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ORIGINAL ARTICLE

Temperature change of epidural space by radiofrequency use in biportal endoscopic lumbar surgery: safety evaluation of radiofrequency

Dong Hwa Heo[1] · Don Yong Park[2] · Young Ho Hong[1] · Deahwan Kim[3] · Jin Sung Kim[4]

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Abstract

Purpose Articles evaluating radiofrequency (RF) safety are insufficient. Thus, the purpose of this study was to investigate RF safety during biportal endoscopic lumbar decompressive laminotomy by measuring epidural temperature after RF use.

Methods Both in vitro cadaveric study and in vivo study were performed. The epidural temperature was measured at epidural space after RF use in three cadavers. The epidural temperature was measured and analysed according to RF mode, RF power, RF usage time, and saline irrigation patency. In the in vivo study, the epidural temperature was measured after biportal endoscopic surgery. Epidural temperatures were measured around ipsilateral and contralateral traversing nerve roots after 1-s use of RF.

Results In the in vivo study, epidural space temperature was increased by 0.31 ± 0.16 °C ipsilaterally and $0.29 \pm 0.09°$ contralaterally after RF use in coagulation mode 1. The epidural temperature of epidural space was increased by 0.21 ± 0.13 °C ipsilaterally and 0.15 ± 0.21 °C contralaterally after RF use in high mode 2. In the in vitro study, epidural temperature was significantly increased with a long duration of RF use and a poor patency of irrigation fluid.

Conclusion The use of RF in biportal endoscopic spine surgery might be safe. In order to reduce indirect thermal injuries caused by RF use, it might be necessary to reduce RF use time and maintain continuous saline irrigation patency well.

Keywords Biportal endoscopy · Safety · Temperature · Epidural · Radiofrequency

Introduction

The use of radiofrequency (RF) probes is necessary for soft tissue dissection and bleeding control during an endoscopic spine surgery. RF probes are also essential and widely used in biportal endoscopic spinal approach due to the same reason. In cases of biportal endoscopic surgery, RF probes are used, like monopolar or bipolar electrocautery in open conventional spine surgery [1]. Monopolar or bipolar electrocautery tips can cause direct thermal tissue injury during open conventional surgery or minimally invasive spine surgery [2]. Since the heat from the electrocautery is spread into the air and soft tissue, the possibility of indirectly injuring the surrounding neural tissue by the heat generated in the electrocautery may be very low in an open conventional spine surgery or a minimally invasive spine surgery. Biportal endoscopic surgeries are performed through small two portals with very short skin incisions [3]. Compared to an open conventional spine surgery, an endoscopic spine surgery including biportal endoscopy has a little closed environment with continuous saline irrigation. Therefore, RF might cause an indirect thermal neural injury due to elevation of epidural temperature.

Although direct contact thermal injury of neural tissue by RF probe tip can be prevented by surgeon's effort and skill, indirect RF thermal injury by elevation of epidural temperature may not be controlled by surgeons. In arthroscopic knee surgeries, it has been published that there is

✉ Jin Sung Kim
mdlukekim@gmail.com

1 Endoscopic Spine Surgery Center, Neurosurgery, Champodonamu Spine Hospital, Seoul, South Korea

2 Department of Orthopaedic Surgery, David Geffen School of Medicine at University of California Los Angeles, Los Angeles, CA, USA

3 Neurosurgery, Seoul Top-Spine Hospital, Seoul, South Korea

4 Department of Neurosurgery, Seoul St. Mary's Hospital, The Catholic University of Korea, Seoul, South Korea

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a possibility of thermal injury by RF wand [4]. Similarly, there might be an indirect thermal injury by RF use in an endoscopic spine surgery. However, clinical articles on RF injury during endoscopic spine surgery are limited [5]. Thus, the purpose of this study was to determine whether RF could cause indirect thermal injury by measuring temperature rise of the epidural space according to the use of RF.

