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Lateral thermal spread induced by energy devices: a porcine model to evaluate the influence on the recurrent laryngeal nerve

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Abstract

Background Recurrent laryngeal nerve (RLN) paralysis is a frequently observed complication after esophagectomy, and thermal injury is considered to be one of the causes. The difference in the lateral thermal spread associated with the grasping range of various energy devices remains unknown.

Methods Ultrasonic devices (Harmonic® HD1000i and Sonicision™) and a vessel-sealing device (Ligasure™) were studied. We evaluated the temperature of these devices, the activation time required, and the thermal spread on porcine muscle when the devices were used with different grasping ranges (thermal spread study). In addition, we evaluated the influence of thermal spread by short grasping use of the energy devices on the viability of RLN in a live porcine model (NIM study).

Results In the thermal spread study, the temperature of the ultrasonic devices lowered as grasping range increased, whereas the highest temperature of Ligasure was observed when used with two-thirds grasping. The activation time of ultrasonic devices became longer as grasping range increased, whereas the grasping range did not influence the activation time of Ligasure. Thermal spreads 1 mm from the energy devices were unaffected by the grasping ranges. Although the temperature of the Ligasure was lower than that of the ultrasonic devices, thermal spread by Ligasure was significantly greater than that induced by the ultrasonic devices. In the NIM study, the activation of the Sonicision with one-third grasping range did not cause EMG changes at distances of up to 1 mm from the RLN, whereas applying Ligasure with a one-third grasping range 1 mm away from the RLN led to a critical result.

Conclusions The grasping range did not influence the thermal spread induced by the energy devices. Ultrasonic devices may be safer in terms of lateral thermal spread to the RLN than Ligasure.

Keywords Esophageal cancer · Thermal spread · Recurrent laryngeal nerve paralysis · Energy device · Grasping range · Continuous intraoperative neuromonitoring

Esophagectomy remains the mainstay of treatment for esophageal cancer [1, 2]. Esophageal cancer tends to spread through the lymphatic system and lymph nodes, along the recurrent laryngeal nerve (RLN), and frequently involves metastasis [3]. RLN paralysis (RLNP) is frequently observed after esophagectomy, and thermal injury caused by energy devices during RLN lymph node dissection is considered to be one of the causes of RLNP [4–7].

Several experimental studies revealed that advanced energy devices, such as ultrasonic dissectors and vessel-sealing systems, are safer in terms of lateral thermal damage than monopolar diathermy [8, 9]. With regard to thermal injury to the RLN, experimental studies using porcine models demonstrated that the safe distance from the RLN was 1 mm and 2 mm for Harmonic scalpel and Ligasure, respectively [10, 11].

However, both the temperature of the devices and the lateral thermal damage differ depending on the usage of devices

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and conditions. For instance, high-power ultrasonic devices may result in temporary heat production with a temperature of > 200 °C when the activation time exceeds 10 s [12–15]. The extent of thermal damage with ultrasonic devices is greater after a longer activation time and also greater when the cutting time is continuous rather than briefly interrupted [16, 17]. Lateral thermal damage caused by vessel-sealing devices was greater than that caused by ultrasonic devices, although the temperature of the vessel-sealing devices was lower than that of the ultrasonic devices [14].

In clinical practice, unlike the experimental models, surgeons use the energy devices with various grasping ranges and activation times. During RLN lymph node dissection, only the tip of the energy devices is used sometimes. However, the difference in device temperature and the extent of lateral thermal spread associated with various grasping ranges of the energy devices remains unknown.

During the last one and a half decade, intraoperative neuro-monitoring (IONM) has gained increasing acceptance among surgeons as a tool to identify the RLN and to confirm the viability during thyroid and esophageal surgeries [18, 19]. Furthermore, continuous IONM (CIONM) enabled a more seamless monitoring of the functional integrity of the nerve throughout the surgery [5, 20, 21]. With a quantitative measure of electromyography (EMG), IONM can visualize varying degrees of nerve dysfunction due to thermal injury.

The aim of this study was to elucidate the effect of thermal spread to the RLN by various energy devices in a porcine model. For this study, we evaluated device temperature, activation time, and thermal spread on the porcine muscle with different grasping ranges of energy devices (thermal spread study). We also used CIONM to monitor real-time EMG changes in a live porcine model, wherein various energy devices with a short grasping range were activated at various distances from the RLN (NIM study).

Materials and methods

We compared the characteristics of three energy devices, including two ultrasonic devices and a vessel-sealing device. The ultrasonic devices were Harmonic® HD 1000i shears powered by the ETHICON GEN11 generator (HD1000i; Ethicon, Johnson and Johnson, Cincinnati, OH, USA) and Sonicision™ (Sonicision; Medtronic plc, Dublin, Ireland). The HD1000i was used in the energy activation mode, at an operating frequency of 50 kHz and a power level of 5. The Sonicision was used at the maximum power mode at an operating frequency of 55 kHz. The modes of the ultrasonic devices are both capable of dissecting vascular tissue and hemostatic transection of vessels up to 5 mm. The vessel-sealing device was Ligasure™ Maryland powered by the Valleylab™ FT10 energy platform (Ligasure; Medtronic plc, Dublin, Ireland), and the power was automatically controlled by the platform.

The Ligasure is a bipolar electrosurgical instrument that can be used on vessels up to 7 mm. These energy devices were the latest instruments of each manufacturer in 2018 and were connected to an appropriate generator.

