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Lateral temperature spread of monopolar, bipolar and ultrasonic instruments for robot-assisted laparoscopic surgery

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Objective

- To assess critical heat spread of cautery instruments used in robot-assisted laparoscopic (RAL) surgery.

Materials and Methods

- Thermal spread along bovine musculofascial tissues was examined by infrared camera, histology and enzyme assay.
- Currently used monopolar, bipolar and ultrasonic laparoscopic instruments were investigated at various power settings and application times.
- The efficacy of using an additional Maryland clamp as a heat sink was evaluated.
- A temperature of 45 °C was considered the threshold temperature for possible nerve damage.

Results

- Monopolar instruments exhibited a mean (SEM) critical thermal spread of 3.5 (2.3) mm when applied at 60 W for 1 s. After 2 s, the spread was >20 mm.
- For adjustable bipolar instruments the mean (SEM) critical thermal spread was 2.2 (0.6) mm at 60 W and 1 s, and 3.6 (1.3) mm at 2 s.
- The PK and LigaSure forceps had mean (SEM) critical thermal spreads of 3.9 (0.8) and 2.8 (0.6) mm respectively, whereas the ultrasonic instrument reached 2.9 (0.8) mm.
- Application of an additional Maryland clamp as a heat sink, significantly reduced the thermal spread.
- Histomorphometric analyses and enzyme assay supported these findings.

Conclusions

- All coagulation devices used in RAL surgery have distinct thermal spreads depending on power setting and application time.
- Cautery may be of concern due to lateral temperature spread, causing potential damage to sensitive structures including nerves.
- Our results provide surgeons with a resource for educated decision-making when using coagulation devices during robotic procedures.

Keywords

robotic, bipolar, monopolar, harmonic, thermal spread, cautery, tissue damage

Introduction

The number of robot-assisted laparoscopy (RAL) procedures has dramatically increased in recent years. In the USA, robotic systems had an ≈75% adoption rate between 2007 and 2009 [1,2]. In this same period, RAL operations increased by 250% worldwide [1]. One major advantage of the DaVinci system is the superior three-dimensional view [3,4]. However, maintaining good visibility requires continuous haemostasis. Stepwise ligation techniques used in open procedures are technically demanding and prolong surgery time; they are only used at specific steps. Clips are more efficient, but require additional instruments and bare a risk of detaching. Further, metal clips can impair the quality of follow-up CT scans. Cauterizing haemostasis, forming an 'autologous clip', is often favoured by laparoscopic surgeons. Advantages of cauterisation include shorter operation times, easy handling and decreased blood loss [5]. Currently, electric (mono- or bipolar) or ultrasonic energy is used to generate the heat required for tissue coagulation, which occurs when the temperature rises above 45 °C [6–9]. Above this temperature, denaturation of proteins occurs and cells begin to die at temperatures from 57 to 65 °C [7].

Therefore, tissue temperatures of >45 °C created by these instruments can damage adjacent, sensitive structures, particularly nerves. In radical prostatectomy (RP), damage to the neurovascular bundle (NVB) impairs erectile function and

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urinary continence, with subsequent reduced quality of life [10]. The use of conventional electric coagulation has been linked to a higher erectile dysfunction rate [11], and therefore the use of coagulation devices during the nerve-sparing steps is still debated [12,13] and the physical effects should be investigated in detail.

In the present study, we systematically evaluated the critical thermal spread of robotic coagulation devices in a clinically relevant model [14]. Considering power setting and duration, we describe the extent of thermal damage produced by robotic instruments. Furthermore, we show the benefits of using a second instrument for protection of surrounding tissues. We hope to provide surgeons with a resource for educated decision-making when using coagulation devices during urological surgeries.

Material and Methods

A standardised *in vitro* model [14] was used to evaluate heat spread. Briefly, thin strips of fresh bovine muscle fascia with a mean diameter of 4 mm and length of 6 cm were dissected and kept at 4 °C until use. The strips were held in place by two clamps applying constant tractions of 25 g and pre-heated to 32 °C, which corresponds to the peritoneal temperature measured during robot-assisted laparoscopic RP (RALP) by a temperature probe. To hold this temperature during the experimentation the strip constructs were positioned above a warm water bath set to 32 °C.

Robotic and Laparoscopic Instruments

Four robotic and laparoscopic instruments were assessed: Hot Shears®, Permanent Cautery Hook® (both monopolar), Maryland Bipolar Forceps®, and PreCise Bipolar Forceps® (Intuitive Surgery, USA). Three modern tissue-sealing devices with proprietary electric generators that employ active feedback to optimise power output were used: PK Dissecting Forceps® (Intuitive Surgery, USA) and LigaSure LF 1537® (Valleylab, Covidien, USA), both bipolar instruments, and the ultrasonic Harmonic ACE Curved Shears®, which induces cellular friction via a vectored vibration of the clamp, leading to structural changes in proteins and consecutive coagulation of vessels and tissue [15].