Materials and methods

In vivo study

Only patients with single level lumbar central or lateral recess stenosis were enrolled in this study. All patients had central or lateral recess stenosis of lower lumbar level (L4-5 or L5-S1). Multi-level stenosis, traumatic lesion, herniated lumbar disc disease, juxta-facet cyst, and lumbar segmental instability were excluded. This investigation was performed in accordance with our institutional guidelines, which complied with international laws and policies (institutional review board of **** Hospital).

We performed right or left-sided single level unilateral laminotomy with bilateral decompression (ULBD) for the treatment of lumbar central or lateral recess stenosis using a biportal endoscopic approach (Fig. 1). The pump pressure of saline irrigation was set at 30 mmHg during operation. Ipsilateral laminotomy was performed using a drill and Kerrison Rongeur. Bilateral ligament flava were removed for decompression of both traversing nerve roots (Fig. 2).

We used two types of RF probe: a 90-degree RF probe and a steerable small diameter bipolar RF probe (Delphi

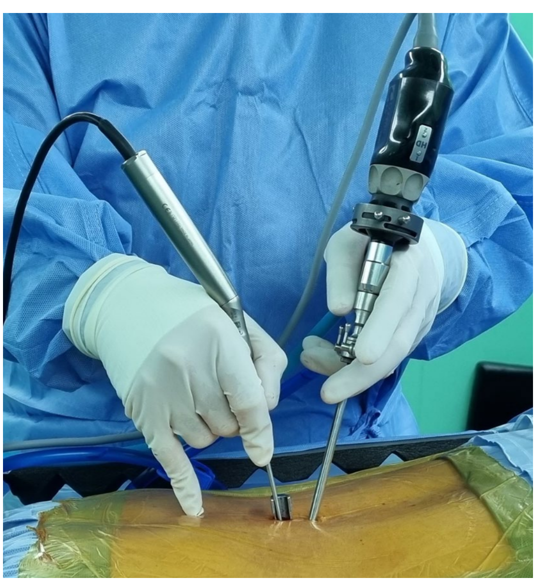

Fig. 1 Overview of biportal endoscopic lumbar surgery

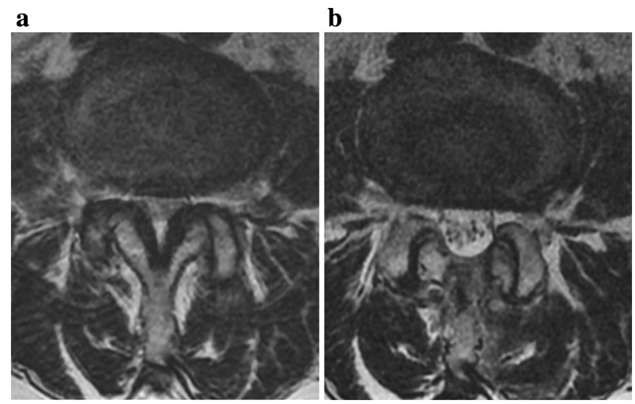

Fig. 2 Preoperative (**a**) and postoperative (**b**) magnetic resonance images of lumbar central stenosis. Preoperative lumbar central stenosis was well decompressed after biportal endoscopic unilateral laminotomy with bilateral decompression (**b**)

Plus, C & S medical, South Korea) in biportal endoscopic ULBD (Fig. 3).

In our clinical experience of real ULBD operation, 90-degree RF probe has a coagulation mode and an ablation mode. Correlation between each RF mode and Watt (power) is summarised in Table 1. Coagulation mode 2 (C2) and ablation mode 2 (A2) were usually used for soft tissue dissection, and bleeding control until the dura was exposed. After exposure of the dura, coagulation mode 1 (C1) of a 90-degree RF probe and a High 2 mode (H2) of a steerable small diameter bipolar RF were used for coagulation (Fig. 3 and Table 1).

