Capacitive coupling leading to electrical skin burn injury during laparoscopic surgery

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Purpose: Trocar-site burns occurring during laparoscopic surgery have been reported in various cases, and several efforts to reduce them are underway. This study aimed to analyze the effect of capacitive coupling on trocar site by observing electrical and histological changes for electrical skin burn injury.

Methods: To measure the electrical changes relating to capacitive coupling, the temperature, current, voltage, and impedance around the trocar were measured when an open circuit and a closed circuit were formed using insulation intact instruments and repeated after insulation failure. After the experiment, the tissue around the trocar was collected, and microscopic examination was performed.

Results: When open circuits were formed with the intact insulation, the impedance was significantly reduced compared to the cases of closed circuits (142.0 Ω vs. 109.3 Ω, p = 0.040). When the power was 30 W and there was insulation failure, no significant difference was measured between the open circuit and the closed circuit (147.7 Ω vs. 130.7 Ω, p = 0.103). Collagen hyalinization, nuclear fragmentation, and coagulation necrosis suggesting burns were observed in the skin biopsy at the trocar insertion site.

Conclusion: This study demonstrated that even with a plastic trocar and electrosurgical instruments that have intact insulation, if an open circuit is formed, capacitive coupling increases, and trocar-site burn can occur. When using electrocautery, careful manipulation must be taken to avoid creating an open circuit to prevent capacitive coupling related to electrical skin burn.

Keywords: Electric burns, Electrocoagulation, Laparoscopy, Surgical instruments, Wounds and injuries

INTRODUCTION

In the laparoscopic approach, monopolar electrosurgery is essential. Complications related to monopolar electrosurgery involve several mechanisms, such as direct coupling, insulation failure, and capacitive coupling [1]. Educational recommendations and clinical efforts are conducted to reduce the complications relating with electrocautery. At present, instead of the metal trocars, plastic trocars are used in most cases because unintentional contact with electrosurgical instruments can cause electrical tissue damage [2]. When using an electrosurgical instrument, activation before tissue contact can elevate abruptly electrical power (watt) to increase the risk of unintended electrical injury; it is called as an open circuit. Therefore, to reduce the electrical damage, using
an instrument that can form a closed circuit was recommended [1,3].

Insulation failure is a major cause of uninduced bowel injury during laparoscopic abdominal surgery [4,5] and can lead to serious consequences. Specifically, during laparoscopic surgery, it can cause bowel injury in an area outside the surgeon’s field of view, leading to fatal results such as delayed bowel perforation and peritonitis. Thus, to prevent insulation failure related complications, disposable devices are used or checks for insulation failure are performed in advance. Moreover, thermal injury has also been reported at the trocar insertion site after using an electrosurgical instrument [6,7]; it was considered to be caused by electrical damage due to insulation failure with direct coupling or capacitive coupling. Capacitive coupling is defined as the current transferred from the active electrode through intact insulation to the adjacent conductive material without direct contact [8].

This study aimed to analyze the capacitive coupling effect on trocar site by observing electrical and histological changes when a closed circuit and an open circuit are formed in laparoscopic surgery. Furthermore, the effect of the insulation failure on the formation of capacitive coupling was evaluated for electrical skin burn injury.

**MATERIALS AND METHODS**

Current, voltage, and impedance were measured using a multimeter (287 True-RMS multimeter; Fluke, Everett, WA, USA), and temperature was measured using a thermometer (566 IR thermometer, Fluke). An electrosurgical generator (Force FX-9c; Valleylab, Minneapolis, MN, USA) and 5-mm plastic trocars (Laport-MU; Sejong Medical, Paju, Korea) were used in the experiment.

A 12-mm plastic trocar was installed in the navel of the pig for the camera, and then two 5-mm plastic trocars were inserted into the right and left abdominal walls of the pig. A device with intact insulation was introduced through a 5-mm trocar. After attaching the tip of electrocautery to the small intestine in the abdominal cavity, the temperature, voltage, current, and impedance around the trocar were measured while cutting the small intestine wall with 30 W of power in the coagulation mode for 30 seconds (closed circuit). The same items were measured by activating the electrocautery at a distance of approximately 5 cm from the wall of the small intestine for 30 seconds with 30 W of power in the coagulation mode (open circuit) (Fig. 1).