Power Sources

An Erbe VIO (Erbe Medical, Germany) generator powered all electrosurgical devices. A Harmonic Generator 300 (Ethicon Endo-Surgery Inc., USA) powered the ultrasonic instrument. Tissue-sealing devices required either a Gyrus ACMI PK/SP Generator (Gyrus, Olympus, USA; for PK) or a Valleylab Force Triad Energy Platform (Valleylab, Covidien, USA; for LigaSure).

Operating Parameters

Monopolar and bipolar instruments were investigated at different power settings (30, 60, and 90 W) using a 1 s application time, and thereafter at 60 W for 0.5, 1, 2, and 4 s. The tissue-sealing devices were applied up to their termination signal. The PK Dissecting Forceps® were also subjected to different application times (0.5 and 1 s), which is not recommended for the LigaSure device. The ultrasonic instrument was operated in three power modes (1, 3, 5) for 1 s, as well as at various application times (0.5, 1, 2 and 4 s) in power mode 3. For completeness, the ultrasonic instrument was also applied until termination signal (power mode 5 at 4 s).

To evaluate if an additional instrument could serve as a heat sink [14] the measurements at 1 s were repeated with a Maryland instrument placed laterally to the cauterisation instrument (mono- and bipolar: 60 W; harmonic: power mode 3; automatic for PK forceps and LigaSure device). Further, the average temperature rise of the additionally placed Maryland was measured over time.

Macroscopic Assessment of Temperature Spread

To assess lateral temperature spread, a high-performance infrared camera (FLIR SC660, FLIR USA) with a thermal sensitivity of <30 mK and a resolution of 640 × 480 pixels was mounted 30 cm above the tissue samples. Videothermography was performed throughout the procedure (image frequency 30 Hz), allowing for radiometric analysis over time. Each experiment was repeated six times and analysed via ThermaCAM Researcher Professional® software. For analysis, a 20-mm orthogonal line (region of interest) was drawn at the location of maximal temperature spread. All calculations, including average temperature and, temperature curve, were made in Microsoft Excel. In all experiments, 45 °C was defined as the 'critical' temperature for potential neural damage [11].

Enzymatic Assessment of Temperature Spread

Evaluation of thermal damage at the protein level required use of a modified lactate dehydrogenase (LDH) assay [16,17]. As a ubiquitous Krebs-cycle protein, LDH is an established marker for cell damage. To preserve remaining enzymatic function, cauterized tissue samples were immersed in Tissue-Tek O.C.T. Compound® (Sakura, Japan), snap-frozen, and stored at −80 °C. Cryo-sected samples of 50 μm were placed on glass slides and incubated at 4 °C in a medium containing 0.1 M Veronal buffer [16,17], 1.5 ng β nicotinamide adenine dinucleotide (NADH, Sigma Aldrich, N1511), 15 mg L(+) lactic acid-sodium salt (Sigma Aldrich, L7022) and 2.5 mg nitroblue tetrazolium chloride (NBTC, Sigma Aldrich, N6876) overnight. The extent of tissue with significant protein damage was assessed by light microscopy (Leica Application Suite, Leica Germany) measuring the distance to the blue-stained, healthy tissue.

Statistics

Differences between groups were assessed via one-way ANOVA and Bonferroni *post hoc* testing. A $P < 0.05$ was considered to indicate statistical significance. All presented data are expressed as the mean (standard error of the mean, SEM).

Results

Influence of Application Time on Thermal Spread

Spatial temperature distribution caused by different devices was investigated in regard to application time and power setting (Fig. 1). At 60 W, the Hot Shears and Cautery Hook showed thermal spreads of 3.5 (2.3) and 2.5 (0.7) mm, respectively, when applied for 1 s (Table 1). At 2 s, the Cautery Hook's spread increased to 19.4 (3.7) mm, while the Hot Shears surpassed 20 mm. At 4 s, spreads of >20 mm were found for both devices ($P < 0.001$).

Use of the Maryland and PreCise Forceps at 60 W for 1 s resulted in lateral temperatures >45 °C measured within 2.1 (1.2) and 2.2 (0.6) mm, respectively. At 2 s, heat spread increased to 3.6 (1.3) and 2.9 (0.5) mm at 4 s was 4.9 (0.6) and 3.1 (0.1) mm ($P < 0.001$).