Device temperatures were measured using TVS-500EX thermography (Nippon Avionics, Tokyo, Japan) (Fig. 1a). Tissue temperatures were measured using a six-channel model of AM-8000K thermocouple (Anritsu Meter, Tokyo, Japan), which enables simultaneous temperature measurement of multiple places (up to six places) (Fig. 1B). These channels can be connected to temperature probes, which are flexible temperature sensors featuring extra-fine thermocouple wires covered with a Teflon-coated sheath, with a diameter of 0.9 mm, a temperature range from − 200 to 300 °C, and a response time of 0.5 s. Both the thermal spread and NIM studies were conducted on two separate porcine models during different experimental days, and each energy device was prepared in each study.

Thermal spread study

Porcine muscle was used for the thermal spread study. The porcine muscle tissues, sliced into 3-mm thick sections from the same block of porcine muscle, were removed from the refrigerator (4 °C) 4 h before the study and stored at laboratory ambient temperature (20 °C). One sliced porcine muscle tissue was used for activation of each energy device. Four temperature probes of thermocouples were arranged; three were fixed at 2-mm intervals, and the other was fixed at a 5-mm interval, allowing simultaneous temperature measurement at four points (Fig. 1C). Subsequently, this thermocouple was applied on the porcine muscle at 1-, 3-, 5-, and 10-mm distances from the energy device and positioned at the midpoint of the grasping part of the energy device (Fig. 1D). In this study, the grasping range of the energy device was changed to one-third, two-thirds, and three-thirds (Fig. 1E–G). The energy devices were placed on the tissue five times in each grasping range without counter traction. The ultrasonic devices were activated until tissue division. The Ligasure was activated until completion of the activation cycle indicated by the seal-cycle-complete tone sounds, and the cutting process was performed. Between the activations, all devices were placed in ordinary normal saline and wiped to ensure the same starting temperature. Subsequently, the activation time of the energy devices was measured. The temperature at the tip of the energy devices and on the porcine muscle at 1-, 3-, 5-, and 10-mm from the energy device was continuously measured for 20 s from the start of activation. Thermal spread was shown by temperature differences from the initial temperature at each location of the porcine tissue.

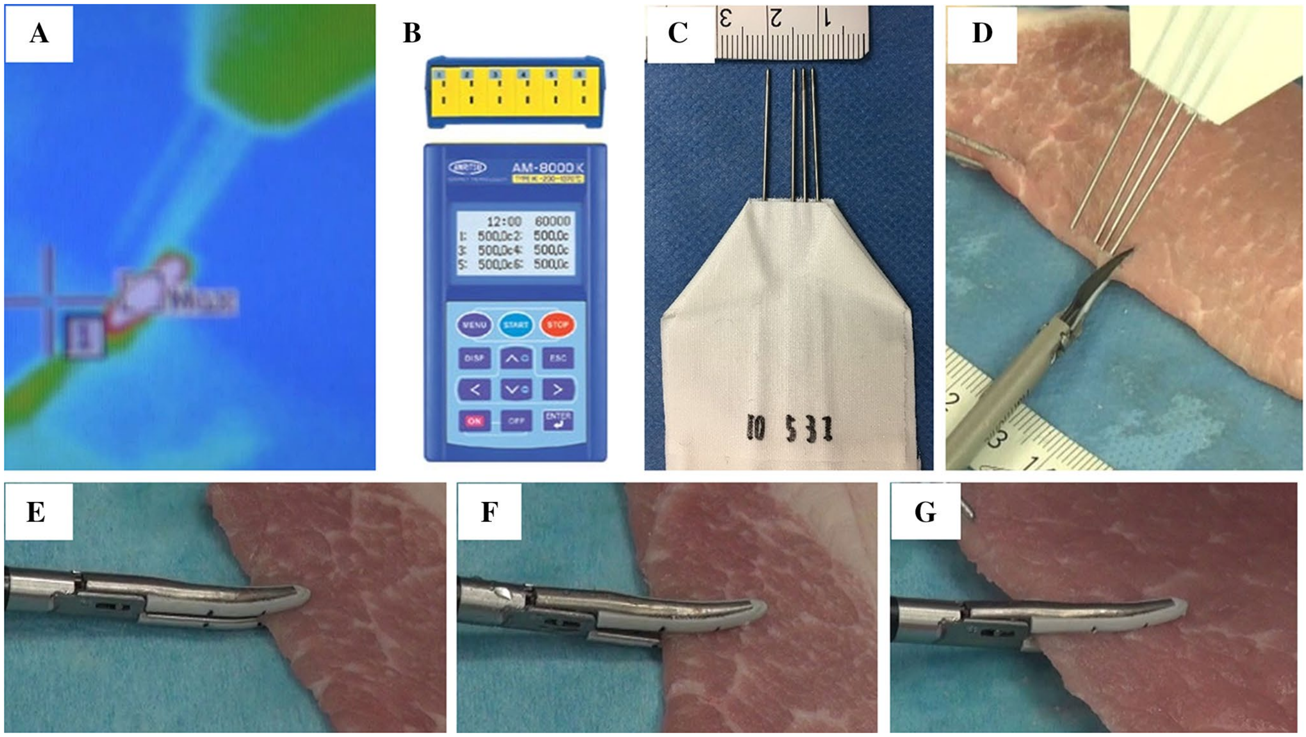


Fig. 1 Thermal spread study. **A** Energy device temperatures were measured for 20 s from the start of energy device activation using TVS-500EX thermography (Nippon Avionics, Tokyo, Japan). **B** Six-channel model of AM-8000K thermocouple (Anritsu Meter, Tokyo, Japan), which enables simultaneous temperature measurement of up to six places. **C** Four temperature probes, flexible temperature sensors featuring extra-fine thermocouple wires covered with a Teflon-coated sheath, were arranged; three were fixed at 2-mm intervals, the other was fixed at 5-mm intervals, allowing simultaneous temperature measurement at 1, 3, 5, and 10 mm from the energy device. **D** This thermocouple was applied on the porcine muscle and positioned at the midpoint of the grasping part of the energy device. The tissue temperatures are continuously measured for 20 s from the start of energy device activation. **E** Grasping range of the energy device: one-third. **F** Grasping range of the energy device: two-thirds. **G** Grasping range of the energy device: three-thirds