To measure the electrical change relating to the insulation condition of laparoscopic instruments, the insulation layer of the device was intentionally scratched to make a failed insulation condition. Electrical experiments were performed under intact and failed insulation conditions. All electrical experiment processes were repeated six times in the same manner. To induce electrical skin burn, electrocautery with a power of 30 W was activated for 10 minutes through a 5-mm trocar. After removing the trocar, the skin into which it entered was excised. After fixing the tissue in 10% formalin solution, paraffin blocks were prepared at intervals of 5 mm and stained with hematoxylin and eosin. Pathologic analysis was performed to evaluate skin tissue change from the epidermis to the subcutaneous fat layer that was related to electrical skin burn.

Statistical analysis was performed on the measured data using an independent sample t-test with IBM SPSS for Windows, version 25 (IBM Corp., Armonk, NY, USA). Significance was set at $p < 0.05$.

**RESULTS**

The electrical characteristics were organized by dividing the four items, namely, skin temperature, current, voltage, and impedance, around the trocar into closed and open circuits (Table 1). When open circuits were formed with the intact insulation, the impedance was significantly reduced compared to the cases.
of closed circuits (142.0 Ω vs. 109.3 Ω, \( p = 0.040 \)). No significant differences were found in the temperature, current, and voltage between the two groups. When the power was 30 W and there was insulation failure, no significant difference was measured between the open circuit and the closed circuit (147.7 Ω vs. 130.7 Ω, \( p = 0.103 \)). Likewise, no significant differences were observed in the temperature, current, and voltage between the two groups (Fig. 2).

Collagen hyalinization was observed in the biopsy performed at the trocar insertion site, and nuclear fragmentation and coagulation necrosis suggesting electrical burns were observed. Also, fat degeneration was observed in subcutaneous fat layer (Fig. 3).

### DISCUSSION

Impedance has an inverse relationship with capacitance (Fig. 4), that is, as the capacitive coupling increases, the impedance decreases. In the case with a power of 30 W and intact insulation, a significant decrease in impedance in the open circuit indicates an increase in capacitive coupling. Because increased capacitive coupling is related to burns \([9]\), this experiment showed that electrical skin burns can occur when the material of the trocar is plastic and the insulation of the electric cauterizer is intact. In the case with a power 30 W and insulation failure, no significant difference was noted in impedance, which shows that the risk of electrical burns around the trocar was lower in the case of insulation failure.

This is the opposite of what was expected. Surgeons assume that burns will not occur if they have a plastic trocar and electrosurgical instrument with intact insulation. However, contrary to expectations, if there is insulation failure, the impedance change around the trocar is insignificant because the current is transmitted through the place where insulation failure occurs. When the insulation is intact, because both the insulation and the plastic trocar act as non-conductors, the current accumulates in the skin where the trocar is inserted owing to capacitive coupling. Electrical burns occur at the trocar site because of this electrical change.

In the presence of insulation failure, the risk of intestinal perforation in the abdominal cavity increases \([3,4]\). Although intestinal damage caused by insulation failure is a complication of current caused by direct contact (closed circuit), trocar-site burn due to capacitive coupling occurs when an open circuit is formed. Therefore, when the surgeon activates the instrument for electrical cauterization, tissue contact helps prevent trocar-site burns. In the case of intact insulation, even if a part other than the activated cauterizer comes into contact with the field outside the field of view, the current is not transmitted by the insulation. Therefore, because intestinal damage is not possible, it is reasonable to activate the electric cauterizer while maintaining a closed circuit.