Heat spread of the PK forceps and the LigaSure device was 3.9 (0.8) and 2.8 (0.6) mm, respectively, when applied up to the termination signal. However, as not all surgeons apply the PK instrument up to the termination signal it was also assessed at 1 s, showing heat spread of 2.5 (0.5) mm ($P < 0.001$).

If the power was set to level 3, the spread of the harmonic instrument for 1, 2 and 4 s was 1.3 (0.2), 1.6 (0.3) and 2.1 (0.7) mm, respectively ($P = 0.03$). The thermal spread of all tested instruments during an ultra-short activation (0.5 s) ranged between 0.8 and 1.3 mm.

Influence of Power Setting on Thermal Spread

The temperature spread increased significantly with output power (Table 2). The Hot Shears and Cautery Hook had critical spreads of 16.8 (4.0) and 8.8 (4.2) mm, respectively, at 30 W for 1 s. A power increase to 60 W resulted in temperature spread increases to 3.5 (2.3) and 2.5 (0.7) mm. Spreads of 16.8 (4.0) and 8.8 (4.2) mm were observed at 90 W ($P < 0.01$; $P = 0.014$).

The Maryland forceps increased their thermal spread from 1.5 (0.8) to 2.1 (1.2) to 2.6 (0.6) mm at 30, 60 and 90 W, respectively ($P = 0.021$). Similar findings were seen with the PreCise Forceps, with spreads of 1.1 (0.6), 2.2 (0.6) and 2.5 9(0.6) mm at the same power settings ($P = 0.02$).

The harmonic instrument was evaluated at minimum (1), average (3), and maximum (5) power settings. At 1 s, it had significant spreads of 1.1 (0.3), 1.3 (0.2) and 1.8 (0.7) mm, respectively ($P = 0.043$). However, when it was used at maximum power up to the termination signal, the spread increased to 2.9 (0.8) mm.

Maryland Forceps as a Heat Sink

We hypothesised that the Maryland forceps could be used as a heat sink if placed alongside a cautery device, thereby protecting adjacent tissue from thermal injury. In this setting, the following distances of heat spread were observed (Table 3): Using a Maryland alongside at 60 W for 1 s, the heat spread of the monopolar Hot Shears and Cautery Hook was 3.0 (6.1) mm ($P = 0.59$) and 1.4 (1.3) mm ($P = 0.005$), respectively; bipolar Maryland and PreCise forceps achieved 1.0 (0.3) mm ($P = 0.023$) and 1.4 mm ($P = 0.036$), respectively. The ultrasonic instrument had a spread of 1.0 (0.7) mm ($P = 0.117$). The automatic PK and LigaSure forceps achieved 1.9 (0.4) mm ($P = 0.01$) and 2.2 (0.5) mm ($P = 0.028$). Heat absorption by the additional Maryland forceps was shown by a mean (SEM) temperature rise of the instrument of 9.2 (4.5) °C.

Enzymatic and Histological Assessment

Microscopic examination of tissue showed no carbonisation in the muscle fascia samples (Fig. 2). Histomorphological analysis via LDH-staining defined thermal damage at the protein level. If monopolar instruments were used at 60 W for 1 s (Fig. 2A), intact enzymatic function was seen at 2.4 (0.2) mm (Hot Shears) and 2.2 (0.1) mm (Cautery Hook). The bipolar Maryland and PreCise forceps showed vital cell patterns at 1.3 (0.2) mm and 1.6 (0.2) mm, respectively.

Application times of 0.5, 1, 2 and 4 s led to correspondingly increased zones of damaged cells. For instance, the bipolar Maryland (Fig. 2B) showed intact enzymatic function at 0.3 (0.02), 1.3 (0.2), 2.3 (0.2) and 2.6 (0.6) mm, respectively. In parallel to this, a higher power output led to a wider field of protein denaturation. LDH-staining of Maryland experiments for 1 s with different Watt settings (Fig. 2C) showed practically no collateral damage for 30 W (0.1 [0.1] mm), whereas vital cells started at 1.3 (0.2) mm with 60 W and 1.5 (0.02) mm with 90 W away from the instruments imprints.

Cell damage by the PK forceps and Harmonic Shears (power setting 3) occurred as far as 1.4 (0.01) and 1.2 (0.1) mm, respectively. Cells with intact proteins were found at 1.5 (0.1) mm on either side of the LigaSure device. When using Maryland forceps as a heat-sink, the LDH-staining showed reduced protein damage up to 0.1 (0.1) mm at 30 W, 1.3 (0.2) mm at 60 W and 1.5 (0.02) mm at 90 W.