NIM study

Animal and anesthesia

A Duroc–Landrace–Yorkshire female piglet (weight, 54.3 kg) underwent surgery to evaluate the EMG signal pattern for thermal RLN injury by the Sonicision and Ligasure. The animal experiments were conducted in compliance with the protocol reviewed by the Institutional Animal Care and Use Committee and approved by the Intervention Technical Center, Kobe, Japan (Permit Number: IVT17-18). The piglet was fasted for 24 h but was allowed water before the experiment. Ketamine (10 mg/kg), xylazine (2 mg/kg), and atropine (0.5 mg/body) were injected into the muscle for sedation. After the piglet was anesthetized by inhalation of isoflurane (5%) in pure oxygen (3 L/min), NIM® EMG endotracheal tube (size #6, Medtronic Xomed, Inc., Jacksonville, FL, USA) was inserted without administration of a muscle relaxant. The tube was placed under visual control to ensure electrode contact with the vocal cord. General anesthesia was maintained with isoflurane (1–3%) and controlled ventilation.

IONM setting and operation design

The NIM-Response® 3.0 system (Medtronic Xomed, Inc., Jacksonville, FL, USA) was used both for CIONM and intermittent neurostimulation (INS) using impulses of 100 µs and 1 mA. For INS, a conventional handheld stimulation probe was used to identify the RLN and vagus nerve (VN) at 4 stimulations/s. For CIONM, the automated periodic stimulation (APS) system was used with 1 stimulation/s and impulses of 100 µs and 1 mA using 2-mm vagal electrodes [22, 23].

A wide collar cervical incision was made extending through the subcutaneous tissue; the platysma muscle was cut, and the superior flap was mobilized and retracted. The RLNs were exposed on the lateral side of the trachea after dividing and retracting the sternohyoid and sternothyroid muscles. To provide optimal APS electrode stability, we accessed the carotid sheath via the lateral approach through the lateral border of the sternocleidomastoid muscle. The VN was carefully dissected free from the fascia, and an APS electrode was placed on the VN (Fig. 2A). Subsequently, the baseline EMG signals for the amplitude and latency were calibrated automatically.

This study was designed to evaluate the distance from the RLN where the Sonicision (maximum power mode) or Ligasure can be safely applied. The energy devices with one-third of the grasping range were applied thrice to the soft tissue 5 mm from the RLN. When a significant EMG change, such as amplitude reduction or prolonged latency was not observed, the distance was progressively decreased to 1 mm, and repeated tests were performed up to three times for the same RLN (Fig. 2B). The protocol was halted when a significant adverse EMG change occurred; the EMG was then continuously monitored for 20 min to assess the recovery of the EMG signal.

The amplitude is generally believed to represent the number of fibers participating in the depolarization event, and vocal cord depolarization amplitudes range from 100 to 800 µV during normal awake volitional speech. However, latency is considered to be associated with the speed or ease of stimulation-induced depolarization and depends on the distance of the stimulation point to the ipsilateral vocal cord [18]. These EMG parameters of the porcine model have been demonstrated to be comparable to reported human data [24, 25].

In this study, the EMG signals for amplitude and latency, before device activation, were determined as the mean values of 20 stimulations just before each device was activated. Moreover, the EMG signal after device activation was determined as the mean value of 20 stimulations after device activation was completed.

Events with amplitudes < 100 µV were counted as loss of signal (LOS). The activation time of the energy device

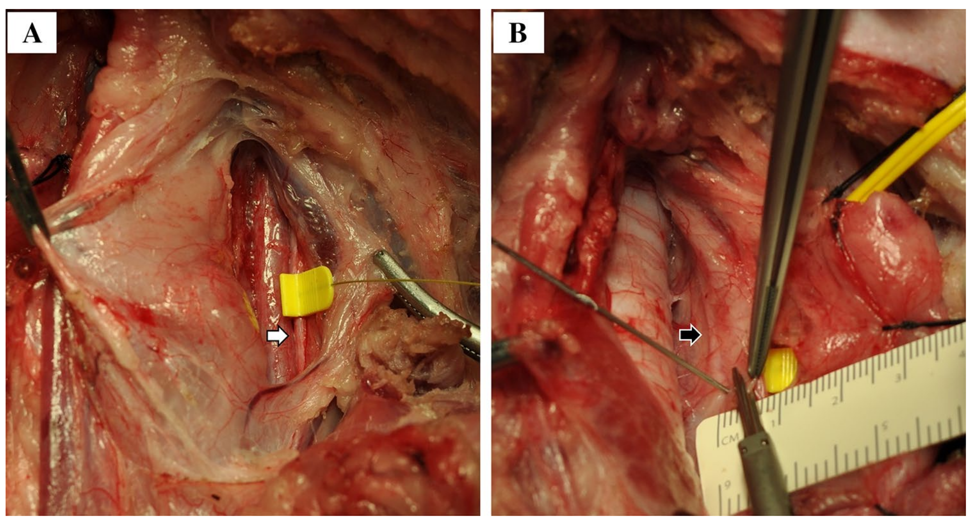


Fig. 2 NIM study. **A** For optimal APS electrode stability, we accessed the carotid sheath via the lateral approach through the lateral border of the sternocleidomastoid muscle. The VN was carefully dissected free from the fascia, and an APS electrode was placed on the VN. White arrow, VN. **B** The Sonicision (maximum power mode) with one-third of the grasping range was applied to the soft tissue at 1 mm from the RLN. Black arrow, RLN