A sterile disposable temperature monitoring probe for human (E-temp, ETP1030, Ewha Biomedics, South Korea) was used for temperature measurement of working space and epidural space (Fig. 4). We measured temperature elevation after using C2 and A2 in the working space (interlaminar space, over the ligamentum flavum). After dura exposure, epidural temperature was measured after using C1 of a 90-degree RF probe and High 2 (H2) mode of a steerable small diameter bipolar RF. Epidural temperatures were measured around ipsilateral and contralateral traversing nerve roots after one second of RF use.

In vitro cadaveric study

Firstly, we made two left-sided portals for a biportal endoscopic approach for each of three fresh frozen cadavers under C arm fluoroscopic guidance. The two left-sided portals were made like in a real ULBD operation. Left-side approach of unilateral laminotomy with bilateral decompression was performed without dura injury at L3-4, L4-5, and L5-S1 in each of the three cadavers. Ipsilateral and contralateral ligamentum flava were completely removed like in a real operation. Epidural temperature was measured after

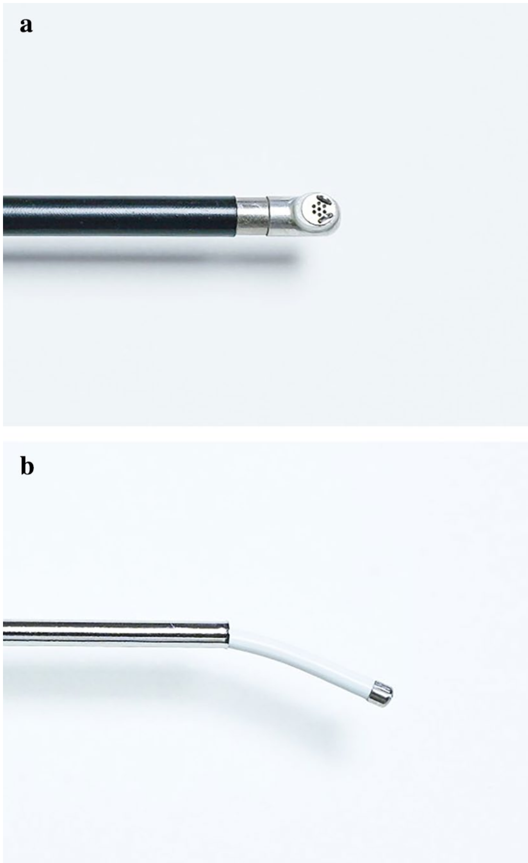

Fig. 3 Two types of radiofrequency used in biportal endoscopic lumbar surgery and cadaver study. **a** A 90-degree radiofrequency probe, **b** A steerable small diameter bipolar radiofrequency probe

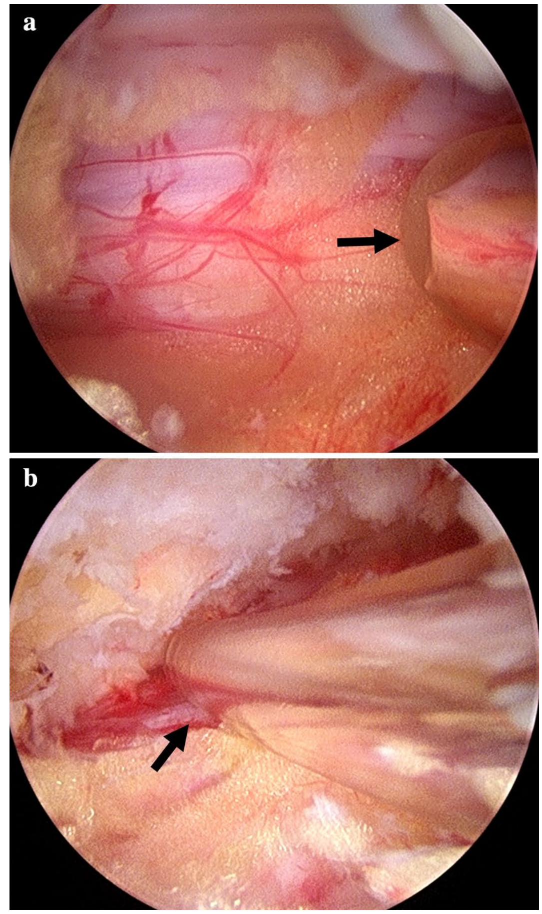

Fig. 4 A disposable temperature monitoring probe used to measure the temperature of epidural space (black arrow). **a** Ipsilateral, **b** contralateral