Discussion

In the present study, we evaluated a selection of several electrosurgical instruments routinely used in robotic surgery. To prevent damage to adjacent, sensitive structures, awareness

Fig. 1 Temperature measurements for the following instruments: (**a**) Hot Shears (monopolar curved scissors); (**b**) Permanent Cautery Hook (monopolar); (**c**) Maryland bipolar forceps; (**d**) PreCise bipolar forceps; (**e**) PK dissecting forceps; (**f**) Harmonic ACE curved shears, (**g**) LigaSure 5-mm LF 1537 with an automatic power output and termination signal. I) Representative thermal images. II) Measurement using different power setting, application time of 1 s. Power settings: a–d) 30, 60, 90 W; (**e**) automatic; (**f**) 1, 3, 5; (**g**) automatic, termination signal (*). III) Measurement using different application times, power settings. a–d) 60 W; (**e**) automatic; (**f**) left: level 3, right: level 5 to termination signal (*). Application times of 0.5, 1, 2, 4 s.

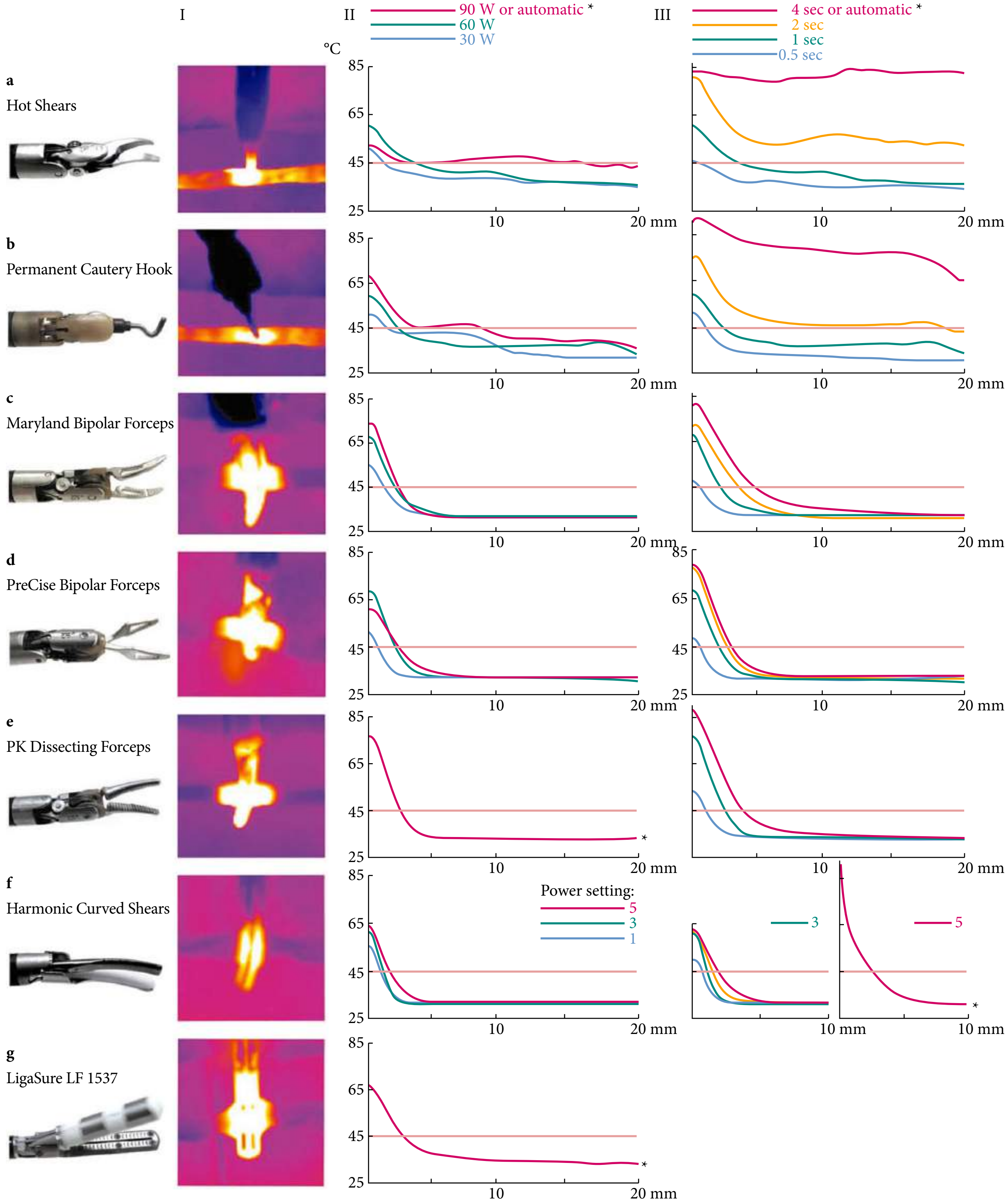

Table 1 Influence of application time on thermal spread (critical temperature spread >45 °C).