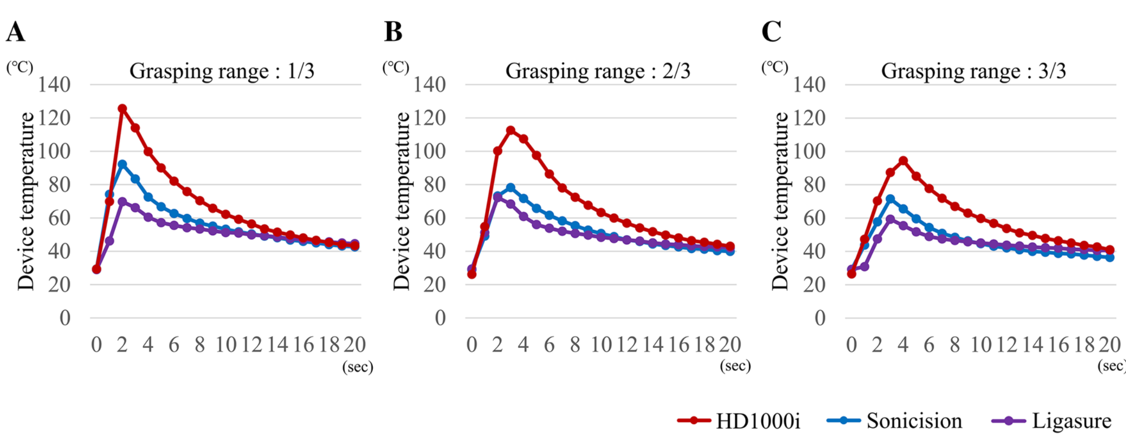


Fig. 3 Temporal changes in the device temperature (thermal spread study). **A** Device temperatures with one-third of the grasping range. **B** Device temperatures with two-thirds of the grasping range. **C** Device temperatures with three-thirds of the grasping range

was measured. Device temperatures and temperature on the RLN were continuously measured for 20 s from the start of activation. A temperature probe of the thermocouple was applied on the RLN and positioned at the midpoint of the grasping part of the energy device.

Statistical analysis

Statistical analyses were performed with JMP 10 software (SAS Institute, Cary, NC, USA). All P values are two-sided, and significance levels were set at 5%. The Mann–Whitney U test, Student's t test, and one-way analysis of variance were used, as appropriate, to compare the data of each group. Dunnett multiple adjustment was performed for pairwise comparisons of results obtained for one-third, two-thirds, and three-thirds of the grasping range.

