Utility of a microwave surgical instrument in sealing lymphatic vessels

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Abstract

BACKGROUND: This study assessed the ability of a novel microwave coagulation surgical instrument (MWCX) to seal lymphatic vessels when compared with LigaSure (Valleylab, Boulder, CO), the Harmonic Scalpel (HS; Ethicon Endo-Surgery, Cincinnati, OH), and electric cautery.

METHODS: The burst pressure of pig inguinal lymphatic vessels was assessed after the sealing of vessels with each surgical instrument. The rate of lymphorrhrea from pig mesenteric lymphatic vessels was also investigated using indocyanine green and visualized with the Photodynamic Eye system (Hamamatsu Hotoniks, Hamamatsu, Japan).

RESULTS: Burst pressures were higher with MWCX (average, 300 mm Hg), LigaSure (average, 290 mm Hg), and HS (average, 253 mm Hg) when compared with electric cautery (average, 152.3 mm Hg; vs MWCX: \( P < .002 \), vs LigaSure: \( P < .002 \), vs HS: \( P < .004 \)). The rate of lymphorrhrea was significantly lower with LigaSure (13.3%), HS (18.8%), and MWCX (13.3%) when compared with electric cautery (77.3%; vs LigaSure: \( P < .001 \), vs HS: \( P < .001 \), vs MWCX: \( P < .001 \)).

CONCLUSIONS: MWCX was equivalent to LigaSure and HS in terms of the ability to seal lymphatic vessels.

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Various energy-based devices have been used for vessel sealing and tissue dissection, particularly within abdominal surgery. These include electric cautery, the LigaSure system (radiofrequency; Valleylab, Boulder, CO), and the Harmonic Scalpel (HS [ultrasonic energy]; Ethicon Endo-Surgery, Cincinnati, OH). Microwave energy is another type of energy that induces thermal damage of tissues, resulting in coagulation necrosis; this strategy has been used for tissue coagulation of liver tumors.\(^1\)\(^2\) We have developed a scissors-type microwave coagulation surgical instrument (MWCX) for clinical use as a third-generation energy device.

Lymphadenectomy, which is commonly performed during the resection of malignant tumors, can result in lymphorrhrea\(^3\) and lead to intractable ascites, hypoalbuminemia, edema,\(^4\) a poor quality of life, and longer hospital stays. Lymphatic vessels and sentinel lymph nodes can be visualized via parenteral administration of a small amount of indocyanine green (ICG), which collects in lymphatic...
vessels, and can be subsequently visualized via fluorescence in response to infrared light. This strategy can also detect lymphorrhea after ligation with various surgical instruments; if the vessels are filled with ICG, leaking fluorescent lymph fluid can be visualized using the Photodynamic Eye (PDE) system (Hamamatsu Hotoniks, Hamamatsu, Japan). This study assessed the ability of MWCX to seal lymphatic vessels when compared with Ligasure, HS, and electric cautery.

Materials and Methods

Animals

Experiments were performed with the approval of the Animal Use Committee of Shiga University of Medical Science, Shiga, Japan. The 5 adult female pigs (weight, 40 to 58 kg) used in this study were purchased from SHIMIZU Laboratory Supplies Co, Ltd (Kyoto, Japan). The animals were bred under specific pathogen-free conditions and cared for in accordance with the guidelines set forth in the Guide for the Care and Use of Laboratory Animals published by the National Institutes of Health (Bethesda, MD). All animal experiments were performed at the animal laboratory of Shiga University of Medical Science.

After intramuscular administration of ketamine hydrochloride (10 mg/kg), anesthesia was maintained with inhalation of 2% isoflurane. Saline (0.9%) was administrated during anesthesia. Animals were spontaneously ventilated during surgery and were killed by an overdose of anesthetics.

Instruments

The HS (Model ACE36P), electric cautery (Gyrus Medical, Maple Grove, MN), and LigaSure Precise were used according to the manuals provided by the manufacturers. MWCX was used according to our manual (Fig. 1). The sealing time was approximately 3 seconds, depending on the size of the vessels, when using electric cautery, HS, or MWCX to avoid producing undue tension on the vessels. The sealing time for LigaSure was determined automatically. The power used by each device was as follows: electric cautery, 40 W in the coagulate mode; LigaSure, 2.0 W; HS, 3.0 W in the minimum mode (HSMIN) and 5.0 W in the maximum mode (HSMAX); and MWCX, 60 W per 60 seconds.