Device	Mean (SEM) thermal spread for the tested application times, mm				*P*
	0.5 s	1 s	2 s	4 s	
Hot Shears	1.3 (1.9)	3.5 (2.3)	>20	>20	<0.001
Hook	1.3 (0.8)	2.5 (0.7)	19.4 (3.7)	>20	<0.001
Maryland	0.8 (0.6)	2.1 (1.2)	3.6 (1.3)	4.9 (0.6)	<0.001
PreCise	1 (0.6)	2.2 (0.6)	2.9 (0.5)	3.1 (0.1)	<0.001
PK	1.3 (0.4)	2.5 (0.5)	3.9 (0.8)*	n.a.	<0.001
Harmonic 3	1.1 (0.2)	1.3 (0.2)	1.6 (0.3)	2.1 (0.7)	0.03
Harmonic 5	n.a	1.8 (0.7)	n.a.	2.9 (0.8)§	0.08
LigaSure	n.a.	n.a.	n.a.	2.8 (0.8)§	n.a.

**The PK instrument sowed a termination signal after ≈2 s, therefore 4 s was not possible. The harmonic instrument was assessed with an average power setting of 3. For the sake of completeness the instrument was also measured at the maximal level 5 for 1 s and up to the termination signal (§). LigaSure was measured at the termination signal (§). n.a., not applicable.*

Table 2 Influence of power setting on thermal spread (critical temperature spread >45 °C).

Device	Mean (SEM) thermal spread at various power settings, mm				*P*
	30 W*	60 W**	90 W***	Automatic	
Hot Shears	2.6 (1.2)	3.5 (2.3)	16.8 (4.0)		<0.001
Hook	1.8 (0.8)	2.5 (0.7)	8.8 (4.2)		0.014
Maryland	1.5 (0.8)	2.1 (1.2)	2.6 (0.6)		0.021
PreCise	1.1 (0.6)	2.2 (0.6)	2.5 (0.6)		0.02
PK	n.a.	n.a.	n.a.	2.5 (0.5)	n.a.
Harmonic	1.1 (0.3)	1.3 (0.2)	1.8 (0.7)		0.043
LigaSure	n.a.	n.a.	n.a.	2.8 (0.6)§	n.a.

*Harmonic: * = level 1, ** = level 3, *** = level 5, PK and LigaSure: automatic. LigaSure application up to termination signal (§). Application time for all other intruments: 1 s. n.a.,not applicable.*

Table 3 Influence of an additional Maryland bipolar forceps held next to the cautery device, to serve as a heat sink, on thermal spread (>45 °C).

Device	Mean (SEM) thermal spread, mm		*P*
	Instrument alone	Instrument with added Maryland heat sink	
Hot Shears	3.5 (2.3)	3 (6.1)	0.59
Hook	2.5 (0.7)	1.4 (1.3)	0.005
Maryland	2.1 (1.2)	1 (0.3)	0.023
PreCise	2.2 (0.6)	1.4 (0)	0.036
PK*	2.5 (0.5)	1.9 (0.4)	0.001
Harmonic[†]	1.3 (0.2)	1 (0.7)	0.117
LigaSure[‡]	2.8 (0.6)	2.2 (0.5)	0.028

*The Hot Shears, Permanent Cautery Hook, Maryland bipolar forceps and the PreCise bipolar forceps were used at a setting of 60 W for 1 s; *The PK instrument was applied for 1 s in an automatic power setting; [†]The Harmonic ACE curved shears were applied for 1 s at setting 3; [‡]The automatic LigaSure Instrument was used all the way to the termination signal.*

of the potential collateral damage of each individual instrument is crucial. The tissue damage, which increases with application time and power, occurred in all coagulation devices. However, each method displayed a unique heat spread. Monopolar tools possess the highest spreads, followed by bipolar instruments and newer instruments with feedback loops.

Critical heat spreads of >20 mm were found with monopolar devices used for 2 s at 60 W. The use of bipolar energy significantly lowered the thermal spread. Bipolar instruments used for 1 s at 60 W require a safety distance of 2.1 mm. At 4 s, this safety distance quickly increased to 5 mm, while lowering the power to 30 W and 1 s reduced thermal spread to 1.5 mm.

