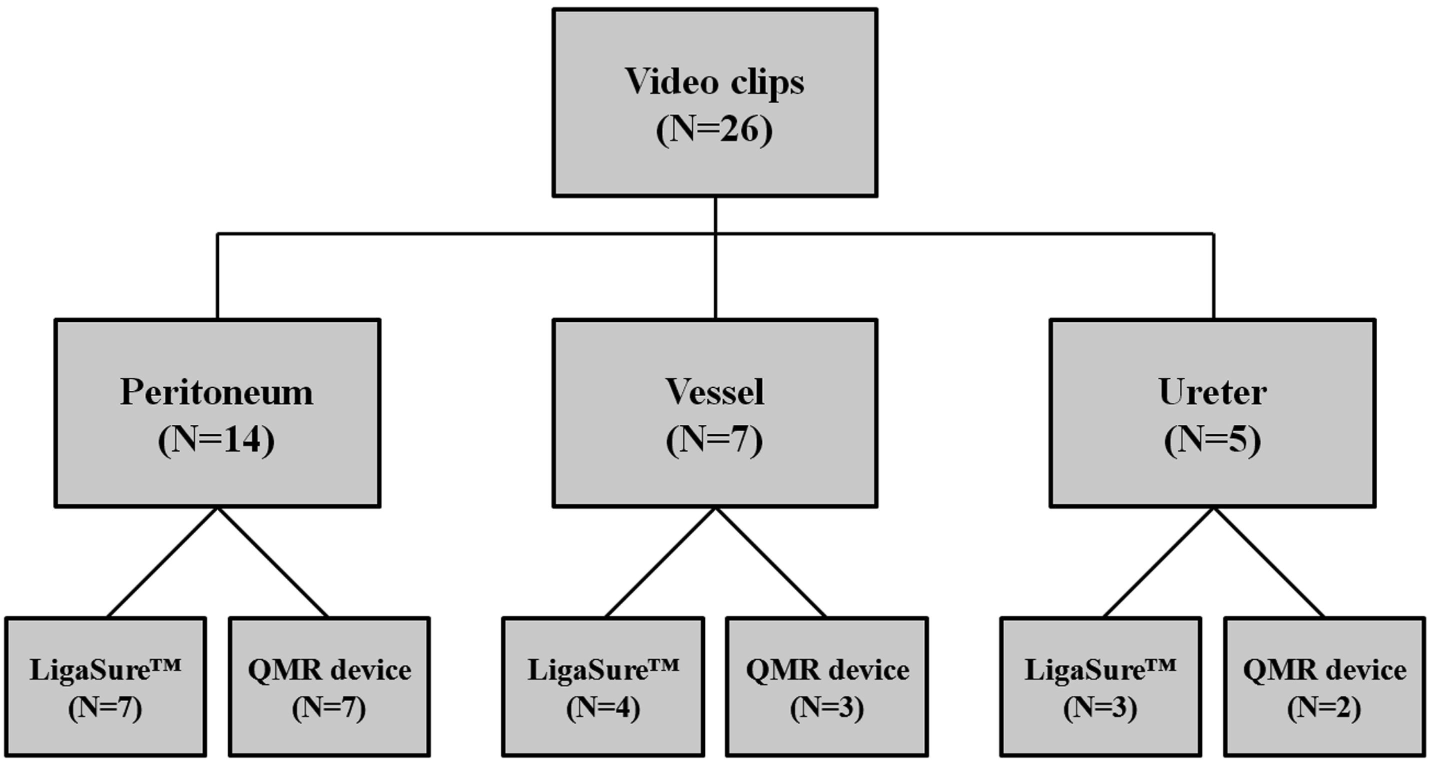

Figure 4

Video clips of sealing of the peritoneum, vessel, and ureter