Table 1 Radiofrequency mode and power (Watt)

A steerable small diameter bipolar RF		90-degree RF	
High 1	7W	Coagulation 1	17W
High 2	10W	Coagulation 2	40W
High 3	13W	Ablation 1	40W
–	–	Ablation 2	60W

complete central decompression. A total of nine levels of three cadavers were enrolled for epidural temperature measurement. Epidural temperature was measured twice at a total of nine lumbar levels of three cadavers.

We used two types of RF probe: a 90-degree RF probe and a steerable small diameter bipolar RF probe (Delphi Plus, C & S medical, South Korea) in this study. A disposable temperature monitoring probe (E-temp, ETP1030, Ewha Biomedics, South Korea) was used for epidural temperature measurement. The pump pressure of saline irrigation was set at 30 mmHg. RF console had a coagulation mode and an ablation mode of a 90-degree RF probe with a high mode of a steerable small diameter bipolar RF (Fig. 2 and Table 1). In an actual biportal endoscopic spine operation, power above A3 or H4 was not used. Thus, we measured temperature of epidural space after RF use in coagulation mode (C1, C2), ablation mode1 (A1, A2), and High mode (H2 and H3). Epidural temperatures were measured after 1-s and 3-s of using a 90-degree RF wand and a steerable small diameter bipolar RF.

In the biportal endoscopic approach, continuous irrigation saline was performed through the endoscopic portal trocar and drained through the working portal. If the working sheath working portal is not inserted, the saline irrigation cannot be drained smoothly and the continuous saline irrigation pump cannot rotate smoothly. The definition of a good patency of irrigation was the condition that a working sheath was inserted for well drainage of saline irrigation. When the working sheath was not inserted and saline irrigation was not drained well, it was defined as a poor patency. Epidural temperature was measured according to saline irrigation patency (good or poor patency). Epidural temperatures were compared by RF type, RF use duration, RF power, and saline irrigation patency.

Statistical analysis

Wilcoxon signed rank test and Mann–Whitney U test were used for statistical analyses. A $p < 0.05$ was considered statistically significant. R 4.2.2 for Windows was used for all statistical analyses.

Results

In vivo study

A total 16 patients were enrolled in this study. There were 5 males and 11 females with a mean age of 65.4 ± 10.3 years old. We performed ULBD for 12 cases of L4-5 and 4 cases of L5-S1. During ULBD surgery, saline stored at room temperature was used and the irrigation pump pressure was set at 30 mmHg. Baseline temperature of working space was 22.4 ± 0.63 °C.

Working space temperature was measured after using C2 and A2 power of a 90-degree RF in the upper part of the ligamentum flavum in the interlaminar space (working space). When using the 90-degree RF in a C2 mode, the temperature of the working space was increased by 0.5 ± 0.08 °C. After using the RF in A2 mode, it was increased by 1.2 ± 0.12 °C (Table 2). When ablation 2 mode was used, the temperature of the working space was significantly increased compared to that in the coagulation 2 mode ($P < 0.05$). The epidural space temperature was measured after ULBD. The temperature of epidural space was increased by 0.31 ± 0.16 °C ipsilaterally and 0.29 ± 0.09° contralaterally after RF use in C1 mode (Table 2). The epidural space temperature was increased by 0.21 ± 0.13 °C ipsilaterally and 0.15 ± 0.21 °C contralaterally after RF use in H2 mode (Table 2). The elevation of epidural temperature was significantly lower in H2 mode than in C1 mode ($P < 0.05$).