Modern vessel-sealing devices, e.g. the PK and LigaSure forceps, are engineered to successfully coagulate blood vessels up to 5 mm in diameter by increased power output and constant impedance measurement [18]. At the termination signal, the PK forceps showed a thermal spread of ≈3.9 mm, whereas the LigaSure and the Harmonic shears showed 3.1 mm and 2.9 mm, respectively. The present macroscopic findings were supported by the results at the protein level. As expected, complete denaturation of LDH required temperatures of >45 °C. Distances measured by histomorphology are generally lower than measured by infrared imaging, as also reported by other authors in the field [19,20]. Histomorphometrical analysis showed a general shift closer to the coagulative device of 0.8 (0.5) mm. The

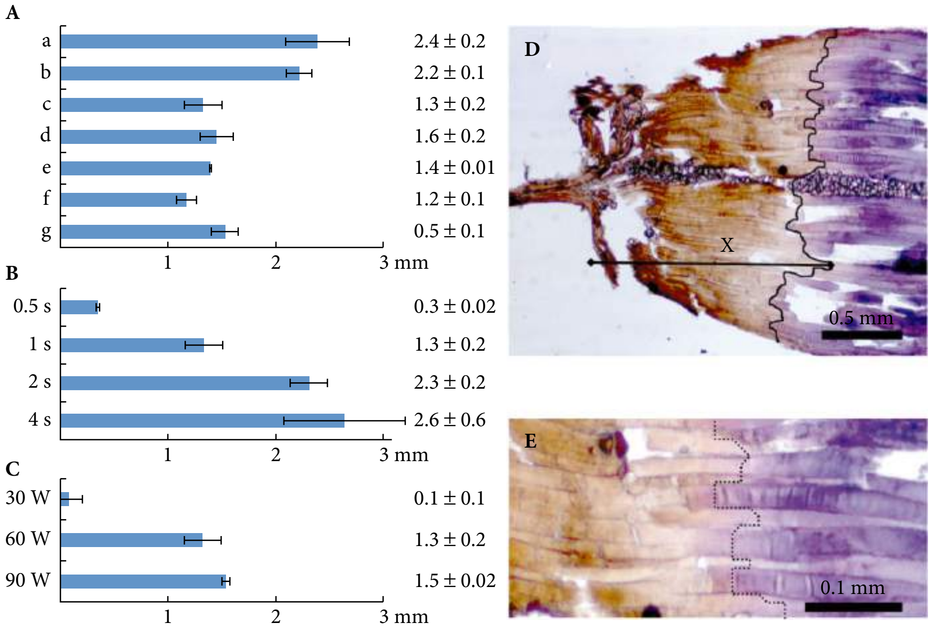

Fig. 2 Histomorphological and enzymatic analysis: (**A**) Distance to vital cell patterns (blue) in LDH-stained cryo-sections in mm. (a) Hot Shears (monopolar curved scissors); (b) Permanent Cautery Hook (monopolar); (c) Maryland bipolar forceps; (d) PreCise bipolar forceps; Settings a–d: 60 W. (e) PK dissecting forceps, automatic power, 1 s; (f) Harmonic ACE curved shears, level 3, 1 s; (g) LigaSure 5-mm LF 1537, automatic, termination signal. (**B**) Example of different application times (0.5, 1, 2 and 4 s) for Maryland bipolar forceps in a setting of 60 W. (**C**) Example of different power settings (30, 60, 90 W) for Maryland bipolar forceps applied for 1 s. (**D**) Representative LDH-staining with demarcation line between LDH-positive and -negative cells. The distance indicated as X was used to calculate the distance to cells with intact LDH-enzyme. (**E**) Higher magnification of demarcation line.

histomorphometric analysis demonstrated the same characteristics of thermal spread with the monopolar devices showing the largest distance to healthy tissue, followed by the bipolar and vessel-sealing devices.