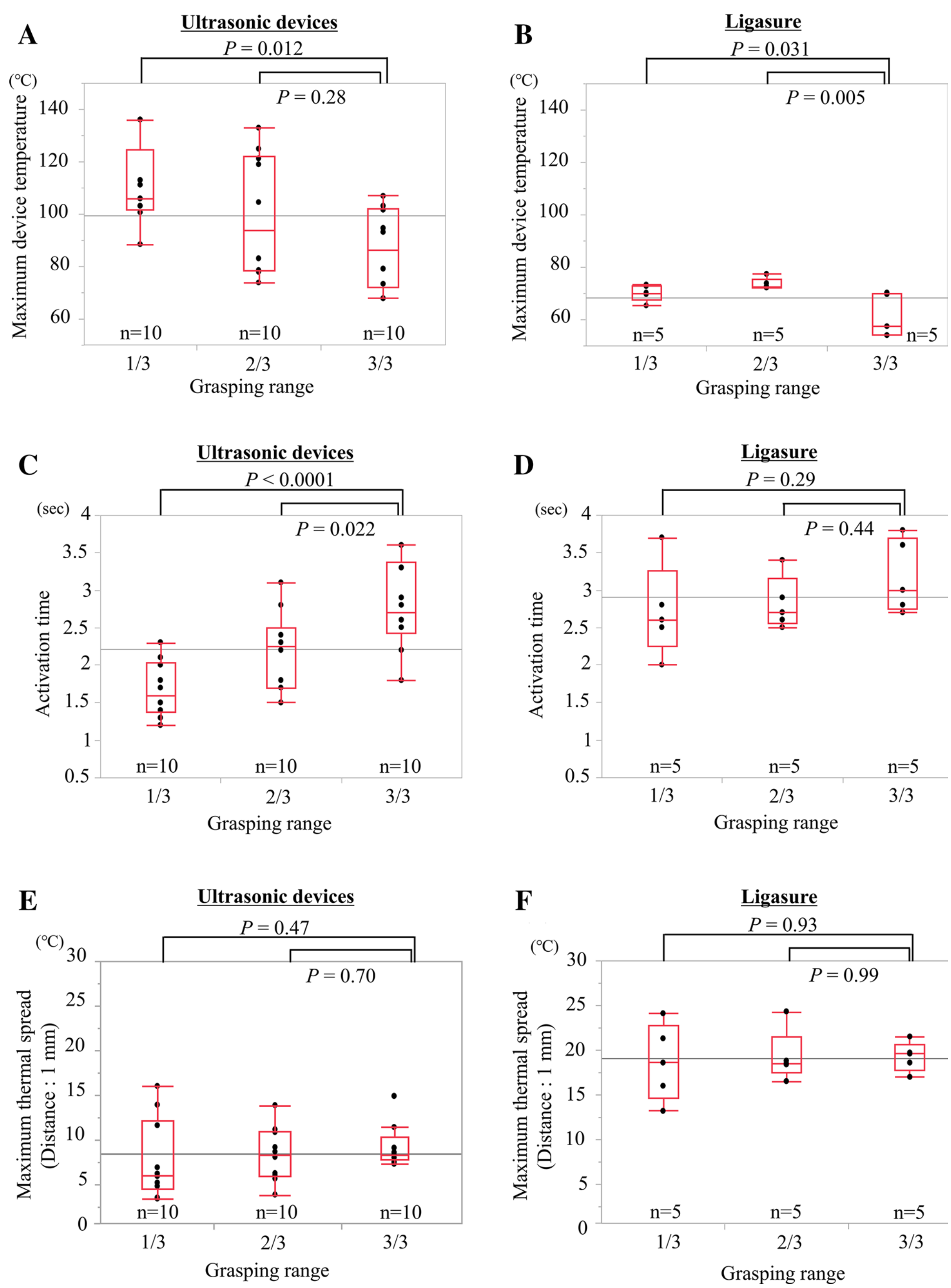
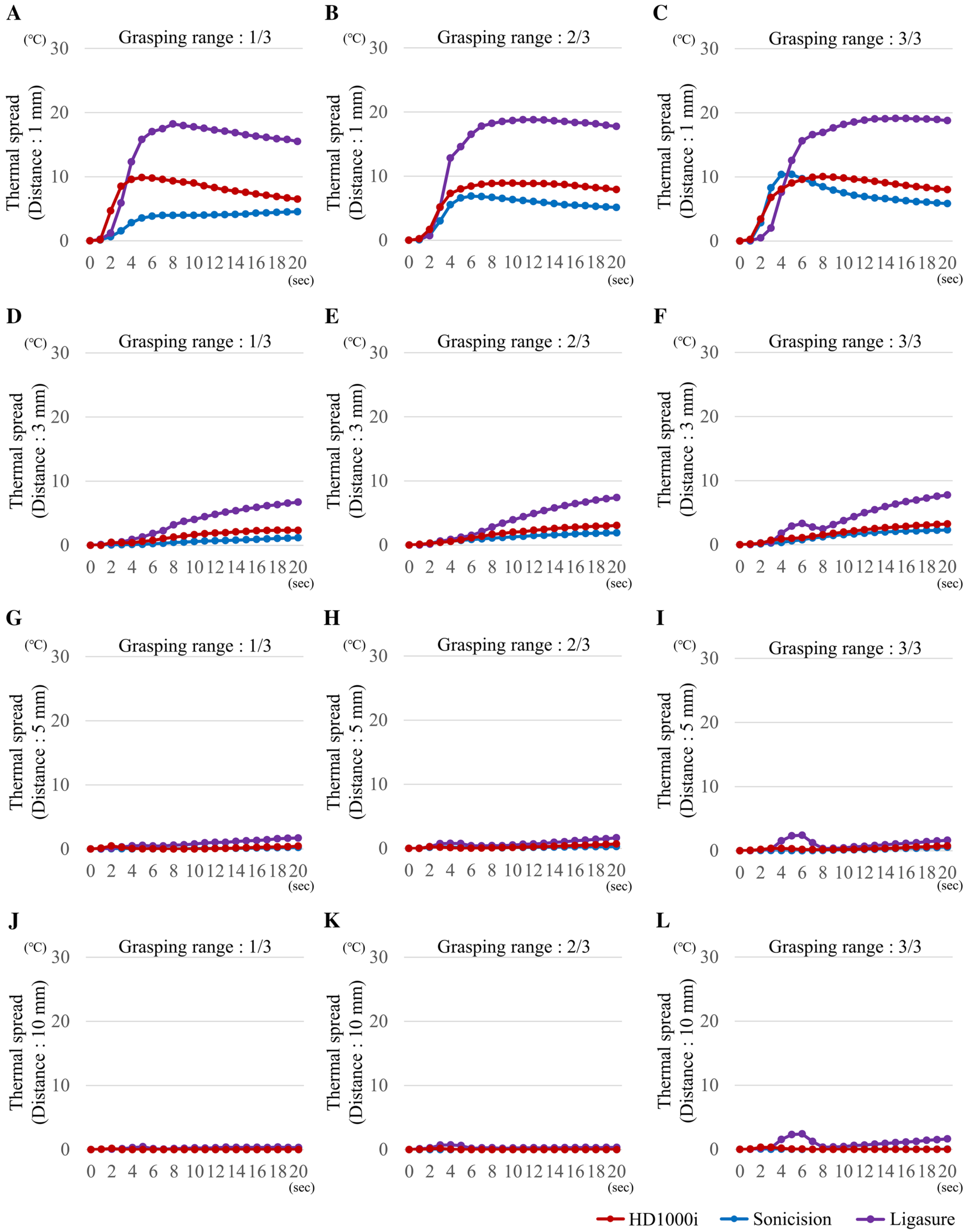


Fig. 4 Comparison of various parameters with respect to the grasping range (thermal spread study). **A** Maximum device temperatures of the ultrasonic devices with respect to the grasping ranges. **B** Maximum device temperatures of the Ligasure with respect to the grasping ranges. **C** Activation times of the ultrasonic devices with respect to the grasping ranges. **D** Activation times of the Ligasure with respect to the grasping ranges. **E** Maximum thermal spreads 1 mm from the ultrasonic devices with respect to the grasping ranges. **F** Maximum thermal spreads 1 mm from the Ligasure with respect to the grasping ranges. Thermal spread: temperature difference