Measurement of the burst pressure

The inguinal lymphatic vessels were exposed and removed under general anesthesia. The burst pressure was measured as described previously. Briefly, vessels (approximately 50 mm in length) were coagulated and cut with electric cautery, LigaSure Precise, HSMIN, or MWCX. All operations were performed while taking particular care to avoid applying any tension on the vessels. A 27-G cannula was inserted into the vessels from 1 stump, and the site was closed by manual ligation with 3-0 silk. The opposite side was sealed using one of the instruments described earlier. The cannula was connected to a syringe and a digital manometer (PG-100; Copal Electronics, Co, Ltd, Tokyo, Japan). The piston of the syringe was gradually forced until the occluded vessel burst. At that point, the pressure was recorded and defined as the burst pressure of the lymphatic vessel. Six lymphatic vessels were used for these experiments in each group. For all segments in each group, the lymphatic vessels burst at the ligated site. This procedure was performed 4 times for every lymphatic vessel.

Evaluation of lymphorrhea from the cut edge of the mesentery

Long midline laparotomy from the xiphoid process to the symphysis pubis was performed. Approximately 0.1 mL ICG (1 mg/mL) was injected into the subserosal layer of the small intestine. Lymphatic vessels in the mesentery were stained and observed using the PDE system. The lymphatic vessels were cut and sealed using each instrument. The presence of lymphorrhea was detected using the PDE apparatus. To prevent bias, lymphorrhea was assessed by a person different from the person who sealed vessels with the instrument. This checker scrubbed each sealed vessel 5 times using a swab for the assessment of lymphorrhea. The checker was blinded to the instrument used to seal the vessels. If ICG was present on the swab, then lymphorrhea was regarded as present. One hundred nine segments of lymphatic vessels in the mesentery were examined, including 22 in the electric cautery group, 26 in the LigaSure group, 16 in the HSMAX group, 15 in the HSMIN group, and 30 in the MWCX group.

Statistical analysis

Analyses were conducted using Excel (Microsoft, Redmond, WA) and Statcel2 (OMS Publisher, Saitama, Japan)
software. The chi-square test was used to compare lymphorrhea data. The Student t test was used to compare burst pressure data. A P value less than .05 was considered statistically significant.

**Evaluation of the cut end of the lymphatic vessel resected by microwave coagulation surgical instrument**

Lymphatic vessels were fixed with 10% formaldehyde and embedded in paraffin. The paraffin-embedded tissues were cut into 3-μm sections and were stained with hematoxylin-eosin. All pathologic specimens were reviewed by a pathologist.

**Results**

**In vitro measurement of the burst pressure**

Fig. 2 shows the burst pressure of the lymphatic vessels in each group. The burst pressure ranged from 112 to 210 mm Hg (average, 152.3 ± 37.38 mm Hg) in the electric cautery group, from 221 to 350 mm Hg (average, 290 ± 48.8 mm Hg) in the LigaSure group, from 214 to 283 mm Hg (average, 253 ± 23.13 mm Hg) in the HSMAX group, and from 248 to 348 mm Hg (average, 300 ± 37.18 mm Hg) in the MWCX group. The burst pressure was significantly higher in the LigaSure, HSMAX, and MWCX groups than in the electric cautery group (vs LigaSure: \(P = .002\), vs HSMAX: \(P = .004\); vs MWCX: \(P = .002\)).

**In vivo evaluation of sealing of lymphatic vessels**

The rate of lymphorrhea after resection of pig mesentery using each surgical instrument was investigated (Fig. 3).

**Histologic findings of lymphatic vessels coagulated by microwave coagulation surgical instrument**

The microscopic view of the cut end of the lymphatic vessels showed marked coagulative degeneration and secure occlusion. The histologic finding of the sealed end of a representative lymphatic vessel is shown in Fig. 4. It had a thin outer coat and a very scant muscle layer.

**Comments**

This report showed that the lymphatic vessel sealing ability of MWCX was comparable with that of LigaSure and HS. In 1979, Tabuse introduced the microwave tissue coagulator for use in hepatic surgery, and this technology has gained widespread acceptance in the management of hepatic carcinoma. Microwave ablation elicits thermal damage of tissue, resulting in coagulation necrosis. We incorporated this microwave technology within a surgical instrument to develop MWCX, a third-generation energy device.