Most scientific papers regarding energy-based surgical devices are mainly focused on determining coagulative potency. However, some investigators have additionally investigated heat spread and thermal damage. Goldstein et al. [21] have analysed the tissue response to surgical energy, particularly the Harmonic ACE, bipolar Gyrus Trisector and LigaSure V. They found that the damage to the adjacent tissue is not directly related to the temperature of the blade, but also depends on the energy mode and application time. However, quantification of lateral tissue damage was based only on haematoxylin and eosin (H&E) staining. Hruby et al. [18] assessed the sealing effect for different vessel diameters and bursting pressures of arteries and veins using the same instruments as Goldstein et al. [21]. Again peripheral energy spread was analysed by histomorphology only. They were able to show that LigaSure V was superior in sealing large vessels (up to 7 mm) but had a larger energy spread compared with the Harmonic ACE (0.6 vs 4.5 mm). However, of primary importance in surgeries in the proximity of highly vulnerable tissues, e.g. bowel anastomosis, thyroidectomy or nerve-sparing RP, is the extent of significant heat spread [15,22,23]. Brzeziński et al. [24] analysed 76 thyroidectomy procedures for lateral thermal spread when using monopolar and bipolar diathermy devices, as well as a bipolar vessel sealing system (Thermostapler™) by comparing a 30 and 60 W setting. The infrared camera imaging showed a higher heat spread for all instruments in the 60 W compared with the 30 W setting. However, with the single and comparably long application time of 5 s the observed differences were not statistically significant (4.9–5.8 mm). The ultrasonic dissection device Harmonic Scalpel™ and a LigaSure™ vessel sealing device was later compared in a porcine model [25]. The infrared images again showed no significant difference in terms of heat spread (1.37 vs 1.54 mm). Each of these two studies used a different temperature threshold of 42 °C and 60 °C. However, the widely accepted temperature threshold for potential tissue damage, especially for the vulnerable neural structures is set at 45 °C [6–9,11].

In RP, damage to the NVB leads to a significant effect on erectile function and urinary continence with subsequent considerable loss of quality of life [10,15]. Conventional electric coagulation devices during open surgery have been shown to cause a significantly higher rate of erectile dysfunction if used near the NVB during RP [11]. Nevertheless, coagulation devices are still widely used during RALP. Several methods have been described to reduce collateral thermal damage for nerve-sparing RP, e.g. ultrasonic shears, potassium-titanyl-phosphate (KTP)-laser and electric sealing devices in combination with ice cold irrigation (e.g. EnSeal™, Ethicon) [19,26]. Infrared imaging showed a significantly lower heat spread for the KTP-laser compared with the ultrasonic device (1.07 vs 6.4 mm). However, the experiment was performed on NVBs in two dogs only and again the threshold temperature was set at 60 °C [26]. The use of ice cold irrigation significantly minimised tissue damage compared with conservative use of the EnSeal™ device (0.39 vs 1.12 mm) as assessed by histomorphological analyses [19]. The present results show that the placement of additional Maryland forceps next to the sensitive tissue significantly lowered the heat spread by an Mean (range) of 0.8 (0.3–1.1) mm. During the coagulation process the additional Maryland forceps served as a heat sink and warmed up by 10 °C.

We examined the thermal spread and cell damaging effect of all available robotic instruments capable of cautery in a reproducible setting using a standardized model [14]. The goal of this study was not to assess the effectiveness of haemostasis, but to assess the thermal spread of the different devices in detail. The *in vitro* method does not fully represent the *in vivo* situation met during surgery. However, it has been shown to produce values highly comparable to *in vivo* investigations [27] and enables us to soundly compare different devices, power settings, and times. The present investigations clearly show that surgeons should start any preparation with a low power setting, minimise application time and use bipolar energy, if applicable, in order to prevent collateral damage.

In conclusion, bipolar robotic instruments used for <2 s require safety distances of 3.6 mm depending on energy settings. Bipolar devices and Harmonic shears show significant spreads of ≈3 mm. Monopolar devices exhibit a significantly larger spread if used for >1 s and should only be used with extreme caution. Placement of Maryland forceps next to heat-generating devices significantly reduces the heat spread and provides additional safety.

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Conflict of Interest

None declared.

References

1 **Yates DR, Rouprêt M, Bitker MO, Vaessen C.** To infinity and beyond: the robotic toy story. *Eur Urol* 2011; 60: 263–5

2 **Sunnyvale C.** Intuitive Surgical data. 2011

3 **Mottrie A, De Naeyer G, Schatteman P, Carpentier P, Sangalli M, Ficarra V.** Impact of the learning curve on perioperative outcomes in patients who underwent robotic partial nephrectomy for parenchymal renal tumours. *Eur Urol* 2010; 58: 127–32

4 **Hayn MH, Hussain A, Mansour AM et al.** The learning curve of robot-assisted radical cystectomy: results from the International Robotic Cystectomy Consortium. *Eur Urol* 2010; 58: 197–202

5 **Daskalopoulos G, Karyotis I, Heretis I, Delakas D.** Electrothermal bipolar coagulation for radical prostatectomies and cystectomies: a preliminary case-controlled study. *Int Urol Nephrol* 2004; 36: 181–5

6 **Ahlering TE, Eichel L, Chou D, Skarecky DW.** Feasibility study for robotic radical prostatectomy cautery-free neurovascular bundle preservation. *Urology* 2005; 65: 994–7