A
Grasping range : 1/3
Thermal spread (Distance : 1 mm)
B
Grasping range : 2/3
Thermal spread (Distance : 1 mm)
C
Grasping range : 3/3
Thermal spread (Distance : 1 mm)
D
Grasping range : 1/3
Thermal spread (Distance : 3 mm)
E
Grasping range : 2/3
Thermal spread (Distance : 3 mm)
F
Grasping range : 3/3
Thermal spread (Distance : 3 mm)
G
Grasping range : 1/3
Thermal spread (Distance : 5 mm)
H
Grasping range : 2/3
Thermal spread (Distance : 5 mm)
I
Grasping range : 3/3
Thermal spread (Distance : 5 mm)
J
Grasping range : 1/3
Thermal spread (Distance : 10 mm)
K
Grasping range : 2/3
Thermal spread (Distance : 10 mm)
L
Grasping range : 3/3
Thermal spread (Distance : 10 mm)
(℃)
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20
(sec)
HD1000i
Sonicision
Ligasure

◂**Fig. 5** Temporal changes in the thermal spreads (thermal spread study). **A** Thermal spreads 1 mm from the energy devices with one-third of the grasping range. **B** Thermal spreads 1 mm from the energy devices with two-thirds of the grasping range. **C** Thermal spreads 1 mm away the energy devices with three-thirds of the grasping range. **D** Thermal spreads 3 mm from the energy devices with one-third of the grasping range. **E** Thermal spreads 3 mm from the energy devices with two-thirds of the grasping range. **F** Thermal spreads 3 mm from the energy devices with three-thirds of the grasping range. **G** Thermal spreads 5 mm from the energy devices with one-third of the grasping range. **H** Thermal spreads 5 mm from the energy devices with two-thirds of the grasping range. **I** Thermal spreads 5 mm from the energy devices with three-thirds of the grasping range. **J** Thermal spreads 10 mm from the energy devices with one-third of the grasping range. **K** Thermal spreads 10 mm from the energy devices with two-thirds of the grasping range. **L** Thermal spreads 10 mm from the energy devices with three-thirds of the grasping range. Thermal spread: temperature difference

Results

Thermal spread study

Device temperature related to the grasping range

The device temperatures varied considerably among the energy device types and grasping ranges (Fig. 3 and Supplementary Table 1). In the ultrasonic devices, maximum device temperatures significantly decreased with an increase in the grasping range (Fig. 4A). Meanwhile, in Ligasure, the maximum device temperature was the highest when the grasping range was two-thirds, and the maximum device temperature was the lowest with full grasping (Fig. 4B). The maximum device temperatures were lower in Ligasure than in the ultrasonic devices, irrespective of the grasping range, and the influence of the grasping range was more evident in the ultrasonic devices than in Ligasure (Fig. 4A, B).

Activation time of the energy devices related to the grasping range

The changes in activation time related to the grasping ranges showed a similar pattern between HD1000i and Sonicision; the activation time of ultrasonic devices became longer as the grasping range increased. In contrast, the activation time of Ligasure was not affected by the grasping range (Fig. 4C, D and Supplementary Table 1).

Thermal spread induced by the energy devices

The thermal spread at each location varied considerably among the energy device types and grasping ranges (Fig. 5 and Supplementary Table 1). The maximum thermal spreads were compared among the devices at each location (Fig. 6). Ligasure demonstrated significantly higher maximum thermal spreads than both ultrasonic devices at each location (Fig. 6), although the increase in the maximum thermal spread was approximately 25 °C at the highest. The shorter the distance, the higher the difference in the maximum thermal spreads between Ligasure and ultrasonic devices. In the ultrasonic devices, the maximum thermal spreads were very small at > 3-mm distance, and they were < 1.0 °C at 5 and 10 mm (Fig. 6 and Supplementary Table 1). The maximum thermal spreads at 1 mm from the devices were not affected by the grasping range (Fig. 4E, F).

NIM study

Table 1 shows the results of the NIM study. Neither amplitude nor latency was changed after activation of the Sonicision by one-third grasping range at a distance of 5 mm and 1 mm from the RLN. The mean temperatures at the RLN were 33.2 °C and 33.9 °C when Sonicision was activated at 5 mm and 1 mm away from the RLN, respectively. After activation of the Ligasure by one-third grasping range at a distance of 5 mm and 1 mm from RLN, the mean amplitude was 98.2% and 71.0%, respectively, and the mean latency was 97.2% and 93.8%, respectively. The mean temperatures at the RLN were 40.1 °C and 52.6 °C when Ligasure was activated at 5 mm and 1 mm from the RLN, respectively. During the third activation of the Ligasure at a distance of 1 mm from the RLN, immediate LOS (78 μV of the amplitude) was observed, and EMG signals did not recover after a 20-min recovery period (Fig. 7).

Discussion

Energy devices have a possible risk of thermal injury to the adjacent tissues. However, quantitative data on lateral thermal spread in the respective devices are limited. In addition, although surgeons practically use the devices with different grasping ranges based on the situation, no information was found on the difference in the thermal spread related to the grasping ranges in respective devices. Therefore, for surgeons performing esophagectomy, understanding the thermal spread induced by the energy devices in different situations is very helpful.