Table 2 Temperature elevation of working space and epidural space by radiofrequency in vivo study

Space	Radiofrequency mode	Ipsilateral	Contralateral
Working space (Interlaminar space)	Coagulation 2 (C2)	0.5 ± 0.08 °C	–
	Ablation 2 (A2)	1.2 ± 0.12 °C	–
Epidural space (Exposure dura)	Coagulation 1(C1)	0.31 ± 0.16 °C	0.29 ± 0.09 °C
	High 2 (H2)	0.21 ± 0.13 °C	0.18 ± 0.21 °C

In vitro study

Nine levels (L3-4, L4-5, and L5-S1) of three fresh frozen cadavers were used for epidural temperature measurement. Irrigation pump pressure was set at 30 mmHg. Baseline temperature of epidural space was 21.2 ± 2.2 °C. In case of H2 power with good patency of irrigation saline, epidural temperature was increase 0.11 ± 0.33 °C after 1 s of use and 0.19 ± 0.06 °C after 3 s of use of a steerable small diameter bipolar RF (Table 3, Fig. 5a).

In case of high H2 with poor patency of irrigation saline, epidural temperature was increased 0.22 ± 0.07 °C after 1 s of use and 0.37 ± 0.09 °C after 3 s of use of a steerable small diameter bipolar RF. Epidural temperature was significantly increased in H3 mode than in H2 mode ($P < 0.05$). It was also significantly increased in poor irrigation patency than in good irrigation patency ($P < 0.05$) (Table 3, Fig. 5b, c).

In case of H3 power with good patency of irrigation saline, epidural temperature was increased 0.18 ± 0.76 °C after 1 s of use and 0.30 ± 0.07 °C after 3 s of use of a steerable small diameter bipolar RF (Table 3, Fig. 5a).

In case of a high H3 mode with a poor patency of irrigation saline, epidural temperature was increased 0.32 ± 0.11 °C after 1 s of use and 0.52 ± 0.12 °C after 3 s of use of a steerable small diameter bipolar RF. Epidural temperature was significantly increased in H3 mode than in H2 mode ($P < 0.05$). It was also significantly increased in poor irrigation patency than in good irrigation patency ($P < 0.05$) (Table 3, Fig. 5b, c). It was also significantly increased in poor irrigation patency than in good irrigation patency ($P < 0.05$) (Table 3, Fig. 5b, c).

Table 3 Comparison of the degree of elevation of epidural temperature according to radiofrequency mode, use duration and irrigation patency in cadaver study

Mode	Good irrigation patency	Poor irrigation patency*
H2 1-s	0.11 ± 0.33	0.22 ± 0.07
H2 3-s	0.19 ± 0.06	0.37 ± 0.09
H3 1-s	0.18 ± 0.76	0.32 ± 0.11
H3 3-s	0.30 ± 0.07	0.52 ± 0.12
C1 1-s	0.21 ± 0.06	0.42 ± 0.07
C1 3-s	0.43 ± 0.05	0.63 ± 0.05
C2 1-s	0.34 ± 0.09	0.61 ± 0.08
C2 3-s	0.44 ± 0.02	0.88 ± 0.09
A1 1-s	0.60 ± 0.10	0.93 ± 0.07
A1 3-s	0.84 ± 0.09	1.40 ± 0.21
A2 1-s	0.97 ± 0.14	1.52 ± 0.09
A2 3-s	1.40 ± 0.07	2.43 ± 0.13