Capacitive coupling that occurs in laparoscopic surgery can be thought of simply as capacitance in a cylindrical capacitor (Fig. 4). If the inner cylinder is regarded as an electrosurgical instrument and the outer cylinder is considered the skin surface where

### Table 1. Analysis of changes in temperature, current, voltage, and impedance in closed and open circuits

| Variable     | Closed circuit | Open circuit | \( p \) value |
|--------------|----------------|--------------|---------------|
| Intact insulation |                |              |               |
| Skin         |                |              |               |
| Temperature (°C) | 31.8           | 31.6         | 0.330         |
| Current (mA)  | 79.0           | 62.3         | 0.175         |
| Device       |                |              |               |
| Voltage (mV)  | 183.0          | 220.0        | 0.104         |
| Impedance (Ω) | 142.0          | 109.3        | 0.040*        |
| Insulation failure |            |              |               |
| Skin         |                |              |               |
| Temperature (°C) | 31.3           | 31.1         | 0.719         |
| Current (mA)  | 68.3           | 63.7         | 0.193         |
| Device       |                |              |               |
| Voltage (mV)  | 210.7          | 218.3        | 0.371         |
| Impedance (Ω) | 147.7          | 130.7        | 0.103         |

The power of the electrosurgical instruments remained the same at 30 W. When the insulation was intact, an open circuit was formed, and a significant decrease in impedance occurred. In the case of insulation failure, no significant difference was found between the open circuit and the closed circuit.

\(^{*}p < 0.05\).
the trocar is inserted, the capacitance is inversely proportional to the distance from the center to the skin surface. This was determined according to the incision size of the trocar insertion site. In this study, as there was no control for incision size, the effect could not be examined; however, in a subsequent study, the related effect should be analyzed. The strength of study lies in that it is the first to examine the presence or absence of insulation, among the factors associated with burns occurring at trocar sites. In previous studies, capacitive coupling was reported to increase as the generator power setting increased when the electric cauterizer was in the coagulation mode, and the activation time increased [6]. Disposable instruments are recommended to prevent complications caused by insulation failure [1]. In such cases, care must be taken to avoid forming an open circuit.

We experienced a case of trocar-site burn after laparoscopic low anterior resection for a rectal cancer patient. When the patient was observed until 4 days after surgery, wound healing was delayed, and scars remained even after wound healing was completed (Fig. 5). This study is meaningful because the electrical causes of the clinical situation such as trocar-site skin burn were explored using an in vivo experiment.

One limitation of this study is that the activation time of the electrosurgical instrument was limited to 10 minutes. In actual surgery, an electric cauterizer such as Bovie is used through a trocar for a short period of 1 hour to a maximum of 4 hours or more. This means that an electric current similar to that in an actual clinical trial could not be maintained. However, because this study directly measured the electrical properties around the trocar, the effect of capacitive coupling on the tissue could be numerically observed. The existence of the difference in electrical properties means that if the activation time is as long as the actual operation time, the effect of the electric current will be continuously applied and histological changes will occur more clearly. A follow-up study that increases the activation time of electrocautery to induce a situation similar to that of actual clinical practice is necessary.
Even if a plastic trocar and an electric cautery with intact insulation were used, the tendency of capacitive coupling increased when an open circuit was formed. When a disposable electrosurgical instrument is used, insulation is expected to be intact. Therefore, when using disposable devices, care must be taken to avoid creating an open circuit. When using reusable instruments, more attention should be paid to direct coupling with bowel injury caused by insulation failure rather than trocar-site burns due to capacitive coupling. In the future, an experimental study on the additional direction to reduce burns in the case of intact insulation is necessary.

In conclusion, this study demonstrated that even with a plastic trocar and electrosurgical instruments that have intact insulation, if an open circuit is formed, capacitive coupling increases, and trocar-site burn can occur. When using disposable devices, care must be taken to avoid creating an open circuit to prevent electrical skin burns.

NOTES

Ethical statements

This study was approved by the Institutional Animal Care and Use Committee at Pusan National University Hospital (No. PNUYH-2018-60).

Authors’ contributions

Conceptualization: GMS
Methodology: All authors
Investigation: MSK, GMS, SUY, GRJ, DHS, JYK, KRB
Formal analysis: WJK, MSK, GMS
Project administration: IYL, MSK, GMS

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Writing—review & editing: All authors
All authors read and approved the final manuscript.

Conflict of interest

All authors have no conflicts of interest to declare.

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