In the present study, we found that the temperature of the ultrasonic devices increased based on the decrease in the grasping range. The ultrasonic devices simultaneously coagulate and cut the tissue using high-frequency mechanical energy. The effects of ultrasonic devices on biological tissues are considered to involve three mechanisms: tissue

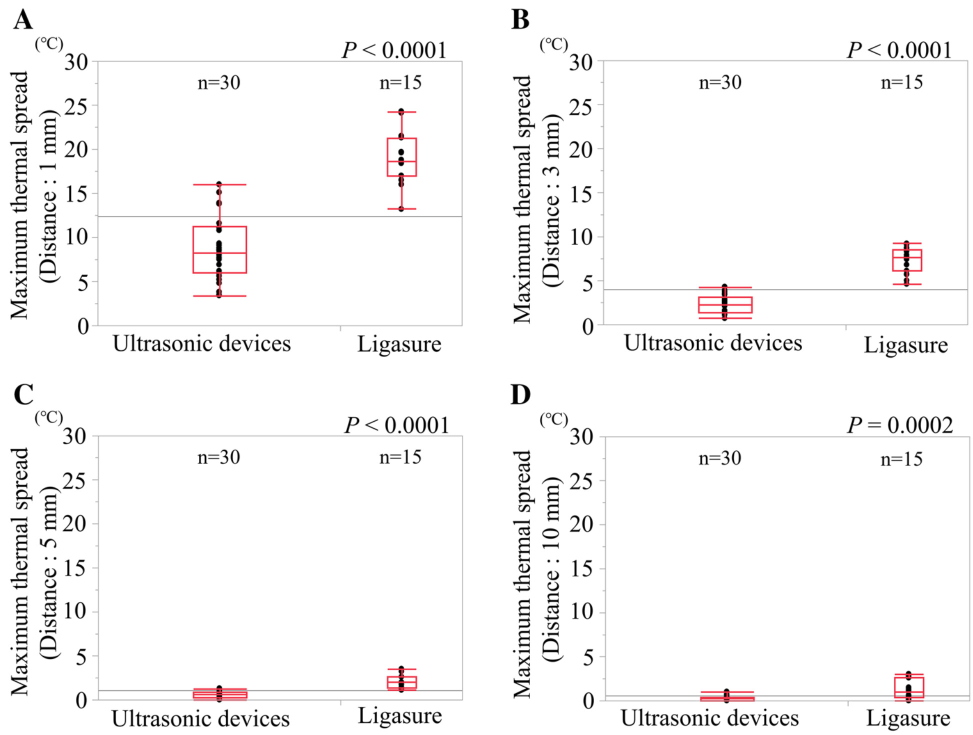


Fig. 6 Comparison of maximum thermal spread at the distance from the energy device (thermal spread study). **A** Maximum thermal spread 1 mm from the ultrasonic devices and Ligasure. **B** Maximum thermal spread 3 mm from the ultrasonic devices and Ligasure. **C** Maximum thermal spread 5 mm from the ultrasonic devices and Ligasure. **D** Maximum thermal spread 10 mm from the ultrasonic devices and Ligasure. Thermal spread: temperature difference

destructive energy released in the process of cavitation, heat generation as a result of internal tissue friction, and protein denaturation through the mechanical disruption of tertiary hydrogen bonds [26]. The increase in the device temperature observed in the smaller grasping ranges is considered to be due to the friction between the active blade and the nonactive tissue pad without interposing tissue. Therefore, surgeons should pay attention not to touch the vital organs with the ultrasonic devices immediately after the activation, particularly when used with a short grasping range.

On the contrary, the decreased grasping range of ultrasonic devices was significantly associated with decreased activation time. This may be why the thermal spread induced by the ultrasonic devices was not affected by the grasping ranges, although the temperature of these devices became higher as the grasping range decreased. These results indicate that short grasping range of ultrasonic device would not increase the risk of thermal spread if the activation was completed as soon as the tissue was divided. Some studies reported that the ultrasonic device was valuable in dissecting near the nerves when used appropriately [27–29]. This study revealed that the increases in the tissue temperatures induced by the ultrasonic devices with various grasping ranges were very limited.

The temperature of the vessel-sealing device after activation was much lower than that of ultrasonic devices. Although the temperature of Ligasure was also affected by the grasping range, the changes were smaller than those observed in the ultrasonic devices. The temperature was highest when used with two-thirds grasping and was lowest when used with full grasping. Theoretically, in contrast to the ultrasonic devices, the activation of bipolar devices without interposing tissue does not generate heat. However, the liquid content from the porcine tissue, which flows into the non-grasping part of the device during the activation, seems to influence the changes in temperature. The grasping range did not affect the activation time in the case of Ligasure. The thermal spread induced by Ligasure was not also affected by the grasping range.

The thermal spread induced by the vessel-sealing device was greater compared with the ultrasonic devices, which was contrary to the device temperature data. The result was consistent with that reported by Hruby et al. [14]. We also revealed that grasping ranges do not influence the thermal spread neither in the vessel-sealing nor in the ultrasonic devices. Thermal spread 1 mm from the Ligasure could reach approximately 20 °C by any grasping range.

There are different technological mechanisms for temperature elevation between the bipolar and the ultrasonic devices. In contrast to heat generation, as a result of internal tissue friction by the ultrasonic device, the vessel-sealing device achieves tissue sealing and hemostasis by two primary mechanisms: compression of tissue and the local delivery of radiofrequency (RF) energy, which results in cellular and tissue heating [30].