*$P < 0.05$

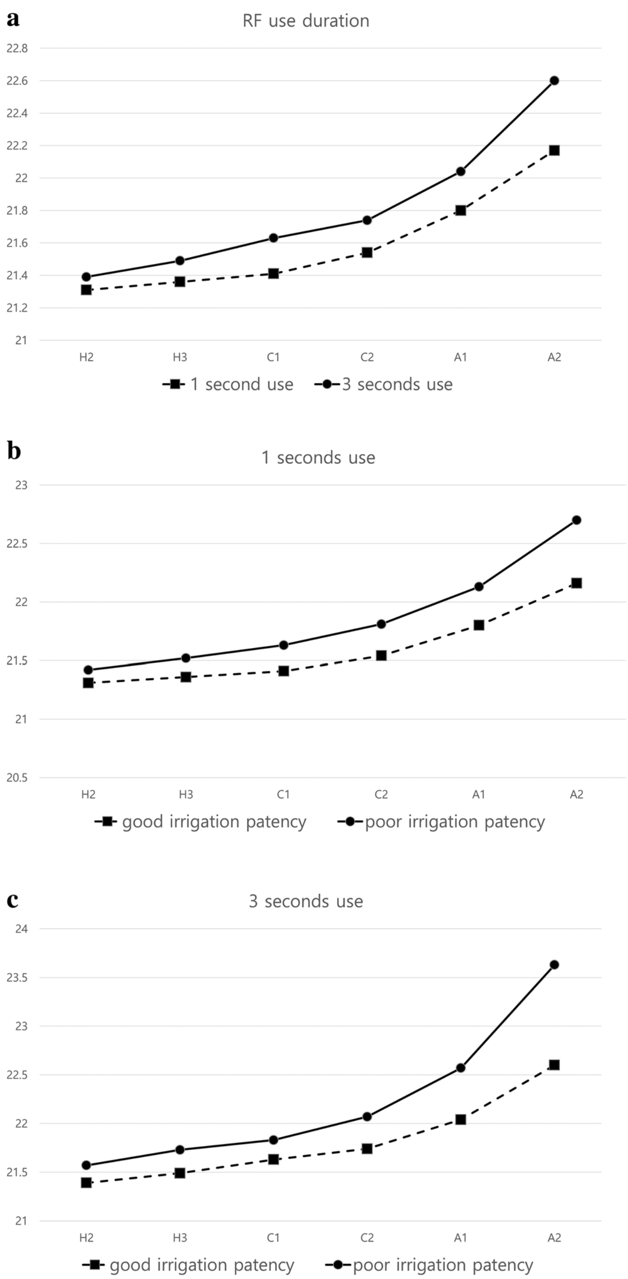

Fig. 5 Comparison of epidural temperature change according to duration of radiofrequency use (**a**). Comparison of epidural temperature elevation according to irrigation saline patency (**b**: 1 second use of radiofrequency, **c**: 3 seconds use of radiofrequency). Epidural temperature elevation was significantly affected by radiofrequency use time and irrigation fluid patency ($P < 0.05$)

Epidural temperature in coagulation or ablation mode of 90-degree RF was measured. In an environment with a good irrigation patency, epidural space temperature was increased by 0.21 ± 0.06 °C in C1 mode, 0.34 ± 0.09 °C in C2 mode, 0.60 ± 0.10 °C in A1 mode, and 0.97 ± 0.14 °C in A2 mode after using RF for 1 s (Fig. 5a, b). Epidural space temperature was increased by 0.43 ± 0.05 °C in C1 mode, 0.44 ± 0.02 °C in C2 mode, 0.84 ± 0.09 °C in A1 mode, and 1.40 ± 0.07 °C in A2 mode after using 90-degree RF for 3 s (Fig. 5a, c). In an environment with poor irrigation patency, epidural space temperature was increased by 0.42 ± 0.07 °C in C1 mode, 0.61 ± 0.08 °C in C2 mode, 0.93 ± 0.07 °C in A1 mode, and 1.52 ± 0.09 °C in A2 mode after using RF for 1 s (Table 3 and Fig. 5b). Epidural space temperature was increased by 0.63 ± 0.05 °C in C1 mode, 0.88 ± 0.09 °C in C2 mode, 1.40 ± 0.21 °C in A1 mode, and 2.43 ± 0.13 °C in A2 mode after using 90-degree RF for 3 s (Table 3 and Fig. 5c).