7 **Lantis JC II, Durville FM, Connolly R, Schwaitzberg SD.** Comparison of coagulation modalities in surgery. *J Laparonedosc Adv Surg Tech A* 1998; 8: 381–94

8 **Zohar Y, Sadov R, Strauss M, Djialdetti M.** Ultrastructural study of peripheral nerve injury induced by monopolar and bipolar diathermy. *Ann Otol Rhinol Laryngol* 1996; 105: 673–7

9 **Wondergem J, Haveman J, Rusman V, Sminia P, Van Dijk JD.** Effects of local hyperthermia on the motor function of the rat sciatic nerve. *Int J Radiat Biol Relat Stud Phys Chem Med* 1988; 53: 429–38

10 **Penson DF, McLerran D, Feng Z et al.** 5-Year urinary and sexual outcomes after radical prostatectomy: results from the prostate cancer outcome study. *J Urol* 2005; 173: 1701–5

11 **Ahlering TE, Skarecky D, Borin J.** Impact of cautery versus cautery-free preservation of neurovascular bundles on early return of potency. *J Endourol* 2006; 20: 586–9

12 **Lepor H, Gregerman M, Crosby R, Mostofi FK, Walsh PC.** Precise localization of the autonomic nerves from the pelvic plexus to the corpora cavernosa: a detailed anatomical study of the adult male pelvis. *J Urol* 1985; 133: 207–12

13 **Walsh PC, Lepor H, Eggleston JC.** Radical prostatectomy with preservation of sexual function: anatomical and pathological considerations. *Prostate* 1983; 4: 473–85

14 **Eberli D, Hefermehl LJ, Müller A, Sulser T, Knönagel H.** Thermal spread of vessel-sealing devices evaluated in a clinically relevant in vitro model. *Urol Int* 2011; 86: 476–82

15 **Ong AM, Su LM, Varkarakis I et al.** Nerve sparing radical prostatectomy: effects of hemostatic energy sources on the recovery of cavernous nerve function in a canine model. *J Urol* 2004; 172: 1318–22

16 **Balogh K.** Oxidative Enzyme activity in skeletal cartilage and bone. *Invest Lab* 1961; 10: 839–45

17 **Sherwood ME, Flotte TJ.** Improved staining method for determining the extent of thermal damage to cells. *Lasers Surg Med* 2007; 39: 128–31

18 **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: 2689–93

19 **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: 1991–6

20 **Družijanić N, Pogorelić Z, Perko Z, Mrklić I, Tomić S.** Comparison of lateral thermal damage of the human peritoneum using monopolar diathermy, Harmonic scalpel and LigaSure. *Can J Surg* 2012; 55: 317–21

21 **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: 61–3

22 **Karakiewicz PI, Tanguay S, Kattan MW, Elhilali MM, Aprikian AG.** Erectile and urinary dysfunction after radical prostatectomy for prostate cancer in Quebec: a population-based study of 2415 men. *Eur Urol* 2004; 46: 188–94

23 **Phillips CK, Hruby GW, Durak E et al.** Tissue response to surgical energy devices. *Urology* 2008; 71: 744–8

24 **J Brzeziński J, Kałużna-Markowska K, Naze M, Stróżyk G, Dedecjus M.** Comparison of lateral thermal spread using monopolar and bipolar diathermy, and the bipolar vessel sealing system ThermoStapler™ during thyroidectomy. *Pol Przegl Chir* 2011; 83: 355–60

25 **Smith CT, Zarebczan B, Alhefdhi A, Chen H.** Infrared thermographic profiles of vessel sealing devices on thyroid parenchyma. *J Surg Res* 2011; 170: 64–8

26 **Gianduzzo TR, Colombo JR Jr, Haber GP et al.** KTP laser nerve sparing radical prostatectomy: comparison of ultrasonic and cold scissor dissection on cavernous nerve function. *J Urol* 2009; 181: 2760–6

27 **Wallwiener CW, Rajab TK, Krämer B, Isaacson KB, Brucker S, Wallwiener M.** Quantifying electrosurgery-induced thermal effects and damage to human tissue: an exploratory study with the fallopian tube as a novel in-vivo in-situ model. *J Minim Invasive Gynecol* 2010; 17: 70–7

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Abbreviations: KTP, potassium-titanyl-phosphate (laser); LDH, lactate dehydrogenase; NVB, neurovascular bundle; RAL, robot-assisted laparoscopy; RALP, robot-assisted laparoscopic prostatectomy; RP, radical prostatectomy.