Due to joule heating of the RF energy, severe damage can easily occur even in a distance of several millimeters

Table 1 Comparison of electromyographic (EMG) signal changes during thermal injury

Distance from the RLN (mm)	Temperature before activation		EMG before activation		Activation time (s)	Temperature after activation				EMG after activation			
	Thermography (°C)	RLN (°C)	Amplitude (μV)	Latency (ms)		Device		RLN		Amplitude		Latency	
						°C	Mean (°C)	°C	Mean (°C)	μV (%)	Mean (%)	ms (%)	Mean (%)
Sonicision (maximum power mode)													
5	38.0	31.7	444	4.8	2.5	136.8	110.1	33.3	33.2	436 (98.2)	100.4	4.7 (98.7)	99.7
	35.7	32.3	436	4.8	1.6	105		32.7		438 (100.5)		4.8 (100)	
	37.3	32.8	403	4.8	2.3	88.4		33.6		413 (102.5)		4.8 (100.4)	
1	35.7	33.5	416	4.7	1.8	134.8	118.8	33.6	33.9	411 (98.8)	98.4	4.8 (102.1)	98.7
	38.0	33.6	392	4.8	1.5	97.7		34.2		381 (97.2)		4.7 (97.9)	
	35.7	32.7	395	5.0	2	124		33.9		392 (99.2)		4.8 (96.0)	
Ligasure													
5	35.7	31.5	396	4.9	6	85.7	85.2	40.9	40.1	391 (98.7)	98.2	4.8 (98.0)	97.2
	37.3	33.1	391	4.8	4.9	85.7		42.3		397 (101.5)		4.7 (97.9)	
	35.7	34.0	411	4.8	4.7	84.1		37.1		388 (94.4)		4.6 (95.8)	
1	37.3	32.4	393	4.9	3.5	79.1	80.6	42.3	52.6	385 (98.0)	71.0	4.9 (100)	93.8
	37.3	33.3	381	4.7	5.4	83		59.9		359 (94.2)		4.7 (100)	
	37.3	32.7	376	4.8	4.5	79.6		55.6		78 (20.7)		3.9 (81.3)	

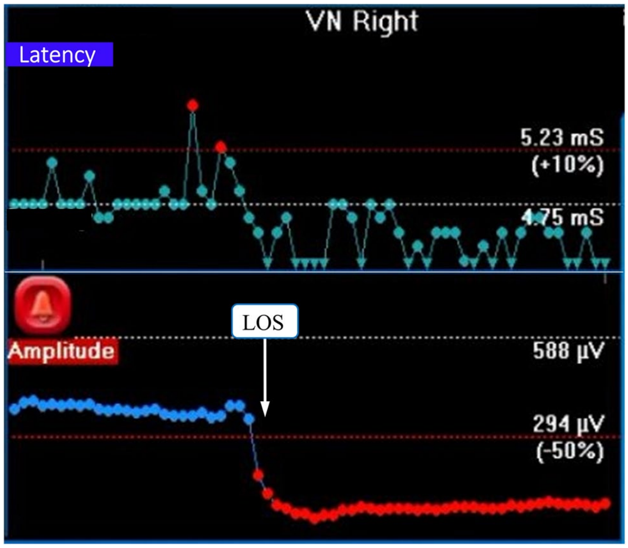


Fig. 7 Real-time EMG changes during the third application of the Ligasure 1-mm from the RLN (NIM study). The latency (above) and amplitude (below) waveforms are displayed separately. EMG signals had progressive decreases, especially in the amplitude. The mean amplitude of 20 stimulations after device activation was 78 µV (LOS), and an alarm was displayed on the monitor screen (red bell sign) with acoustic alert. EMG signals did not recover after a 20-min recovery period. (Color figure online)

from the bipolar device [31]. Habermann and Muller recommended that the bipolar device should not be used in the vicinity of sensitive structures until thermal dose–effect characteristics will be available in more detail [31].

In the NIM study, we confirmed that the ultrasonic device can be safely used at a distance of 1 mm from the RLN. When combined with the results of the thermal spread study, we considered that the ultrasonic devices can be used near the RLN. In contrast, LOS was observed during the third activation of the Ligasure at 1 mm from the RLN. Proteins begin to denature when the temperature reaches 60 °C [32]. Lin et al. [33] investigated a critical temperature of RLN in a porcine model using the CIONM system, and also found that 60 °C was a critical temperature. In this study, the temperatures of the RLN 1 mm from the Ligasure almost reached 60 °C after the second and third activations of the Ligasure. Considering these results, Ligasure activation at 1 mm from the RLN may lead to critical results because of the thermal spread to the tissue.

The present study has several limitations. This study is an animal study, specifically using porcine tissue. The temperatures of the energy devices and surrounding tissue are influenced by multiple variables, including tissue type, tissue thickness, type of energy devices, power setting, cutting time, and counter traction [9, 17, 29, 31, 34]. Therefore, translation of these animal data to humans should be performed carefully. In addition, there is a lack of histological data to evaluate the effects of thermal injury after activation of the energy devices. Although many studies have reported histological thermal spread, there are no clear criteria describing how it should be measured [34]. We prioritized the objective evaluation of thermal spread using thermography, thermometer, and CIONM.

Conclusion

Although the grasping range significantly influenced the device temperature, it did not affect the thermal spread induced by the energy devices. The temperature of the ultrasonic devices was much higher than that of Ligasure, and the temperature increased as the grasping range was shortened. Therefore, surgeons should pay attention not to touch vital structures with ultrasonic devices during and after the activation. Meanwhile, the thermal spread induced by Ligasure was greater compared with the ultrasonic devices, although the device temperature of the ultrasonic devices was significantly higher than that of Ligasure. The ultrasonic devices may be safer in terms of lateral thermal spread to the RLN than Ligasure.

Compliance with ethical standards

Disclosures Drs. Masaru Hayami, Masayuki Watanabe, Shinji Mine, Yu Imamura, Akihiko Okamura, Masami Yuda, Kotaro Yamashita, Tasuku Toihata, Yoshiaki Shoji, and Naoki Ishizuka have no conflicts of interest or financial ties to disclose.

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