The epidural temperature was significantly increased when RF was used for 3 s than when it was used for 1 s ($P < 0.05$) (Table 3 and Fig. 5a). Also, epidural temperature increased significantly when irrigation patency was poor compared to that when irrigation patency was good ($P < 0.05$) (Fig. 5b, c).

Discussion

RF probes have been used in arthroscopic joint surgery and endoscopic spine surgery. The use of RF is especially necessary for bleeding control and soft tissue dissection during endoscopic spine surgery including uniportal and biportal endoscopic spine approaches. In the past, a steerable bipolar RF tip has been usually used in full endoscopic (uniportal) spine surgery for the treatment of lumbar disc disease. The output power of a small diameter steerable bipolar RF tip is low. Therefore, the possibility of thermal injury is low during full endoscopic spine surgeries including interlaminar and transforaminal approaches.

Recently, indications of endoscopic spine surgery have been expanded from disc disease to stenosis and instability [3, 6, 7]. Endoscopic posterior lumbar laminectomy has been popularly performed for the treatment of lumbar lateral recess or central stenosis [3]. Various kinds of RF tips have been tried for effective biportal endoscopic laminectomy or laminotomy. A biportal endoscopy and a large working channel full endoscopy have been used for endoscopic laminectomy and endoscopic lumbar interbody fusion. A 90-degree RF tip (like ArthroCare RF) can be used in interlaminar full endoscopic approaches and biportal endoscopic approaches. The output power of a 90-degree RF tip is stronger than that a steering bipolar type RF (Fig. 3). The output power of coagulation mode 2 of a 90-degree RF is 40W, which is four times of that of a high mode 2 of a steering bipolar RF (10W) (Table 1). Thus, it might cause thermal injury during an endoscopic spine surgery.

There are two types of thermal injury by RF use in biportal endoscopic lumbar surgeries: direct injuries caused by direct contact of the RF tip after applying heat to the neural tissue and indirect heat damage caused by temperature elevation of the working space or epidural space after using RF. Thermal injury caused by direct contact of the RF tip after applying heat to the neural tissue can be prevented with experience and effort of the operator. However, indirect thermal damage, in which the temperature of the working epidural space rises due to the use of RF, can occur regardless of the operator's experience or effort. Although RFs have been commonly used in endoscopic spine surgeries, there are few studies on the safety of RF use in endoscopic spine surgeries including biportal endoscopic spine approaches.

Endoscopic spinal surgery is performed in a closed environment, unlike an open conventional spine surgery. The surgical site of conventional spine surgery is completely exposed and the heat generated when bipolar or unipolar cauterization tips are used during surgery is dissipated into the air and surrounding soft tissue. However, the skin incision in spinal endoscopic surgery is very small. The endoscopic spine surgery is performed in a closed environment like arthroscopic joint surgeries. Therefore, the temperature of working space may rise when instruments that can generate heat are used. RF probe tip can create a plasma layer through conductive medium such as saline. Plasma-based energy produces heat to be applied the soft tissue. Finally, thermal effect of plasma energy can be used as ablation and coagulation for soft tissues [4, 5]. Although RF can perform coagulation and ablation through plasma generation, it has the disadvantage of generating heat. As heat is generated by RF, it can cause thermal damage to surrounding tissues [4, 5, 8].