Electric cautery uses plasmakinetic technology that triggers fast, predictable, controlled elevations in tissue
temperature to modify soft-tissue structures or seal blood vessels.\textsuperscript{10} LigaSure uses a combination of electrothermal energy with physical pressure to create vessel fusion.\textsuperscript{11} HS uses ultrasonic energy through blade vibration at 55,500 times per second, and this causes denaturation of protein in the tissue, forming a sticky coagulum.\textsuperscript{12} The pressure exerted on the tissue with the blade surface collapses blood vessels and allows the coagulum to form a hemostatic seal.\textsuperscript{12} These devices represent different energy resources that each offer specific advantages over traditional electrocoagulation. Microwave energy is different from these other energy sources in that heat is generated within the tissue rather than applied externally; this allows more efficient and uniform transmission of heat throughout the tissue.

Lymphorrhea is a common postoperative complication of lymphadenectomy and results in intractable ascites, hypoalbuminemia, and edema.\textsuperscript{3} Marutsuka et al\textsuperscript{13} reported that lymph node dissection opens the lymphatic channels and allows the spread of viable cancer cells into the peritoneal cavity in patients with malignancies. In that study, it was assumed that the dissected lymphatic vessels were completely sealed by the surgical instrument. LigaSure and HS are used to seal vessels and for tissue dissection, and they can occlude and divide vessels firmly, as shown in several studies.\textsuperscript{10,14,15} Kanehira et al\textsuperscript{5} reported that the burst pressure of a sealed artery was similar when comparing an ultrasonically activated device with the LigaSure device.\textsuperscript{5} Abe et al\textsuperscript{4} reported that the burst pressure after occlusion with an ultrasonically activated device was higher for an artery than for a lymphatic vessel, and this relationship was dependent on the outer diameter of the vessels. Lymphatic vessel walls are thin compared with the arterial wall. In our report, the burst pressure of lymphatic vessels was more than 200 mm Hg in the LigaSure, HS, and MWCX groups. This pressure is much higher than the normal lymphatic pressure (ie, 5 to 10 mmHg), suggesting that these devices produce a good seal. Furthermore, the burst pressure was significantly higher in the LigaSure, HS, and MWCX groups than in the electric cautery group. These data suggest that MWCX has a lymphatic vessel sealing ability that is comparable with LigaSure and HS.

ICG is used for the evaluation of lymphorrhea from the cut edge of the mesentery. ICG is currently used as a near-infrared fluorescent contrast agent for image-guided oncologic surgery in cancer-related surgery\textsuperscript{16} and is used to facilitate the sentinel lymph node procedure in patients with breast cancer.\textsuperscript{17} ICG provides a higher signal-to-background ratio because of lower autofluorescence and increased tissue penetration at 820 nm.\textsuperscript{16} It can be vividly visualized using the PDE system, which projects lymphatic flow synchronously. The use of ICG and PDE imaging for sentinel lymph node biopsy has been described.\textsuperscript{18–20} This is the first study to use this strategy to evaluate lymphorrhea, which has previously only been indirectly characterized through the determination of the burst pressure.\textsuperscript{4,5} This method enabled excellent visualization of the lymphatic vessels and lymphorrhea and determination of lymphatic flow. Although the evaluation of this method is not quantitative, the sealing of thin lymphatic vessels can be investigated in vivo. In this experiment, the rate of lymphorrhea was greatest in the electric cautery group when compared with the other groups. Therefore, MWCX appears to have comparable ability with LigaSure and HS in terms of avoiding lymphorrhea. In this experiment, the incidence of lymphorrhea was high when compared with the burst pressure of the lymphatic vessels. It was reported that the burst pressure was dependent on the outer diameter of vessels.\textsuperscript{5} Lymphatic vessels in the mesentery are thin when compared with those in the inguinal area. Tsimoyiannis et al\textsuperscript{21} performed a prospective randomized trial comparing the use of ultrasonically activated shears and electrosurgery in extended lymph node dissection for gastric cancer. They reported that the rate of postoperative lymphorrhea was significantly reduced with the use of ultrasonically activated shears.

In conclusion, MWCX is a third-generation energy device incorporating microwave technology that has a lymphatic vessel sealing ability that is comparable with the LigaSure and HS devices. Furthermore, the PDE system is beneficial for the assessment of lymphorrhea. MWCX appears to be a good device for lymphatic vessel sealing and lymph node dissection and possibly for the sealing of other types of vessels as well.

References