In joint arthroscopic surgeries, there are heat-related complications from RF [8]. Chondrolysis, dermal burn, osteonecrosis, and peripheral nerve injury by RF use have been reported [4, 8]. Especially, there are thermal injuries of axillary nerve and capsule disintegration by RF in shoulder arthroscopic surgeries [8]. Soft tissue thermal injury can occur at temperatures above 43 °C and cartilage thermal injury can occur at temperatures above 50 °C [4, 9]. Temperature below 50 °C may be safe for preventing chondrocyte death and neural injury in arthroscopic surgeries [4]. A paper reporting RF thermal injury in knee arthroplasty has recommended the use of a duration of less than 2 s and a lower power of less than level 2 to reduce cartilage damage [10]. Animal experiments on thermal injury of biportal cauterization used in spinal surgery have reported that a temperature increase in 50 degrees or more causes neural tissue thermal injury [1, 2]. The use of bipolar forceps could raise the temperature to 40.4 °C in the animal study. It has been reported that saline irrigation is important for reducing the increase in ambient temperature during bipolar cauterization [1]. In this study, continuous saline irrigation was also important in reducing the rise in epidural temperature caused by RF. In an in vitro experimental setting, thermal injury of animal sciatic nerves occurred at high temperature more than 45 °C. Morphologically unmyelination of nerve or electrophysiological conduction block occurred irreversibly at a temperature of at least 45 °C [11, 12]. In this in vivo study, the temperature of the epidural space did not increase for more than 1 degree after RF use. Therefore, the possibility of indirect thermal injury due to the use of RF is expected to be very low. Experimental animal studies will be needed to confirm whether an increase in epidural temperature by RF causes thermal injury to the nervous tissue and causes histological and electrophysiological changes.

In this study, when continuous saline irrigation patency was well maintained, the epidural temperature did not rise more than 1 °C in RF coagulation or ablation mode. Continuous saline irrigation secures a clear view during endoscopic surgery and plays a role in reducing bleeding during surgery. Another role of continuous saline irrigation is that it can prevent the rise of epidural temperature due to the use of RF. According to this study, when saline irrigation patency was good, the elevation of epidural temperature was statistically lower than the poor patency of continuous saline irrigation maintaining continuous saline irrigation output patency might prevent an increase in epidural pressure. It might also prevent an increase in epidural temperature and thermal injury due to the use of RF [3, 13]. To maintain continuous saline irrigation patency well, it is strongly recommended to insert various types of working sheaths into the working portal [3]. The epidural temperature may rise depending on the power (mode), frequency, and duration of RF use [5]. To prevent thermal injury caused by RF, it is necessary to reduce the frequency and power of RF use [5]. It is also better to use RF several times in a short time to prevent thermal injury than using RF for a long time. To control bleeding around the dura, it might be safer to use a steerable small diameter bipolar type RF than using a 90-degree type (ArthroCare type). Since ablation mode has higher power than coagulation mode, it is more suitable for soft tissue dissection. The energy of the ablation mode was higher than that of the coagulation mode (Table 1). It could increase the epidural temperature significantly. To prevent neural tissue thermal injury, we strongly recommend not to use ablation mode after dura exposure. In this study, the temperature of the epidural space at the baseline was measured to be about 20 degrees. Because saline stored at room temperature was used, the temperature of the surgical site was lower than body temperature. Since hypothermia might occur due to continuous irrigation of low-temperature saline, the use of warm saline should be considered if long-time endoscopic surgery is to be performed.

The present study has several limitations. In this study, the in vitro study used the fresh frozen cadaver. Therefore, the body temperature of cadavers was lower than that of humans, and the biological environment was different. Therefore, there were limitations in applying the results of this study to humans. And the number of cadaver used in the experiment and the number of patients were small. In order to derive more accurate experimental results, a study involving a large number of patients and cadaver will be required. In addition, various types of RF tips and RF products of various companies need to be studied in the future.

Conclusions

Epidural temperature was not increased more than 1 °C in a high mode (H2) of a steerable small diameter bipolar RF, in a coagulation mode (C1 and C2), or in an ablation mode (A1) of a 90-degree RF. The possibility of indirect thermal injury due to the use of RF might be low. RF may be safely used in biportal endoscopic spine surgery for the treatment of lumbar lateral recess or central stenosis. The use of low-power and short-duration RF can reduce the possibility of thermal injury. Maintaining good irrigation patency during surgery can also reduce the elevation of epidural temperature caused by RF.

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Declarations

Conflict of interest Dr Jin-Sung Kim is consultant in RIWOSpine, (GmbH, Germany) and Elliquence (LLC, USA).

Ethics approval Approval obtained from Institutional review board.

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